XX.—ON ARTIFICIAL REFRIGERATION.

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A.—INTRODUCTION.

Ice, water, and steam, strikingly exemplify the nature of changes, or the different physical states, produced in matter by heat. Ice is a transparent or translucent solid, which melts into water on the addition of 142.66 heat units (Regnault). This water has to be raised from the normal temperature of melting ice, viz, 32° Fahr., to 212° to boil, and every pound converted into steam absorbs 965.7 heat units, without affording thermometric indications of the change. The heat is said to have become latent, but it is lost in molecular motion.

The latent heat of water is higher than that of any other agent, and a great depression of temperature ensues when, from a limited amount of water, vapor promptly rises. Thus, water placed in porous earthenware vessels, which are protected from active surface air-currents, by being placed in shallow pits, freezes in Bengal. Windy nights in summer are unfavorable to the process. It is on still and cloudless nights that active radiation, into open space, favors the crystallization of the water.

Probably with the ice thus formed and the efflorescent salts at hand, the Hindoos first attempted artificial refrigeration. Nitre—the sal petræ of Geber or nitrum of Albertus Magnus—was regarded by the ancients as the *primum frigidum*, the cold element of the earth. It occurred on the borders of the Ganges, in Ceylon, and elsewhere as a natural surface deposit, and, after the rainy season, a crust one-third of an inch in thickness may be gathered from the ground. It is dissolved out of the saltpetre earths, which at Tirhoot, in Bengal, contain from 8 to 9 per cent. of pure potassium nitrate. The mercury descends 18 or 20 degrees if a thermometer be plunged into water simultaneously with nitre. Mixed with ice, a temperature between 5 and 6 degrees below 32° Fahr. is obtained; and we learn, that as early as 1550, the Roman nobles cooled their wines by a mixture of snow and nitre. This frigorific mixture is mentioned by Latinus Tancredus, a professor of medicine in Naples, in his work De Fama et Siti, published in 1607. Villa Franca, a Spaniard, had been credited with the invention, but in all probability the practice was derived from Asia, and popularized by the Portuguese after the first discovery of India. Common salt and ice were adopted by Fahrenheit as the means of obtaining the temperature 0 of his thermometer, and this mixture was widely known to the learned throughout Europe. In Southern Italy it was used for cooling lemonades, and from thence, in the middle of the seventeenth century, sprang the Paris "limonadiers," as well as the preparation of flavored ices and creams, the *gelati* and *sorbetti* of the Italians.

Neapolitans and Swiss Italians have remained preeminent in the management of cafés and the preparation of iced confections. They established themselves early in all the large cities of Europe. It is but recently that an Italian Swiss, by the name of Carlo Gatti, died wealthy and esteemed in London. He was the first practical introducer of ice-creams to the British public. His stall stood forty years since in Hungerford fish-market, and he himself has informed me that, in his early days, he had great difficulty in inducing people to appreciate his *gelati*. He walked about the market with a glassful of ice-cream, and offered spoonfuls to passers-by until they began to acquire the taste for and recognize the wholesome character of cold delicacies. They dreaded them as much as the Brazilians have dreaded ice until recently, being regarded as productive of serious illness. Gatti not only introduced his ice-creams, but did much to popularize the use of ice in London, and to the last he retained a large share of a trade, greatly encouraged by his discrimination and integrity.

In Gatti's early days, Thomas Masters published his Ice Book (1844), which contained some interesting historical data, though the work appeared to advertise patent ice-cream freezers, knife-cleaners, &c. It tended to make the use of ice popular, especially among the rich; and, the growing wants of the metropolis, compelled fishermen to use more and more ice year by year.

The growing wealth of British cities, the facilities for the transport of fish by sea, and a wider appreciation of wholesome fish food, drove the trawlers further and further, year after year, seeking fresh ground and using more ice, the greater the catches and the longer the distance of the fishing-grounds reached from shore. An enterprising firm, of late years organized as a limited liability company (Messrs. Hewett & Co.), established a fleet of steam carrying vessels as their fish business grew.

The steamers are small and carry about 35 tons of ice each, some more, some less. Were they larger, the difficult process, of transferring the fish from the boats, would be attended with even greater danger than it is at present. The steamer is small enough to drop into the trough of the sea with the boat, and the two hug each other, without danger of a crushing collision.

It is in this way that England, and especially London and the fishing-ports of Great Yarmouth and Grimsby, have become the centres of a very extensive and lucrative ice-trade from Norway. In the early days of the British ice-trade a company was formed to import ice from the New World, and "Wenham Lake" ice became the staple and favorite brand.

The distance by sea from America led to enterprising dealers visiting Norway, and Lake Oppegaard was purchased with the privilege of renaming it; the purchasers having made all necessary arrangements for shipments of ice thence to England, the lake has ever since gloried in the name of Wenham. Drobak, Drammen, Christiania, Brockstadt, and other Norwegian ports supply England also.

Mr. Holdsworth,* writing in 1874, said: "It is yet a question whether it will *pay* to apply steam to the actual trawlers, but we had an opportunity in 1872 of observing in an experimental vessel the practical advantage gained by its use, both when fishing and going to and returning from the fishing ground." This at once indicates the probability of using refrigerating machines instead of bulky, costly, and deteriorating processes, and likewise render fishermen altogether independent of ice-crops and ice-merchants.

B.—IMPORTANCE OF FISH-CULTURE IN GREAT BRITAIN.

The favorable conditions of an extensive sea-shore, encirling islands which can be crossed by rail in a few hours, with innumerable streams, to permit the ascent of spawning fish, are most tempting to the fish culturist, and would indicate that a large fish trade could be developed even without ice. The slow progress in the artificial propagation of fish in England is a matter for surprise.

Until this scientific remedy can be applied, the ice-question is a serious one all round the British Isles, and, indeed, the supply of fish, to inland towns, is determined more by the scarcity of ice than the scarcity of fish. The Irish coast would supply large quantities of excellent fish, and many a fishing-village might be made populous and prosperous by an unfailing supply of cheap ice.

C.—ORIGIN OF KNOWLEDGE OF ARTIFICIAL COOLING.

The germ of all the modern improvements in making ice dates back to 1755, when the great Dr. Cullen, Professor of Medicine in the University of Glasgow, attempted to determine whether the solution of certain substances, in spirits of wine, was attended with elevation or lowering of temperature. One of his pupils, entrusted with these experiments, observed that, on withdrawing the thermometer from the alcoholic solution, the mercury fell, and, with the aptitude of an original observer, Cullen tried the pure spirit. By moistening the bulb with a feather and blowing to hasten evaporation, the temperature dropped from 44° to below 32°. He pursued his investigations further, and tried a variety of volatile substances, of which he found the "quick-lime spirit of sal ammoniac" the most powerful. This is a singularly felicitous anticipation of the knowledge we now possess, that no liquid, boiling at low temperatures, absorbs more heat than ammonia.

* Deep-Sea Fishing and Fishing Boats. London, 1874.

In one of his experiments Cullen used nitrous ether, when the heat of the air was 53°. He set the vessel, containing ether, in one a little larger containing water, and placed the two under the receiver of an air-pump. On exhausting the receiver and maintaining the vessels in vacuo for a few minutes, the water in the outer vessel was frozen and the ether recipient coated with a firm and thick crust of ice.

Dr. Cullen explains in his Essay* that he had endeavored to give a notion, of the comparative power of these fluids in producing cold, by the order in which he has set them down, as follows:

1. The quick-lime spirit of sal ammoniac.
2. The æther of Frobenius.
3. The nitrous æther.
4. The volatile tincture of sulphur.
5. Spirits of wine.
6. Spirit of sal ammoniac made with the fixed alkali.
7. Brandy.
8. Wine.
9. Vinegar.
10. Water.
11. Oil of turpentine.
12. Oil of mint.
13. Oil of pimento.

Cullen adds: "From the above enumeration, I imagine it will appear that the power of evaporating fluids in producing cold is nearly according to the degree of volatility in each." . . . . . "From the fact that the cold is made greater by whatever hastens the evaporation, and particularly that the sinking of the thermometer is greater as the air in which the experiment is made is warmer, if dry at the same time, I think we may now conclude that the cold produced is the effect of evaporation."

Dr. Cullen's desire to investigate this subject had been increased by reading M. de Mairan's Dissertation sur la Glace, published in 1749, and he had also been informed of Richmann's researches. Richmann had taken notice of the effect of evaporating fluids in producing cold, but does not impute it to the evaporation alone.

I was fortunate in finding Richmann's papers in the first volume of the Transactions of the St. Petersburg Academy of Sciences for the years 1747 and 1748, in the Congressional Library in Washington, and I subjoin the full titles.† In the same volume I was gratified to dis-

* Of the cold produced by evaporating fluids, and of some other means of producing cold, by Dr. William Cullen (May 1, 1755). Published in Essays and Observations, Physical and Literary. Read before a society in Edinburgh, and published by them. Vol. II. 1756. p. 145.

† G. W. Richmann's papers are four in number: 1st. De quantitate caloris, quæ post miscelam fluidorum certo gradu calidorum oriri debet cogitationes. 2d. Formulæ pro gradu excessus caloris, supra gradum caloris mixti ex nivi et sale ammoniaco, post miscelam duarum massarum aquearum diverso gradu calidarum confirmatio per experimenta. 3d. Inquisitio in legem, secundum quam calor fluidi in vaso contenti, certo temporis intervallo, in temperie aeris constantes eadem descrescit vel crescit et detectio eius, simulque thermometrorum perfecte concordantium construendi ratio hinc deducta. 4th. Tentamen legera evaporationis aquæ calidæ in aere frigidori, constantis temperiei definiendi.—Novi Commentarii Academiæ Scientiarum Imperialis Petropolitanæ. Tom. 1, ad annum 1747 ut 1748.

cover a memoir of special value, entitled "Meditationes de Caloris et Frigoris Causa—Auctore Michaele Lomonosow, which has, so far as I am aware, been entirely overlooked by writers on the history of the Theory of Heat. Here I can only state that he recognizes *the sufficient cause of heat as consisting in the motion of matter*, and although for the most part in hot bodies no motion can be perceived by sight, nevertheless it is manifested by its effects. Thus, iron heated almost to ignition, may be quiescent to the eye, but if bodies are brought in contact with it, they melt or resolve themselves to vapors; *that is, their parts are excited by motion.* "Who would deny," says the logical Lomonosow, "that when a violent wind traverses a forest the leaves and boughs of the trees are agitated, although on looking from a great distance no motion could be detected by sight?" I hope elsewhere to publish comments on this remarkable contribution to science, published over fifty years before Benjamin, Count of Rumford, opened his classical Essay on Heat as follows: "Without entering into those abstruse and most difficult investigations respecting the nature of fire which have employed the attention and divided the opinions of speculative philosophers in all ages; without even attempting to determine whether there be such a thing as an igneous fluid or not; whether what we call heat be occasioned by the accumulation or by the increased action of such a fluid, or whether it arises merely from an increased motion in the component particles of the body heated, or of some elastic fluid by which those particles are supposed to be surrounded, and upon which they are supposed to act, or by which they are supposed to be acted upon; in short, without bewildering myself and my reader in this endless labyrinth of darkness and uncertainty," &c., &c. Lomonosow was evidently unknown or neglected, as he has been ever since, so far as I can learn, and it is with infinite satisfaction that I direct attention to a hidden treasure of immense interest to all engaged in the study of physics, and who, in the cause of truth and justice, always desire to give credit where credit is due.

What does he tell us about the nature of cold? He anticipates all that has been said of the *absolute zero*—of the point at which all heat motion ceases. He says: "No celerity of motion can be assumed so extreme that another greater cannot be conceived, since the latter also may justly be referred to calorific motion. Therefore, a supreme and ultimate highest possible grade of heat in respect of motion does not exist. On the other hand, however, the same motion may be diminished to such a degree that finally the body shall be totally at rest, and no further diminution of the motion can follow. Necessarily, therefore, a supreme and ultimate degree of cold will consist in absolute rest of particles." He tells us that "everything which appears to us cold is only less warm than our organs by which we feel." How far-seeing and accurate is the statement that "it is not to be supposed that the congelation of bodies is a criterion of ultimate cold, for metals solidified immediately after liquefaction are also ice of their kind; yet are they so hot that combustible bodies brought in contact with them are set on fire."

Let us see how he disposes of the *primum frigidum* and *summum frigidum* of other philosophers, of and before his time. He says: "Since the air is always and everywhere observed to be fluid, and therefore (as demonstrated) warm, it follows that all bodies encompassed by the terrestrial atmosphere are warm, although they may appear cold to the senses; *and thus an ultimate degree of cold in our terraqueous globe is not given.*" Can anything be more precise and more philosophical?

Here, indeed, in Michael Lomonosow's splendid memoir, do we discover the doctrine of heat energy and the kinetic theory of gases, traced hitherto, by recent writers, only as far back as 1811 to Avogadro. The history of thermodynamics must now contain a long and deeply-interesting chapter referring to the speculations and close reasoning of Russia's Goethe—a poor fisherman's son, afterward a linguist, rhetorician, poet, dramatist, historian, physicist, and professor of chemistry in the Academy of St. Petersburg—nevertheless forgotten!

D.—DEFINITION OF AN ICE-MACHINE.

I shall only briefly allude now to the laws of heat which control the operations that are to be studied in ice-machines or cold-generators. Cold being only less heat, the entire subject is one of pure thermodynamics, and the labors of Joule, Mayer, Rankine, Clausius, Sir William Thomson, Tait, Tyndall, and others have unfolded the truth of the action of heat-engines, and of the methods by which heat may be abstracted from cold bodies by the energy of heat at higher temperatures. Mr. Alexander Carnegie Kirk, in a paper read in 1874, before the Institution of Civil Engineers in London, defined the mechanical production of cold to be "the removal of heat from a body without the intervention of a colder body, by a continuous circle of operations. Any arrangement for effecting this was merely a heat-engine, whose temperature of absorbing heat was lower than its temperature of ejecting heat, the motive power in this state of things being negative. An air-engine was the type of all refrigerating-machines in which the medium used was incondensable gas. A steam-engine with a surface condenser might be taken as the type of those in which the medium was a vapor or condensable gas. Harrison's ether-machine was the best known of this type."

The analogy with a heat-engine is not altogether simple, since in this the useful work done is the equivalent of heat which disappears during the process, whereas the intervention of motive power to raise heat from water to be frozen to the condenser of an ordinary ice-machine, when abstracted heat is thrown off with a large amount of water going to waste, suggests at once that in an ordinary ice-machine there are two elements to be considered, first, the heat-engine proper, viz, the steam-engine, which operates the second element of the machine, viz, the circulating-pump, dealing with air or liquefiable gases. The same power and the same fuel will give 1 pound of ice per pound of coal burned if air is being compressed, 3 pounds per pound if ether is used, 5 pounds with sulphurous oxide, and at least from 10 to 15 with anhydrous ammonia. The efficiency of the pump, the varying amount of heat of compression in pumping different gases in relation to the heat transferred from the refrigerator to the condenser, and lastly the temperature of available condensing water tend to produce the most complex conditions which a skilful observer can well be called upon to study.

E.—TYPES OF ICE-MACHINES.

Up to the present time there have been five distinct types of ice-machines in the market.

Firstly. The domestic machines, in which salts are liquefied, as explained elsewhere. Ash's piston freezer and Toselli's frigorific mixture machines belong to this group.

Secondly. The form of apparatus, in which, in addition to the power used, usually by hand, in working an air-pump to favor the evaporation of water to be frozen, we have to calculate the cost of absorbing watery vapor by sulphuric acid in vacuo.

Thirdly. Distillation or absorption machines, in which heat has to separate a chemical, say ammonia, from water, and in which the cooling water has to favor the reabsorption of the ammonia gas heated in the refrigerator.

Fourthly. An air-pump with a so-called regenerator or appliances (whether a second pump or otherwise) to cause work to be done in expansion by the compressed air. This is based on Joule's law, subject to slight deviation, that *to effect change of temperature air must be allowed to expand in such a manner as to develop mechanical power.*

Fifthly. The machines composed of a refrigerator and condenser, with an intervening exhausting and condensing pump driven by an engine.

F.—THERMODYNAMIC LAWS.

It is heat we use as the great agent for producing those changes in the physical state of matter whereby the conversion from a gas to liquid, and from a liquid back to gas is effected. There is a definite relation between heat and work as enunciated in the First Law of thermodynamics.* *Heat and mechanical energy are mutually convertible, a unit of heat corresponding to a certain fixed amount of work, called the mechanical equivalent of heat.* Joule has experimented on the heat produced by the agitation of water, and his latest determinations have proved the correctness of the late Professor Rankine's calculations, viz, that the raising of 1 pound of water 1 degree Fahr., from 39° to 40°, if wholly converted into work, will raise a pound weight through 774.1 feet, sub-

* I would counsel all persons interested in steam-engines, ice-machines, &c., to read The Steam Engine considered as a Heat Engine, by James H. Cotterill. London and New York, Spon, 1878.

ject to a small correction, possibly amounting to $\frac{1}{400}$th, on account of the "thermometric scale of error." Heat and mechanical energy being mutually convertible, quantities of heat may be stated in foot-pounds and quantities of work in thermal units. Taking steam, the total and latent heat of evaporation in thermal units at 401° Fahr. is 1,204.2. This multiplied by the mechanical equivalent of heat, say 774.1 gives 932,050 foot-pounds as expressing the total and latent heat of evaporation at 401°. Moreover, a horse-power of 33,000 foot-pounds per minute is equivalent to $\frac{33000}{774}=42.48$ thermal units per minute, or 2,548 thermal units per hour. In working examples it is sufficiently near the truth to calculate 42.5 as the heat which disappears by work done, theoretically, per indicated horse-power, or 2,550 thermal units per hour.

The next Law of thermodynamics, the second, on which the art of refrigeration is based, is that "*heat cannot pass from a cold body to a hot one by a purely self-acting process.*" Mr. Cotterill says on this point, "It is easy to see what enormous consequences the denial of this principle would involve in the theory of the steam-engine, for all the heat expended in the boiler which is not transformed into mechanical energy—that is to say, at least five-sixths of the whole amount—appears in the condenser being employed in heating the condensation-water, and if it were possible by some self-acting contrivance to cause that heat to flow from the condenser into the boiler, it is manifest that the said five-sixths of the consumption of heat might be saved. It is certain, however, that this is impossible, but that to cause the heat to flow from the condenser into the boiler we must have recourse to some artificial process, which, like working a heat-engine backward" (an ice-machine), "involves in some way or other, directly or indirectly, the expenditure of energy to as great or greater amount than we can recover by utilizing that heat in the boiler; and the second law of thermodynamics merely amounts to a statement of this impossibility."

After describing with some detail the principal forms of ice-machines produced since Jacob Perkins's invention in 1834, and with the aid of the foregoing data, I shall be in a better position to explain a new type of ice-machine, the least complicated and most economical capable of construction, and to which I have applied a name perhaps more explicit than elegant in any classic sense, viz, Thermo-glacial Engine.

Meanwhile it is necessary, for the complete understanding of the subject of artificial refrigeration, that some notice be taken of frigorific mixtures and the laws which control the thermometric phenomena due to the admixture of water or ice and certain salts.

G.—ON CRYOGENS OR COLD-GENERATING SALTS.

Prof. Frederick Guthrie, of the Science and Art Department, South Kensington, London, has contributed some very valuable memoirs to the Physical Society on salt-solutions and attached water. Space precludes my giving more than a bare statement of the important results he has arrived at by accurate experiment and admirable reasoning. Under the name "cryohydrates" he includes the bodies resulting from the union of water with another body, and which solidify below the freezing-point of water. These compounds have a constant composition and definite freezing and melting points, and can only exist in the solid form below 0° C. As Mr. Guthrie says, perhaps one of the most interesting aspects of the experimental results is the establishment of fixed temperatures below zero. With the exception of the melting-points of a few organic bodies, such as benzol, and the boiling-points of a few liquids, such as liquid ammonia, sulphurous acid, and carbonic acid, and the defined temperatures to be got from freezing-mixtures, there are no means in the hands of the physicist for obtaining and maintaining with certainty and ease a fixed temperature below 0° C. Now, if we surround a body with one of the solid cryohydrates, the body is kept at a corresponding temperature as long as any of the cryohydrate remains solid, and this with as much certainty as the temperature, 0° C. can be maintained by melting ice. We thus command temperatures between −23° and 0° C. with the greatest precision. Mr. Guthrie has applied the term "cryogen" to an appliance for obtaining a temperature below 0° C.

Looking upon ice as the cryohydrate of water, this is seen to shrink as it loses heat till it reaches 4° C. At this point ice is formed, which, however, is dissolved in the water. A solution is obtained having a temperature of solidification below 4° C., namely, at 0° C. or 32° Fahr. At this the ice and the water solidify together, producing the compound body or cryohydrate called ice, which is thus a cryohydrate of water. The expansion from 4° to 0° (from 39°.2 to 32° Fahr.) is due to the greater and greater amount of ice which the water holds in solution, and whose expansion is greater than the contraction of the water due to the diminished temperature.

Common salt and ice solidify immediately below the temperature −21° to −22° C., which is the lowest temperature to be got by an ice salt-freezing mixture. This minimum temperature seems to be attained between the somewhat wide margins of 3 of salt to 1 of ice, and 1 of salt to 2 of ice. This shows that "freezing-mixtures may be bodies of precise temperatures under widely-varying circumstances."

"It is clear," says Dr. Guthrie, that the liquid portion of a freezing-mixture is a brine of such a composition as to resist solidification at the temperature of the freezing-mixture.

"The enormous latent heat of water, the fact that the specific heat of ice is only about half that of water, while the specific heats of all salts are far less than that of ice, and, therefore, *a fortiori*, less than that of water, together with the good thermal conductivity of water, all argue that, if constantly stirred, all parts of a freezing-mixture will have the same temperature. The fact that the liquid portion of a freezing-mixture of ice and a solid salt is the cryohydrate of that salt, insures the identity of the resulting temperature under various conditions of proportion. The constant tendency to the formation of this cryohydrate by contact between the solids is alway seeking to depress the temperature; while the solidification of the cryohydrate at an indefinitely small fraction of a degree below the temperature of the freezing-mixture and the consequent liberation of heat insure the temperature against such fall."

"Statements, therefore," says Professor Guthrie, "whether previously made by myself or others, that it is advantageous to weigh the salt and ice in definite proportions, that the ice should be dry, that snow is preferable to ice on account of its state of finer division, that additional cold is produced by previously cooling the ice or salt, or both, are to be put aside as untrue—untrue, that is, as far as the temperature or heat tension is concerned. To obtain the greatest quantity of heat absorption with a given amount of salt, such a quantity of ice must be taken as will form with the salt a cryohydrate."

Within very wide limits as to quantity, the temperature of a freezing-mixture may be very independent of the temperature both of the salt and of the ice. Professor Guthrie established this as follows: an ounce of finely-powdered chloride of sodium was cooled in a flask surrounded by a freezing-mixture till its temperature was −15° C. It was then stirred with four ounces of ice, which had been cooled and had the temperature −10°. As soon as liquefaction began, the temperature −22° was reached; and this degree of cold was never surpassed.

The same degree of cold (−22°) resulted from the mixture of 1 ounce of sodium chloride at −15° with 4 ounces of ice at 0°; also, when 1 ounce of salt at +12° C. was mixed with 4 ounces of ice at −12° C.

Indeed, the margin of temperature may be greatly extended. Thus, 1 ounce of sodium chloride in powder was heated to incipient redness and thrown upon 5 or 6 ounces of ice at 0°; after a few minutes' constant stirring, the temperature had reached −22°.

One ounce of dry anhydrous sodium sulphate was heated nearly to redness. and thrown upon 4 ounces of ice at 0°. In a few minutes the temperature had sunk to −0°.7. Again, an ounce of anhydrous copper sulphate was heated to about 600° C. and thrown upon 4 ounces of ice; the temperature at once sank to −0°.5; whereas, if mixed at ordinary temperatures, the reduction would only have been to −2° C.

II.—SPECIAL EXAMPLES OF CRYOHYDRATES.

Some examples of special interest among cryohydrates may be noticed. Ice and chloride of ammonium solidify at −15° C., taking the form of a brilliant white, apparently flocculent mass, lighter than the unsolidified liquid. Decanting liquid separated after awhile, the solidifying parts were seen to be minute crystals, very much resembling ice-flowers, but opaque. "The sides of the beaker become studded with transparent crystals of four sides, which are streaked parallel to the sides. By and by these crystals become perfectly white and opaque, and a third axis of crystallization is developed, which was at first suppressed. The crystals are perfectly beautiful, resembling, where opaque, frosted silver. On allowing a thick cup to freeze, and breaking it, an exquisite pearly appearance is presented. The structure appears then quite fibrous, the fibres running perpendicular to the axis of the cup; and the appearance, as far as structure is concerned, is similar to that of sublimed chloride of ammonium. The temperature remains constant at —15° C., even to perfect dryness."

Shortly after my return to England from Texas, in 1869, where I felt the want of a harmless antiseptic, I was the cause of the manufacture, commercially, of the chloride of aluminium. The strong solution obtained by the double decomposition of chloride of calcium and sulphate of alumina absorbs water from the air with great avidity. On immersing fish in a dilute solution of this chloride, a very remarkable phenomenon was observed. Alumina was deposited on the surface, and hydrochloric acid penetrated the tissues, preserving them under proper management with very slight adventitious flavor. I found that strong solutions would resist congelation to below —10° Fahr. Professor Guthrie found that when thrown upon several times its own weight of ice, the two would liquefy, and the temperature stand above 0° C. "The strongest commercial solution of chloride of aluminium, however, when at the temperature of the air, or at 0°, or at 100° C., will reduce the temperature to —13° C. when poured upon three or four times its own weight of ice." "I suppose," continues Mr. Guthrie, "the anhydrous chloride may be viewed as separating the atoms of the water-molecule, as is supposed to be the case with the chlorides of phosphorus."

In using hydrochloric acid as a cryogen with ice, Professor Guthrie obtained a normal acid, and poured it, in various proportions, upon ice at 0°. Fifty grammes of ice were used in each experiment. The table shows within what small limits of ratio the minimum temperature is reached. The weight of ice is taken as unity.

Weight of ice at 0° C.	Weight of hydrochloric acid.	Resulting temperature.
1	1.5	— 3°
1	0.4	—26°
1	0.3	—23°
1	0.2	—19°

"We are, therefore," says Mr. Guthrie, "when dealing with a cryogen, one of whose constituents is a liquid, much more limited in the range of ratio which we may employ, to procure the maximum cold, than is the case when both are solid."

I.—TABLE OF FREEZING-MIXTURES (GUTHRIE).

The temperatures obtained on mixing the salt with three to six times its weight of ice in lumps of the size of *a pea* downwards.

Name.	Formula of salt.	Temperature.	
		Cent.	Fahr.
Sodium bromide	$Na\,Br$	−28.0	−18.4
Ammonium iodide	$N\,H_4\,I$	−27.0 −28.0	−16.6 −18.4
Sodium iodide	$Na\,I$	−26.5	−15.7
Copper chloride	$Cu\,Cl_2$	−24.5	−12.5
Potassium iodide	$K\,I$	−22.0	−7.6
Sodium chloride	$Na\,Cl$	−22.0	−7.6
Magnesium chloride	$Mg\,Cl_2 + 6\,H_2\,O$	−20.5	−4.9
Strontium chloride	$Sr\,Cl_2 + 6\,H_2\,O$	−18.0	−0.4
Ammonium sulphate	$2\,N\,H_4,\,S\,O_4$	−17.5	+1.0
Ammonium bromide	$N\,H_4\,Br$	−17.0	1.4
Ammonium nitrate	$N\,H_4\,N\,O_3$	−17.0	1.4
Sodium nitrate	$Na\,N\,O_3$	−16.0	3.2
Ammonium chloride	$N\,H_4\,Cl$	−16.0	3.2
Iron chloride	$Fe\,Cl_3$ (commercial)	−16.0	3.2
Calcium nitrate	$Ca\,2\,N\,O_3 + 4\,H_2\,O$	−14.0	6.8
Potassium bromide	$K\,Br$	−13.0	8.6
Aluminium chloride	$Al\,Cl_3$ (in strong solution)	−13.0	8.6
Potassium chloride	$K\,Cl$	−10.5	13.1
Potassium chromate	$K_2\,Cr\,O_4$	−10.2	13.7
Barium chloride	$Ba\,Cl_2 + 2\,H_2\,O$	−7.2	20.3
Strontium nitrate	$Sr\,2\,N\,O_3$	−6.0	21.2
Magnesium sulphate	$Mg\,S\,O_4 + 7\,H_2\,O$	−5.3	23.5
Zinc sulphate	$Zn\,S\,O_4 + 7\,H_2\,O$	−5.0	23.0
Potassium nitrate	$K\,N\,O_3$	−3.0	26.6
Sodium carbonate	$Na_2\,C\,O_3$	−2.2	28.3
Copper sulphate	$Cu\,S\,O_4 + 5\,H_2\,O$	−2.0	28.4
Iron sulphate	$Fe\,S\,O_4 + 7\,H_2\,O$	−1.7	30.
Potassium sulphate	$K_2\,S\,O_4$	−1.5	....
Potassium bichromate	$K_2\,Cr_2\,O_7$	−1.0	30.2
Barium nitrate	$Ba\,2\,N\,O_3$	−0.9	....
Sodium sulphate	$Na_2\,S\,O_4 + 10\,H_2\,O$	−0.7	....
Potassium chlorate	$K\,Cl\,O_3$	−0.7	....
Ammonia alum	$Al_2\,N\,H_4\,2\,S\,O_4 + 12\,H_2\,O$	−0.4	....
Mercury perchloride	$Hg\,Cl_2$	−0.2	....
Ammonium oxalate	$N\,H_4\,C\,O_2$	−0.2	....

The temperatures here recorded are the lowest attainable for each salt independently of the temperature of the salt and its degree of crystalhydration.

Professor Guthrie has determined that *a cryohydrate undergoing solidification may be considered physically as the homologue of a saturated salt-solution in the act of boiling.* Comparing the decomposition of a salt-solution by the loss of heat with the decomposition by gain of heat when such a solution boils, the following points may be noted:

(1.) A solution poorer than the cryohydrate loses heat; ice is formed.

(2.) This goes on until the proportion of the cryohydrate is reached, the temperature falling.

(3.) The cryohydrate may be reached by freezing out ice from a weaker solution, or by any other withdrawal of water.

(4.) When ice separates from a liquid, it remains in contact with the liquid, and endeavors to redissolve therein.

(1.) A solution poorer than that saturated at a given temperature receives heat; vapor is formed.

(2.) This goes on until saturation is reached, the temperature rising.

(3.) Saturation may be reached by evaporation, boiling, or any other withdrawal of water.

(4.) Vapor separated from a liquid is removed from the field of contention, unless the liquid be enclosed with the vapor.

(5.) When by the separation of ice the proportion of the cryohydrate is reached (nearly independent of pressure) ice and the salt separate simultaneously.

(6.) The two bodies (ice and salt) being crystallizable solids, unite to form a crystallizable cryohydrate which exhibits a constant gravimetric composition.

(7.) A cryohydrate in the act of solidification shows identity of composition between the solid and liquid portions. The temperature of solidification is constant.

(5.) When by the separation of vapor the proportion of saturation is reached, (very dependent on pressure), vapor and the salt separate simultaneously.

(6.) One being a solid and the other a vapor, they do not unite, but in their separation preserve a constant gravimetric ratio under like conditions of pressure.

(7.) A saturated solution, when boiling, shows the same ratio between the vapor formed and the salt precipitated as exists between the liquid water present and the salt it holds in solution. The temperature of boiling is (under like pressure) constant.

J.—ORGANIC CRYSTALLOIDS IN WATER.

In discussing the behavior of a few organic crystalloids in aqueous solutions on being cooled and being heated, Professor Guthrie says: "With regard to glycerine, a very remarkable circumstance may be noticed. That it is crystalloid, we have had until lately (1) the indirect evidence depending upon its being an alcohol, and upon several alcohols being known in the solid and crystalline state, while others which are not so known get united with crystalline salts; (2) the direct evidence obtained from its diffusion through colloid septa. Lately, it has been observed to assume the form of a crystalline solid. Again, it has lately been employed in aqueous solution in Pictet's ice-machine as a non-freezable liquid, to yield heat to vaporizing sulphurous acid, and take it from water for the purpose of freezing the latter. The latter faculty of its solution to resist solidification below 0° C. proves, first, that it will form a cryogen, and, secondly, that it will form a cryohydrate; the latter fact again proving, as we shall see, that it is a crystalloid. Pure glycerine dried by being kept for a week over oil of vitriol *in vacuo*, when mixed with finely-crushed ice forms a cryogen whose temperature is —19° C." Professor Guthrie was not aware, when writing the above, that I originated the idea of using the aqueous solution of glycerine in ice-machines, and Mr. Pictet only employed it at the exhibition of scientific apparatus in South Kensington with my permission. The practical advantages have been demonstrated by the total cessation of accidents from ice forming in the refrigerator-tubes and bursting them, and from the absence of all galvanic or corroding action on the metals.

Glycerine, per cent. by weight.	Water, per cent. by weight.	Temperature at which solidification begins.	Nature of solid formed.
		°	
5	95	— 0.8 Cent.	Ice.
10	90	— 2.0 Cent.	Ice.
15	85	— 3.3 Cent.	Ice.
20	80	— 5.0 Cent.	Ice.
25	75	— 6.2 Cent.	Ice.
30	70	— 8.8 Cent.	Ice.
35	65	—11.5 Cent	Ice.
40	50	—13.9 Cent.	Ice.
45	55	—16.7 Cent.	Ice.

Professor Guthrie has not succeeded in getting the cryohydrates of glycerine. As a cryogen, the glycerine behaves as hydrochloric acid and other liquid elements of cryogens, namely, the temperature obtained is lower if the liquid be previously cooled.

K.—CRYOGEN-MACHINES.

Under this name may be included any apparatus calculated to facilitate and bring about the regular admixture of water and a cryogen, the low temperature produced being utilized to make ice, freeze creams, &c. The only practical domestic machines are really of this kind, and to what extent they may hereafter render good service in households and some industries, especially in hot climates, depends much on the careful application of the knowledge acquired by Professor Guthrie and his followers. Many of the salts available for this purpose are remarkable for their stability, and may be used for an indefinite period of time. The cost of the evaporation of water will determine the cost of the resulting cold, and the sun's heat may enable, the parched residents of tropical countries, to enjoy the comfort and luxury of very economical methods of artificial refrigeration.

In relation to fish-culture, the transportation of ova on steamers, and for securing definite and unvarying temperatures at small cost, in moderate compass, the *cryogen-machine* offers many advantages. At sea, exhaust steam may be had in any quantity to dry the salt. The time required to dry the salt, the amount of material to be cooled, and the mechanical facilities for the alternate liquefaction and solidification of the salt are matters of great practical moment which have received but little attention hitherto. In this direction we must anticipate a great revolution in artificial refrigeration, especially as applied to the subjects most immediately under consideration in this paper. I need, therefore, make no excuse for reproducing the following table, showing (1) the chemical formula of the salt, (2) the lowest temperature to be got by mixing the salt with ice, (3) temperature of solidification of the cryohydrate, (4) molecular ratio between anhydrous salt and water of its cryohydrate (water-worth or aquavalent), (5) percentage of anhydrous salt in portions of cryohydrate last to solidify, (6) percentage of anhydrous salt in crop of cryohydrate before the last.

Table of cryogens and cryohydrates. (*Guthrie.*)

Name of salt.	Formula.	Temperature of cryogen, Cent.	Temperature of solidification of cryohydrate, Cent.	Molecular ratio, or water-worth or aquavalent.	Percentage of anhydrous salt in last cryohydrate, M.I.	Percentage of anhydrous salts in next to last cryohydrate.
		°	°			
Sodium bromide	$NaBr$	−28	−24	8.1	41.33	41.61
Ammonium iodide	NH_4I	−27	−27.5	6.4	55.49	57.6
Sodium iodide	NaI	−26.5	−15	5.8	59.45	59.39
Potassium iodide	KI	−22	−22	8.5	52.07	51.72
Sodium chloride	$NaCl$	−22	−22	10.5	23.60	......
Strontium chloride	$SrCl_2+6H_2O$	−18	−17	22.9	27.57	27.5
Ammonium sulphate	NH_4SO_4	−17.5	−17	10.2	41.70	42.2
Ammonium bromide	NH_4B_2	−17	−17	11.1	32.12	32.17
Ammonium nitrate	NH_4NO_3	−17	−17.2	5.72	43.71	43.26
Sodium nitrate	$NaNO_3$	−16.5	−17.5	8.13	40.80	41.3
Ammonium chloride	NH_4Cl	−16	−15	12.4	19.27	19.27
Potassium bromide	KBr	−13	−13	13.94	32.15	31.80
Potassium chloride	KCl	−10.5	−11.4	16.61	20.03	20.07
Potassium chromate	K_2CrO_4	−10.2	−12	18.8	36.27	36.41
Barium chloride	$BaCl_2+2H_2O$	− 7.2	− 8	37.8	23.2	24.0
Strontium nitrate	Sr_2NO_3	− 6	− 6	33.5	25.99	25.91
Magnesium sulphate	$MgSO_4+7H_2O$	− 5.3	− 5	23.8	21.86	......
Zinc sulphate	$ZnSO_4+7H_2O$	− 5	− 7	20.0	30.84	......
Potassium nitrate	KNO_3	− 3	− 2.6	44.6	11 20	......
Sodium carbonate	Na_2CO_3	− 2.2	− 2	92.75	5.97	......
Copper sulphate	$CuSO_4+5H_2O$	− 2	− 2	43.7	16.89	......
Iron sulphate	$FeSO_4+7H_2O$	− 1.7	− 2.2	41.41	16.92	17.35
Potassium sulphate	K_2SO_4	− 1.5	− 1.2	114.2	7.80	7.5
Potassium bichromate	$K_2Cr_2O_7$	− 1	− 1	292.0	5.30	......
Barium nitrate	$Ba2NO_3$	− 0.9	− 0.8	259.0	5.30	2.88
Sodium sulphate	$Na_2SO_4+10H_2O$	− 0.7	− 0.7	165.6	4.55	......
Potassium chlorate	$KClO_3$	− 0.7	− 0.5	222.0	2.93	4.2
Ammonia alum	$Al_2N_4H2SO_4+12H_2O$	− 0.4	− 0.2	261.4	4.7	......
Mercury perchloride	$HgCl_2$	− 0.2	− 0.2	450.0	3.24	3.29

Professor Guthrie has, from the evidence thus adduced, enunciated the general law that if we define as similar salts either (1) those which consist of the same acid united with bases belonging to the same chemical group, or (2) those which consist of the same base united with acids belonging to the same group, or those whose bases belong to the same group, and whose acids belong to the same group—then, *of similar salts, the one which produces the greatest cold when used in a freezing-mixture unites as a cryohydrate with the fewest molecules of water.* And to the following law there seems to be only one pronounced exception: *The temperature at which the cryohydrate is formed is the same as the temperature of the corresponding freezing-mixture.* This latter law, however, has to be taken with reserve as far as those salts are concerned which, like chloride of aluminium and chloride of magnesium, decompose water, and also in regard to those bodies which, like chloride of calcium, unite with water under the liberation of much heat.

L.—CHLORIDE OF CALCIUM ICE-MACHINE.

The first practical cryogen-machine was patented in 1855 by Mr. C. W. Siemens under the title "Improvements in cooling and in freezing water and other bodies." In the apparatus required for these purposes a cistern "rests upon a second cistern." The upper one (of wood or other material) is lined with metal in such manner that a non-conducting substance may be inserted into the spaces "which are left at certain parts between the sides of the cistern and the lining, and between its floor and lining." A plate "extending along two sides of the cistern" divides off a chamber (called the salt-chamber), and another plate on the opposite sides divides off a smaller chamber (called the water-chamber) which communicates with a central chamber by a pipe on the under side of both. The central chamber contains "a series of guides or tubes arranged alternately close on to and a little above" the bottom lining, so as to cause "an upward and downward current of the cooling solution." "An insulating partition on all the four sides" (composed of plates with charcoal powder between them) divides off a chamber "from the space or chamber immediately around the central chamber." And this space is occupied by the vessels which contain the water to be frozen. The lower cistern contains a coil of pipes, and the overflow from the upper cistern is indicated by an outlet-pipe into the lower one, and surrounds the coil. A pump raises the solution, as may be required, from the lower cistern to a third cistern, which is mounted over a boiler, and communicates with it by a pipe carrying a ball tap. A pipe passing from the boiler is extended into a worm inside the third cistern; it then descends and is united with one end of the coil in the lower cistern; the other end of the coil extends upwards "and bends over and into the water-chamber." There is a discharge-tap from the boiler, and under the tap is "a crystallizing vat." The central chamber is filled with crystallized chloride of calcium. The vessels are filled with the substance to be frozen, and are closed with insulating covers. The water-chamber is filled with water, which passes into the central chamber, and penetrates "a considerable mass of the crystals in passing upwards and downwards between the tubes or guides into the space or chamber around." The solution fills this space "up to the level of the overflow of the insulating partition," and passing between the vessels "descends into the narrow surrounding chamber"; when this is filled, the surplus is discharged by the outlet-pipe into the lower cistern. Here the solution absorbs a further portion of heat from the coil "containing condensed water from the boiler." The pump raises the solution into the third cistern; the solution descends, and, having "reached its proper level in the boiler," is made to boil. The steam passing through the pipe and worm is condensed by contact with the solution in the third cistern; it then descends into the coil in the lower cistern, "is considerably cooled by contact with the solution" in this cistern, and rises thence into the water-chamber, "to be there almost reduced to the freezing-point previous to its again entering" the central chamber. "The concentrated solution is drawn from the boiler from time to time," is received into the crystallizing vat, and is there crystallized in from 12 to 24 hours. The crystals thus obtained are put into the salt-chamber "to be cooled down to nearly

32° Fahr., and to be again dissolved" in the central chamber. To produce "intense degrees of cold in the apparatus," a small quantity of ice or snow is put into the central chamber.

In 1858, Mr. Siemens improved the construction of the refrigerator in this machine, and in the system of evaporating the spent solution for the purpose of recrystallization or reproduction of the salt or compound which has been dissolved. He used evaporating-pans over a furnace, or the flues thereof, in such a manner as to afford the means of drawing off the contents of one or more pans into one or more other pans.

Another device for revolving ice-moulds with a freezing-mixture around them was patented in England, in 1862, by Giovanni Battista Toselli, and this form of apparatus is being sold in Paris. The invention consists, first, in the vertical rotation of the liquids to be congealed; secondly, in the very simple shape of the machine with concentric sides and opposite openings, whether such machine be made in whole or in part of metal; thirdly, in the said machines being suitable for the production of ice by chemical means.

M.—GASES AND THEIR LIQUEFACTION.

Van Helmont introduced the word "gas," and in 1752 he established the existence of gas sylvestre (carbonic acid), which Black, three years later, termed *fixed air*. To Van Helmont is due the distinction between a gas and a vapor. Aeriform fluids would not liquefy in cooling, whereas, vapors, he said, required heat to maintain them in the free molecular or gaseous state.

Daniel Bernouilli first stated that gases are formed of material particles, free in space, and animated by very rapid rectilinear movements. The tension of elastic fluids results from the shock of these particles against the sides of the containing vessels. The gaseous molecules manifest the energy of motion termed kinetic (from κινέω, I move). Lucretius held that the different properties of matter depended on such a motion. The law of Boyle or of Mariotte follows as a natural consequence of this idea, and it is this law which interests specially all those who are engaged in the liquefaction of gases and the abstraction of heat by these from surrounding objects, as they return to the gaseous state.

As Professor Wurtz puts it in a recent lecture:* "Suppose a gas occupying a certain volume, and composed of a definite number of material particles, or molecules, so called, to be contained in a closed vessel, such as the cylinder of an air-pump, the pressure on the piston will be determined by the number of shocks of the molecules diffused through the neighboring stratum of gas. If, then, the volume of gas be reduced, the number of particles in this layer will be increased as well as the sum of the shocks, and the pressure will be increased in proportion thereto. *Temperature* is determined by these movements of gaseous molecules.

* On the constitution of matter in the gaseous state, being the Faraday lecture delivered November 12, 1878, at the Royal Institution, London.

The energy of the rectilinear movements, that is to say, the mass of the gaseous molecules multiplied by the square of the velocity, gives the measure of the temperature." The law of Boyle (1662) is as follows: The volume of a gas varies inversely as the pressure; or, in other words, the pressure of a gas is proportional to its density. Cohesion, or the tendency to molecular aggregation, which is so strong in the more liquefiable gases, causes deviations from the law of Boyle, especially near the liquefying point. This cohesion is interfered with materially by the admixture with a condensable gas of one of the, hitherto called, permanent gases. For instance, if air becomes mixed with ammonia or even with ether vapor, the pressure at which the gas liquefies is greatly increased. The presence of air, or of some one of the more incondensable gases in a freezing-machine, interferes materially with the changes in physical state, so essential to the operation of the machine.

Heat absorbed also most naturally affects cohesion; as the temperature of a gas rises beyond a certain well-defined limit for each gas, the molecular movements triumph over cohesion and liquefaction is rendered impossible; as Dr. Andrews states, the *critical point* is attained. This point has been called by Medeleyeff the *absolute boiling-point*. Just as the addition of heat activates the motion to such an extent that the molecules cannot be brought to rest by any amount of superincumbent pressure that we can apply, so the opposite condition may be imagined when all heat has been abstracted. When heat motion ceases, this is the absolute zero, $-460^{\circ}.66$ Fahr., or $-273^{\circ}.7$C.

Dalton extended Boyle's law, and declared that if different gases, which do not act chemically on each other, are mixed together, the pressure exerted is likewise the sum of the separate pressures of the diferent gases, but Dr. Andrews has shown* that by mixing nitrogen with carbonic acid the critical temperature is lowered, and that Dalton's law of density of mixed vapors only holds at low pressures and at temperatures greatly above their critical points.

It is fifty-five years since Faraday (1823) gave precision to our knowledge concerning the effects of pressure and cold on bodies usually gaseous at ordinary temperatures and atmospheric pressure. Northmore had compressed chlorine into a liquid† in 1805–1806. Faraday condensed chlorine into a liquid in 1823, and afterwards succeeded in liquefying hydrochloric acid, ammonia, and other gases. He afterwards learned that Monge and Clouet had liquefied sulphurous acid gas in 1800, and in 1824 Bussy accomplished this at ordinary atmospheric pressure at 12° to 15° below 0 Cent.

Natterer, of Vienna, compressed oxygen, hydrogen, and nitrogen to 3,000 atmospheres without effecting liquefaction.

Dr. Andrews‡ has demonstrated that the gaseous and liquid states

* Proceedings of the Royal Society, 1875.

† Northmore, Nicholson's Journal, XII 368; XIII, 232.

‡ The Bakerian Lecture, Phil. Transactions, 1869.

are only distant stages of the same condition of matter and are capable of passing into one another by a process of continuous change. Confusion has arisen in the use of the almost interchangeable words *gas* and *vapor*. Ether in the state of gas is called a vapor, whereas ammonia and sulphurous oxide in the same state are called gases; yet they are all vapors—the ether from a liquid boiling at 35°, the sulphurous oxide from a liquid boiling at —10°, and the ammonia from one boiling at —37°. The distinction, says Dr. Andrews, is thus determined by the trivial condition of the boiling-point of the liquid, under the ordinary pressure of the atmosphere, being higher or lower than the ordinary temperature of the atmosphere. Such a distinction may have some advantages for practical reference, but it has no scientific value. The critical point of temperature affords a criterion for distinguishing a vapor from a gas, if it be considered important to maintain the distinction at all. Many of the properties of vapors depend on the gas and liquid being present in contact with one another; and this we have seen can only occur at temperatures below the critical point. We may accordingly define a vapor to be a gas at any temperature under its critical point. According to this definition a vapor may, by pressure alone, be changed into a liquid, and may, therefore, exist in presence of its own liquid; while a gas cannot be liquefied by pressure—that is, so changed by pressure as to become a visible liquid distinguished by a surface of demarcation from the gas. If the distinction be accepted, continues Dr. Andrews, carbonic acid will be a vapor below 31° C., a gas above that temperature; ether a vapor below 200°, a gas above that temperature.

The fact that Jacob Perkins, who had designed the first practical freezing-machine, had liquefied gases and probably atmospheric air has not met with the attention it deserves, and believing, as I do, in the true genius of this admirable observer, I perhaps attribute more importance than others might to the following note from Faraday's Experimental Researches in Chemistry and Physics. He says: "As my object is to draw attention to the results obtained in the liquefaction of gases before the date of those described in the Philosophical Transactions for 1823, I need not, perhaps, refer to the notice given in the Annals of Philosophy, N. S., VI, 66, of the supposed liquefaction of atmospheric air by Mr. Perkins, under a pressure of about 1,100 atmospheres; but as such a result would be highly interesting, and is the only additional one on the subject I am acquainted with, I am desirous of doing so, as well also as to point out the remarkable difference between that result and those which are the subject of this and the other papers referred to. Mr. Perkins informed me that the air upon compression disappeared, and in its place was a small quantity of a fluid, which remained so when the pressure was removed, had little or no taste, and did not act on the skin. As far as I could, by inquiry, make out its nature, it resembled water; but if upon repetition it be found really to be the product of compressed common air, then its fixed nature shows it to be a result of a very different kind to those mentioned above, and necessarily attended by far more important consequences."

It is, to say the least, singular that Faraday was not aware in 1823 that any of the gases had been liquefied. This is his own statement, and no one who knows Faraday's character can doubt that he believed what he wrote; but a letter by Faraday claiming the authorship of a paper previously published, over the initial letter of his Christian name, appeared in the very same volume of the Annals of Philosophy referred to above, published in 1823, and which contains the following editorial paragraph: "A paper on the compressibility of water, air, and other fluids, and on the crystallization of liquids, and the liquefaction of aeriform fluids, by simple pressure, was prepared by Mr. Perkins for the purpose of submitting it to the Royal Society; but it was accidentally misplaced previously to the last meeting, and, therefore, could not be announced to the society with the other papers. It contained, we are informed, a minute description, accompanied with figures, of his compressing apparatus; a diagram, showing the ratio of compressibility of water, beginning at the pressure of 10 atmospheres, and proceeding regularly to that of 2,000; and some experiments on the compression of atmospheric air, which appears by them to follow a law varying from that generally assigned to it by philosophers. Mr. Perkins intended to announce also, in this paper, that he had effected the liquefaction of atmospheric air and other gaseous substances, by a pressure equal to that of about 1,100 atmospheres; and that he had succeeded in crystallizing several liquids by simple pressure." In a paper "On the progressive compression of water by high degrees of force with some trials of its effects on other fluids," by J. Perkins, read June 15, 1826, in the Philosophical Transactions for 1826, I find the following:

"With the same apparatus I also made experiments on the compression of other fluids. The most remarkable result I obtained was with concentrated acetic acid; which, after compression with a force of 1,100 atmospheres, was found to be beautifully crystalized, with the exception of about $\frac{1}{10}$ part of fluid, which, when poured out, was only slightly acid.

"I next applied the apparatus to the compression of æriform fluids.

"In the course of my experiments on the compression of atmospheric air, by the same apparatus which had been used for compressing water, I observed a curious fact, which induced me to extend the experiment, viz: that of the air beginning to disappear at a pressure of 500 atmospheres, evidently by partial liquefaction, which is indicated by the quicksilver not settling down to a level with its surface. At an increased pressure of 600 atmospheres, the quicksilver was suspended about $\frac{1}{8}$ of the volume up the tube or gasometer; at 800 atmospheres, it remained about $\frac{1}{4}$ up the tube; at 1,000 atmospheres, $\frac{3}{8}$ up the tube, and small globules of liquid began to form about the top of it; at 1,200 atmospheres the quicksilver remained $\frac{3}{4}$ up the tube, and a beautiful transparent liquid was seen on the surface of the quicksilver, in quantity about $\frac{1}{2000}$ part of the volume of air. The gasometer was at another time charged with carburetted hydrogen," and "it was subjected to different pressures, and it began to liquefy at about 40 atmospheres, and at 1,200 atmospheres the whole was liquefied."

"These instances of apparent condensation of gaseous fluids were first observed in January, 1822; but for want of chemical knowledge requisite to ascertain the exact nature of the liquids produced, I did not pursue the inquiry further; and as the subject has been taken up by those who are eminently qualified for the investigation, I need not regret my inability to make full advantage of the power I had the means of applying."

Jacob Perkins knew probably more than any of his contemporaries as to the means whereby an apparatus could be constructed to stand such pressures. He afterwards invented the steam-gun, and no doubt his knowledge of the liquefaction of gases led him directly to the recondensation of the ether vapor in the ice-machine patented, a drawing of which is appended to this paper. Sir Humphrey Davy appeared in no admirable light on this question in relation to Faraday. He was president of the Royal Society in 1823, and in this year he asked his pupil and assistant to liquefy chlorine. Can Perkins's important paper, drawings and all, have been lost by mere accident? Dr. Andrews has pointed out that to determine the certainty of the liquid and solid state of matter is a much more difficult subject for experiment than the relation between gases and liquids. In this relation Mr. Perkins's observations of the crystalization of acetic acid under pressure is at all events interesting.

However this may be, we may repeat in Mr. Wurtz's words that "the experiments of MM. Raoul Pictet and Cailletet have removed from science the distinction between permanent and condensable gases." Cailletet liquefied oxygen and carbonic oxide on the 2d of December, 1877. Being a candidate for election to a seat in the Academy of Sciences he delayed the announcement, after having consigned a statement of the discovery to a sealed packet, till the session of the 24th of December. At the same time Raoul Pictet's results by low temperature produced with the combined aid of sulphurous and carbonic acid gases were published, and confirmed Cailletet's experiments in which liquefaction has been induced by "détente" or expansion of the gas compressed at low temperature. On the last day of 1877 Cailletet liquefied hydrogen, nitrogen, and atmospheric air, and on the 11th of January M. Pictet solidified hydrogen, proving it to be a metal, as previously supposed by Professor Dumas.

This suspicion had been almost transformed into certainty by the admirable work of Graham, in forming hydrogenium alloys—notably with palladium: and while palladium itself was known to be capable of but feeble magnetism, its hydrogenium alloy was found to become strongly magnetic.

Space forbids that I should prolong this history, but it is important that I should enter into details concerning the one substance of all others capable of absorbing most heat in its transference from the liquid to the gaseous state. All other agents have, in America, practically given way in practice to ammonia, whether as liquid or aqueous ammonia in the Carré machines, or anhydrous ammonia compressed by mechanical means, used mostly by infringers of the Ch. Tellier patent.

N.—ON AMMONIA.

This agent, known to the early alchemists as *spiritus salis urinæ*, in the form of carbonate, was procured by Basil Valentine from sal ammoniac by the action of an alkali. Geber first imported sal-armoniacum from Asia to Europe in the seventh century, and, like sulphate of ammonia, it was obtained as a deposit in the immediate proximity of volcanoes as well as with the boric acid of the Tuscan Maremme. The origin of ammonia from the effete organic matter constantly poured off by the excreta of animals, or in the rotting of vegetable matter, explains its universal diffusion. Whereas we now obtain ammoniacal liquor, supplying commerce with this article, from gas-works where the remains of extinct plants are being burned, centuries since Europe depended on Egypt for the material distilled from the soot of burning camels' dung. Later on, human urine was employed in Europe; and before the era of gas-works animal refuse of all kinds, such as hoofs, horns, bones, &c., furnished the spirits of hartshorn, an aqueous solution, named in Latin *spiritus volatilis salis ammoniaci*. After Stephen Hales's experiment in 1727 by heating lime with sal-ammoniac, liquid ammonia was obtained which we find Cullen calling the quick-lime spirit of sal ammoniac, and he placed it at the head of the list of agents calculated to depress the thermometer by their volatility. In 1774, Priestley discovered what he called *alkaline air*, and Berthollet, in 1785, determined the nature of the gases composing it by the aid of the electric spark, and found them to be hydrogen and nitrogen.

Dr. Angus Smith, in a recent article in the Chemical News (July 26, 1878), says: "Ammonia must ever be one of the most interesting of chemical substances."

"It is now many years," says Dr. Smith, "since Liebig first surprised me by saying that iron ores and aluminous earths were capable of taking up ammonia, and if they were breathed upon we were able even to smell that substance." . . . "If you pick up a stone in a city, and wash off the matter on the surface, you will find the water to contain ammonia. If you wash a chair or a table, or anything in a room, you will find ammonia in the washing; and if you wash your hands you will find the same; and your paper, your pen, your table-cloth, and clothes all show ammonia; and even the glass cover to an ornament has retained some on its surface. You will find it not to be a permanent part of the glass, because you require only to wash with pure water once or twice, and you will obtain a washing which contains no ammonia; it is only superficial."

Liquid ammonia (liquor ammoniæ), or the aqueous solution of ammonia of commerce contains varying quantities of ammonia in water, according to temperature. A mean usually stated is that water dissolves 700 volumes of the gas. At 0° C., 0.875 gramme or 1,148 cubic centimeters of ammonia gas are absorbed by one gramme of water under normal pressure. The avidity of the combination is attended with the evolution of heat, and this fact is demonstrated by passing a current of air through a cold concentrated solution of ammonia, displacing the gas, which carries off the heat of the intruded air, and the liquid falls below −40°, so that by this method mercury may be frozen.

At ordinary temperatures, ammonia is a transparent gas, alkaline in reaction, colorless unless the air contains a little hydrochloric acid, when visible white fumes appear. Its tension at different temperatures varies greatly.

The volumes of ammonia gas at different temperatures are, according to Andréeff, as follows:

Temperature..................	10° C.	0° C. +	10° C. +	20° C.
Volume	0.09805	1.000	1.0215	1.0450

The coefficient of expansion between −11° and 0° C. is, according to the mean of three observations by Jolly, 0.00155; so that at temperatures sufficiently removed from its boiling-point ammonia expands more than a gas.

At −38.5, according to Regnault, or at −35°.7, according to Loir and Drion, ammonia is liquid at atmospheric pressure. By a mixture of chloride of calcium and ice Guyton de Morveau condensed ammonia into a liquid at −52° C., and Bunsen at −40° C. Guyton de Morveau's original experiment, in which he liquefied ammonia at −21° C., shows the influence of an admixture of water in changing the properties of ammonia, an influence which Ch. Tellier had discovered when he recommended and patented the liquefaction by pressure of anhydrous ammonia in ice-machines.

The specific gravity of the liquefied anhydrous ammonia is 0.76, and it is a colorless, very mobile liquid, refracting light more powerfully than water.

Faraday solidified it at −103° Fahr., when its vapor tension was still 5 pounds to the square inch.

The pressures and temperatures at which ammonia gas, dried by chloride of calcium or fused caustic potash, could alone be liquefied, led to the idea, until Tellier dispelled it, that for the purposes of artificial refrigeration it could only be used with water. Prof. F. A. P. Barnard, of New York, one of the commissioners at the Paris Universal Exposition of 1867, wrote in the report I have elsewhere quoted a very clear and definite statement of the views then entertained. M. Tellier's patent was in the secret archives of the French patent-office, and indeed the difficulties in the way of pumping ammonia gas had led him to resort by preference to another agent, patented simultaneously, viz, methylic ether. Professor Barnard says: "Gaseous ammonia is reduced to the liquid form by pressure; but at 20° C. (68° Fahr.) it requires a pressure of not less than eight and a half atmospheres to produce liquefaction, and at 25° C. (77° Fahr.) not less than ten. Thus the pressure required rises very rapidly with the temperature. On the other hand, to liquefy ammonia by cold merely, under the ordinary atmospheric pressure, requires a reduction of temperature down to 38°.5 below zero of the Centigrade thermometer. Ammonia, therefore, evaporates very rapidly even at temperatures extremely low; and as the latent heat of its vapor is great, being estimated at 514° C., it may be used as a powerful means of producing cold, provided any practicable method can be devised for removing the vapor as it is formed. To do this mechanically would require a pump of large dimensions; and inasmuch as considerations of economy as well as of health and the comfort of the operators would require that the vapor should be reduced by compression to the liquid state, the pump should be capable of exerting a pressure of from seven to ten atmospheres. *If, therefore, it were only by mechanical means that ammonia could be condensed, this substance could not be profitably used as a means of producing cold.*"

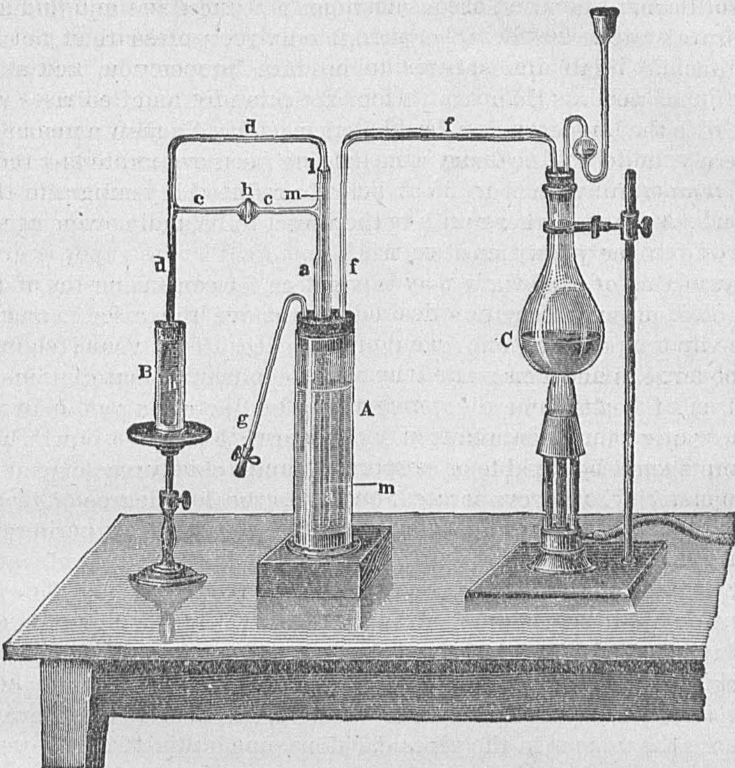
To show what at that time was meant by *liquid ammonia*, and the views Professor Barnard entertained of the unequalled value of ammonia vapor for the abstraction of heat, I have another passage to quote. He says: "It may thus be stated that the latent heat of a kilogram of liquid ammonia is equal to ninety *calories*.* The latent heat of a kilogram of its vapor, that is to say, of ammoniacal gas, amounts to five hundred and fourteen *calories*. The latent heat of water, liberated in the act of congelation, is equal to seventy-nine *calories* per kilogram; so that one kilogram of ammonia would be capable by its evaporation of freezing six and one-half kilograms of water taken at the initial temperature of zero, or five kilograms taken at the temperature of 24° C. (75°.2 Fahr.)."

Alcohol absorbs ammonia readily. Messrs. Roscoe and Schorlemmer, in their admirable Treatise on Chemistry, furnish the following illustration and remarks:† "The condensation of ammonia by pressure and the production of cold by its evaporation can easily be shown by the following experiment: The apparatus required for this purpose consists essentially of two strong glass tubes (*a* and *b*), which are closed below and are connected together by the tubes (*c c*) and (*d d*). The tube (*d d*) ends at (*l*) in a narrower tube (*m m*), which is at this point melted into a tube (*a*). The tube (*a*) is three-fourths filled with an alcoholic solution of ammonia saturated at 8°, and then placed in the cylinder (A). The syphon-tube (*g*) and the tube (*f f*), which reach to the bottom of the

*A French *calorie* signifies the amount of heat required to raise the temperature of a kilogram of water, taken at 0° C. of temperature, 1° C., and this is adopted as a unit.

†I am indebted to Messrs. D. Appleton & Co. for the use of this cut.

cylinder, are fixed in position through the cork. In order now to perform the experiment, the cylinder (A) is nearly filled with warm water;



the glass stop-cock (*h*) is opened, and the tube (*b*) placed in ice-cold water. The water contained in the flask is now quickly boiled, and thus the water in (A) is rapidly heated to 100°, and the ammonia gas driven out of solution until by its own pressure it liquefies in (*b*). As soon as the condensation of liquid ammonia ceases, the ebullition is stopped, and a portion of the hot water is withdrawn from the cylinder by means of the syphon (*g*); cold water is allowed to enter the cylinder, and after awhile this is replaced by ice-cold water. The cylinder (B) is now removed, when the liquefied ammonia begins to evaporate, and is again absorbed by the alcohol, though only slowly. But on closing the stop-cock (*h*) the gas above the alcohol is quickly absorbed, and thus the equilibrium is disturbed. The ammonia now passes rapidly through the tube (*m m*), and is absorbed so quickly that the liquid ammonia in (*h*) begins to boil, by which the temperature is so much lowered that if a test-tube containing water is placed outside (*h*) it is soon filled with ice."

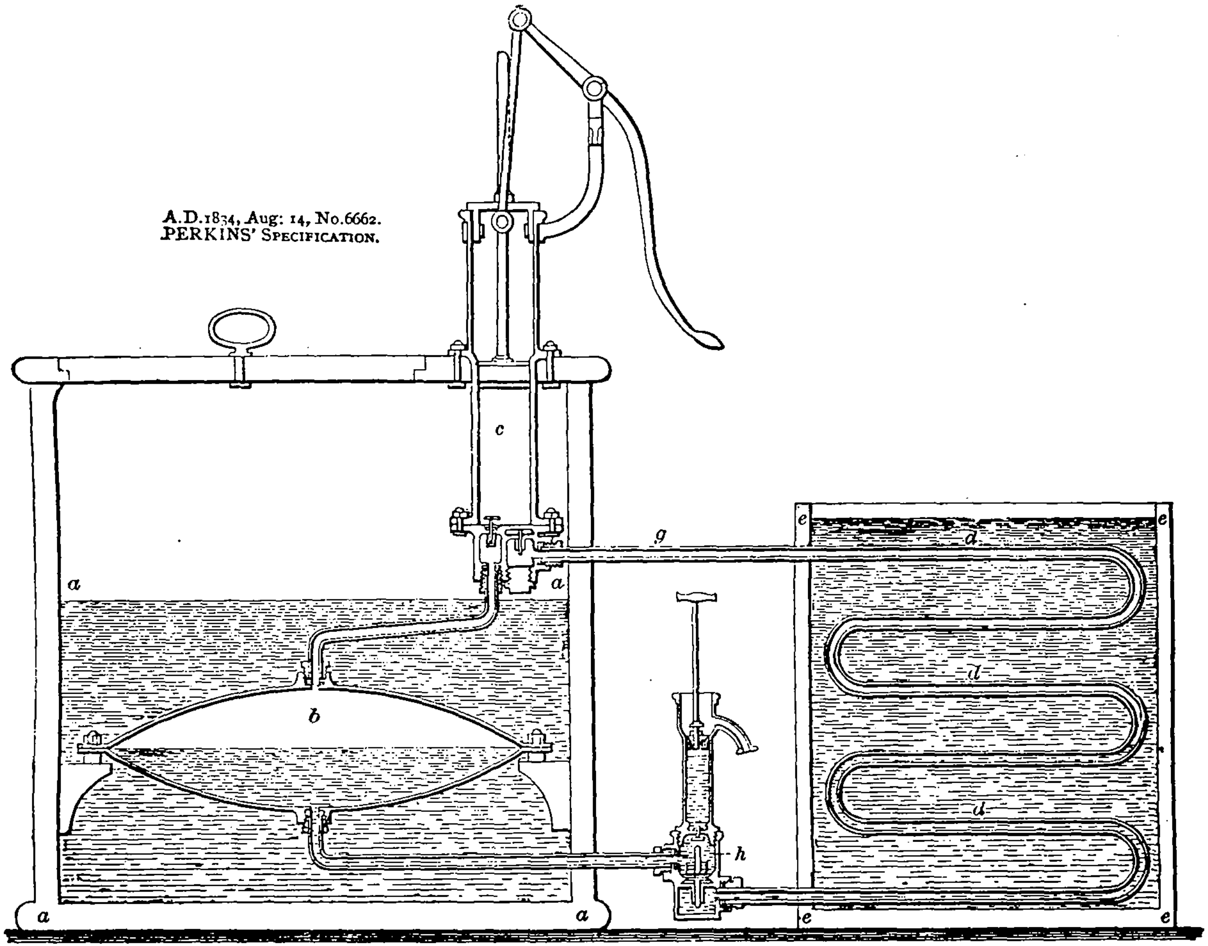
O.—THE PROGRESSIVE STAGES IN ICE-MAKING INVENTIONS.

After Cullen's efforts to freeze water in the receiver of a vacuum-pump, by the rapid vaporization of ether, we have to skip to the second quarter of the current century for a practical step in the direction of artificial-ice-machines. JacobPerkins, whilst a resident in London, devoted himself to the determination of the compressibility of gases and fluids, and as I have stated elsewhere, he undoubtedly recognized that gases and vapors might be condensed into liquids. This property he took advantage of in 1834, in his "Apparatus for Producing Ice and Cooling Fluids." "The object of my invention," said Perkins in his English patent, "is so to use a volatile fluid that the same (having been evaporated by the heat or caloric contained in the fluid about to be reduced in temperature) shall be condensed and come again into the vessel to be again evaporated and carry off further quantities of caloric."

"*Description of the drawing.*—*a* is a cistern for containing the water or other fluid from which it is desired to remove the caloric, and thus reduce its temperature, and even produce ice. This vessel should be well covered in and surrounded by a non-conducting material, in order to prevent the atmosphere or surrounding bodies giving off heat to the water or other fluid contained in such cistern; *b* is a vessel which is to contain the volatile fluid to be evaporated, and I chiefly recommend ether as the material to be evaporated, owing to the low degree of temperature at which, under ordinary circumstances, it becomes aeriform, but under the circumstances hereafter explained it will evaporate at still lower degrees of temperature; *c* is an ordinary pump, which I term the vapour-pump, it being intended to withdraw the vapour as it is generated in the vessel *b*, and to force it through the refrigerating-pipes *d*, contained in the cooling-tank *e*. There is to be a constant supply of cold water to the refrigerating-tank or vessel *e*, in order to cool down and condense the vapour in the pipes *d*. *f* is a pipe leading from the vessel *b* to the pump, having a valve to close the entrance into the pump, in order to prevent the vapour being forced back into the vessel *b* on the return stroke of the piston; *g* is a pipe having a valve opening outwards from the pump. This pipe *g* connects the pump with the refrigerator-pipes *d*; consequently the vapour, on coming into the pump, will be forced into the pipes *d*, and be there condensed, and thence return again into the vessel *b* to be again evaporated. But in order to secure a perfect condensation, I employ a valve, *h*, moderately weighted, say about atmospheric pressure, which prevents the return of the condensed ether till the same has become compressed and forced to give off its caloric to the condensing water on the outside of the condensing-tube *d*. The valve *h* is placed between the condenser and the vessel *b*, as shown in the drawing. It will be seen that most of the parts are shown in sections, in order that their construction may be evident.

"The apparatus being arranged as above described, and as shown in the drawing, I now prepare it for commencing work by filling every part of the apparatus with the volatile liquid to the utter exclusion of the atmospheric air, after which a sufficient quantity of the liquid is drawn off by the small pump attached to the valve *h*, to make sufficient space

A.D. 1834, Aug: 14, No. 6662.
PERKINS' SPECIFICATION.



for the vapour, say at least one-half. The progress of the evaporation of the liquid in the vessel *b* will depend on the quantity of vapour drawn off by the vapour-pump, as well as the quantity of caloric taken up from the liquid surrounding the vessel *b*, and thereby will its temperature be cooled down even to freezing."

I have been informed by Mr. Loftus Perkins, nephew of Mr. Jacob Perkins, that the great success of his uncle's first freezing-machine, as a matter of experiment, alarmed his partners lest he neglected the very lucrative business they were engaged in, and he was compelled to abandon a pursuit most congenial to his tastes. All that lacked to complete the ether-machine, was that extension of surfaces for the effectual freezing of a sufficiently large body of water whilst supplying heat to the ether for evaporation. Three inventors practically completed the work of Perkins, viz, Twining, Harrison, and Daniel Siebe. It were invidious to discriminate against either of these, but the ablest mechanic of the three, Mr. Siebe, having had all the fundamental principles laid before him, competent for any task he undertook, was limited to the engineering question, and to his skill in this respect we have to ascribe the practical success of ether-machines throughout the world.

Prof. Alexander C. Twining, of New Haven, has been justly regarded as having designed the first apparatus being an advance or improvement on the earlier invention of Mr. Jacob Perkins. His first patent was taken out in England on the 3d of July, 1850, and in the United States on November 8, 1853. The last was afterward extended to 1871. Professor Twining has permitted the publication of a statement of the steps taken in the progress of his invention. From 1848 to 1850 he was engaged in repeating Cullen's original ether experiments *in vacuo*, and found that one pound of ether, by its evaporation, was adequate to produce one pound and one-fifth of ice from water at 32° Fahr., besides cooling the ether 28°. He then determined that only 200 superficial feet of thin copper pipe would form an adequate surface for the production of 2,000 pounds of ice in twenty-four hours, even employing water of the temperature at the earth's equator. Ether was found to pass into vapor within a quarter as fast as water in locomotive-boilers; in a partial vacuum, 1 superficial foot of metal supplied heat even at the low temperature of 4° above zero to 5½ pounds of ether per hour.

In relation to the method of freezing water, it was ascertained that the rate of freezing was not appreciably obstructed by the thickness of ice already formed; a congelation of one-eighth of an inch in thickness could be realized per hour; 240 superficial feet would be a sufficient surface on which to freeze one ton of ice per day of twenty-four hours.

"The first attempt at a complete freezing construction was made in the summer of 1850. The machine had only capacity to freeze a pailful of water at one operation. It embraced the evaporating, the condensing, and the freezing parts" as afterward used. "But the mode of applying the freezing power was widely different. Six months were consumed in trials with this machine, and the most discouraging practical difficulties were brought to light. It was not till long afterward that the inventor could discover the proper modes of obviating these difficulties. Nevertheless, this first small machine served as a complete verification of the facts, principles, and numerous small experiments which had been relied upon; and it thus became an encouragement in the end to attempt a vastly larger construction."

On the 15th of February, 1855, an engine calculated to produce 2,000 pounds of ice per day in ten freezing-cisterns of cast iron, each divided into seven water-chambers, was in readiness for trial. With only two cisterns of the ten, 371 pounds of ice were made in eight hours. The water employed for condensation was thirty times in quantity the water frozen. In the vacuum-vessel the tension of vapor began with 5.7 inches of mercury and ended with 2.7 inches. In the condenser, the tension rarely exceeded 2 pounds above the atmosphere. The pump was 8½ inches bore and 18 inches stroke, working 90 double strokes per minute. On the 2d of March, 1855, 661 pounds of ice were made in eleven hours and ten minutes with only four cisterns. In different trials during the summer, eight cisterns of the ten were put on. The machine would at any time freeze up in these cisterns 56 cakes of ice, each 1 foot square and 6 inches thick, and weighing together 1,680 pounds. With ten cisterns, a ton could be frozen.

The great merit of Professor Twining's invention was extending the surface over which ice could be formed, by extending the "freezing-cistern" containing the ice-moulds, and using an uncongealable liquid which was stagnant around the moulds. This was the great advance on Mr. Jacob Perkins. In a patent issued April 22, 1862, he claims a pump to agitate or circulate the uncongealable liquid. Twining described in 1852, but a patent was only issued on the 15th of April, 1862, the method of using a refrigerator, as in the Harrison machine, with vertical tubes closed beneath or entering a *cul de sac*, allowing the ether to run down and its vapor to escape upward. The vaporized liquid thus abstracts heat from a contiguous uncongealable liquid that surrounds the pipes, and in its cold state is drawn out by a circulating-pump in place of running the cold volatile liquid through the freezing-cistern. This pump circulates the brine in open troughs which contain the water-vessels. Professor Twining aimed at extending surfaces, and for this he had described a *percolator*. He had perforations, or perforated branches or channels, girdling every exposed side of each *water-chamber*, and made to inject the ether in jets, or drops or films, upon or between its exposed surfaces or coatings. The volatile liquid thus spread upon or running down the water-chambers freezes through the *uncongealable liquid* and the *water-vessels* in those chambers.

Mr. James Harrison, of Geelong, Australia, did excellent work in his investigations of this subject, and so instructive are his specifications that they may be said to constitute the most substantial contributions to our knowledge of ice-machines at the dates they were respectively published. In his patent, No. 747, dated March 28, 1856, Mr. Harrison tells us that he employs "an air-tight apparatus of three vessels connected by tubes; a vacuum is to be established throughout the apparatus, the air being expelled by the vapor of ether, alcohol, liquid ammonia, or other volatile liquid." Mr. Harrison, so far, adopted Mr. Perkins's plan of obtaining space for his vapor, since the latter recommended filling his machine to repletion, and then taking some, say half, out to make room for vapor. It is quite clear, from the perusal of Mr. Harrison's patent, that the machine was designed to freeze by evaporation of ether, for the alcohol and the liquid ammonia, the latter universally known as a solution of gaseous ammonia in water, would have been of no avail whatever in the apparatus so well described. Indeed, the words, "liquid ammonia or other volatile liquid," inserted at the beginning of his specification, would have required the description of various forms of apparatus made of different materials, for the copper would have been destroyed by the liquid ammonia; and the vague expression, "volatile liquid," he extends to water in his claim, and we well know that had he tried water in the machine he describes, it would have been inoperative. This meaningless attempt to grasp everything, without knowing more than that part of his subject relating to ether, is the main defect of this important contribution to industrial art. He goes on to say:

"The nature of my invention consists in producing cold, by the evaporation of a liquid in one vessel, the withdrawal of the vapor formed, and the getting rid of heat thus withdrawn by the condensation of the vapor in another vessel." . . . "The evaporating-vessel may be of tinned copper, or any air-tight and water-tight material of good heat-conducting power, capable of resisting the atmospheric pressure, and not acted upon by the substances in contact with it, and of any shape, provided there be a sufficient surface of contact respectively to the liquid to be evaporated and the substance to be cooled. In like manner, the condensing-vessel may be of any material and shape, the requisites of strength, conduction of heat, resistance to chemical action, and sufficient surface being attended to." Having described his pump, &c., and referred his readers to their knowledge of heat to supply the data for practical work, he enters into definite calculations bearing on the use of ether. He says: "The requisite surface of the evaporating-vessel may be deduced from the ascertained fact that a surface of 10 square feet will evaporate fully 1 pound of water per minute, with a difference of temperature of 30°; with a less difference, a proportionately larger surface will be required. The latent heat of other liquids being less than that of water, a less surface will suffice for their evaporation. For instance, the latent heat of ether at, say 24° is to that of steam at 212° as 200 to 1,000, nearly; therefore only one-fifth of the surface, or one-fifth of the difference of temperature, will suffice for the evaporation of ether. The same rule will apply to the condensing-vessel, but as no loss except of space can accrue from having the vessels much larger than is by calculation necessary, it will be well to make them of ample capacity and surface."

Mr. Harrison aimed at establishing a broad claim which he stated as follows: "Having thus described the nature of my invention, and the manner of performing the same, I would have it understood that I do not confine myself to the arrangement of apparatus described, but what I claim is, the use of volatile liquids (including water), evaporated *in vacuo*, and reduced to the liquid form in a separate vessel by pressure, for the production of cold, and in the manufacture of ice and generally in all processes where refrigeration is requisite or desirable."

In the month of September, 1857, Mr. Harrison applied for a second patent in which he gave a description of the tinned copper ice-moulds which were used until superseded by Telier's metal plates, and he recommends a great number of moulds to give ample conducting surface, because ice is a bad conductor of heat, and in proportion to the slowness of conduction must the cooling surface be increased. He goes on to say at the end of his patent that "having described the nature of my invention and the manner of performing it, I now proceed to ascertain the points in which it differs from the more general description of the power of refrigeration, by the continual evaporation and condensation of volatile liquids *in vacuo* given in the specification of my patent, No. 747, 1856. I have herein described two new refrigerating-vessels, viz, a tubular boiler, and a series of vertical plates separated by wires, and two new forms of condensers, viz, a coil of tubes connected with a central cylindrical vessel, and a vertical tubular condenser combined with a similar cylindrical vessel."

"I am aware that the employment of saline solutions for carrying frigorific power has been frequently proposed, but the economical use which I make of this agent is not so much for the mere transmission as for the diffusion of this power over a large surface, the necessity for which I have ascertained by original experiments on the conducting power of ice."

"My invention, as now perfected, consists in the combination of a refrigerating process by the continued and self-regulated circulation of a stream of ether, or other volatile liquid, with the continued stream of uncongealable liquid, conveying and diffusing the frigorific effect over large surfaces, and in rendering the process subservient to the manufacture of ice on an economical scale, to cooling worts, &c., to regulating the temperature of apartments, and generally to any process in which a temperature below that of the season or climate is required."

Harrison's ether-machine, constructed with great precision and good workmanship by the late Mr. Daniel Siebe, proved at once the best practical machine for making ice, and the first one was taken to Melbourne, where it was recently, if it be not still, at work. This form of machine has been well made by Messrs. Siddely & Mackay, of Liverpool; and there are places in Ceylon, Java, the East and West Indies, and Australasia where ice is so dear that an ether machine may work at a profit, although making little more than one or two tons of ice per ton of coal burned. The Messrs. Siebe, in conjunction with the late Mr. King, engineer to Messrs. Truman, Hanbury & Co., brewers, London, introduced the Harrison machines with conspicuous success, for the direct refrigeration of water used in brewing, and it was owing to this that I first used one for cooling meat in 1869, and afterwards made several modifications in their construction.

The greatest improvement in ether machines must be credited to Ch. Tellier, for by the introduction of methylic ether, patented in America on January 5, 1869, he avoided a vacuum in his refrigerator, and this both in the sulphuric-ether and sulphurous-oxide machines (especially working at low temperatures) is attended with the introduction of air into the interior of the machine. Air decomposes these agents, but whilst its action is slow in effecting a chemical change, it is instantaneous in modifying the tendency to gaseous liquefaction. A little air mixed with the volatile vapor will soon make a difference of many pounds on the square inch in the condenser and the efficiency of the machine is greatly reduced. M. Tellier lays much stress on the value of his congealer, which is another part of his patents infringed in all the ice-box patents devised. It practically amounts to a box divided into compartments by hollow metallic walls, in which the methylic ether is evaporated. The wooden tank is filled with water, and all the compartments are frozen when the ether is evaporated. This was done to supersede movable moulds, as in Twining's and Harrison's patents, and to avoid the waste and labor of lifting the moulds and dripping the uncongealable brine or other liquid used in the machine.

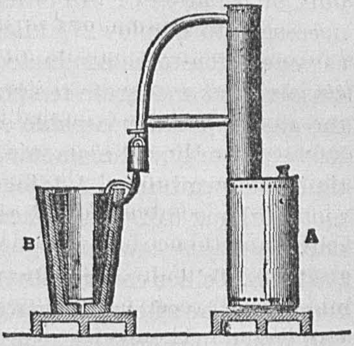
The pump and condenser of the Tellier machine are adapted to such pressures as are required for the condensation of this ether, which boils at 30° below 0 Centigrade. The pressures in the condenser amount to 45 pounds at 60° Fahr.

I regret that I have not by me Tellier's work on Ammonia. To Ch. Tellier is due the credit of the introduction first of the aqueous ammonia in the *absorption* or *distillation* freezing-machines, and afterwards the anhydrous ammonia liquefied by mechanical compression. M. Ferdinand Carré worked in conjunction or simultaneously with Tellier, and the circumstances under which M. Carré obtained the first patent for liquid ammonia, gave him control of the absorption-machines. A keenly-contested suit for infringement led to Carré's rights being sustained, and it is generally understood that he obtained 3,000,000 francs for his patents, which date back to 1862. Professor Barnard has furnished us with an elaborate report on the Carré continuous freezing apparatus. So fascinating was the apparatus as exhibited in 1867, in Paris, that Professor Barnard declared it to be "one of the most valuable contributions which science has yet made to the promotion of human comfort, and to the progress, in certain forms at least, of industrial art. Indeed, when the apparatus is examined in its details, and the ingenious felicity with which the difficulties involved in the problem have been met is understood and appreciated, this invention cannot fail to be recognized as presenting one of the most admirable illustrations of the combination of scientific knowledge with practical skill which the Exposition presented."

A solution of ammonia is introduced into a boiler which is heated by a furnace to about half its altitude. A tube extending upwards conveys the liberated ammoniacal gas to a vessel called the *liquefier*. The upper part of the boiler is occupied by broad shallow vessels pierced with holes, constituting the *rectifier*, so as to return the water to the boiler whilst allowing the escape of the gas. The gas passes to the aforesaid liquefier, which is a combination ot zigzag and spiral tubes in a tank of cold water, and thence into a kind of bin where, under a pressure of 150 pounds at 70° to 80° Fahr., the gas is liquefied. From here the ammonia flows into a small receiver adjoining the refrigerator, and which is called the *distributor*. Thence the liquid passes into zigzag or spiral tubes forming partitions in a tank, and between which the substances to be cooled are placed. These tubes of the refrigerator converge into the *collector*, which is a horizontal tube, from which an ascending pipe returns the ammonia rendered gaseous by heat to a vessel, *the absorber*, partially filled with water, and which greedily absorbs the gas; a current of cold water passes through a coil in this vessel. This water has also to cool the spent liquor from the boiler and which is to reabsorb the gas. When the gas has been reabsorbed, the strong solution is forced by a pump into the boiler.

Taking a machine with a production of 400 pounds of ice per hour, it must distil, liquefy, evaporate in the refrigerator, and redissolve 80 pounds of pure ammonia. The 80 pounds of ammonia with 1,600 pounds of water give 1,680 pounds of liquid to be acted on. This liquid is at first at 62°.6 Fahr., but in work the supplies return to the boiler at or above 140° Fahr., so that for continuous work 1,600 pounds of water have to be raised from 140° to 266° Fahr., or through 126 degrees, and also to convert 80 pounds of pure ammonia from 140° Fahr. into vapor at 266°. The consumption of fuel has been computed in practice at 50 pounds per hour, each pound making eight pounds of ice; besides this, the fuel for the steam-engine has to be supplied, and in most cities the water has to be paid for. That water Professor Barnard calculated at 3,200 gallons per hour, or nearly one gallon per second, making less than five tons of ice per day. Many attempts have been made to improve these machines since by Oscar Kropf, Rees Reece, Martin, Beath, Nishigawa, and others. With condensing and absorbing coils in which water is showered whilst air blows across to favor evaporation, a great economy in water is effected; but the pressures and leaks in these machines are very objectionable, the construction is complicated, parts numerous, and the dehydration of the ammonia is always so far from perfect that it interferes with the efficiency of the machines. They have been useful in temperate climates, but have failed almost universally in those hotter countries where their immense value was anticipated as a certainty.

Carré's intermittent ammonia apparatus has been described in the fewest possible words by Messrs. Roscoe and Schorlemmer, from whose book, through the kindness of the Messrs. Appleton, we have been favored with the annexed illustration. The apparatus consists of two strong iron vessels connected by a vent-pipe of the same metal. The cylinder (A) contains water saturated with ammonia gas at 0°. When it is desired to procure ice, the vessel (A) containing the ammonia solution is gradually heated over a large gas-burner. The ammonia gas is thus driven out of solution, and as soon as the pressure in the interior



of the vessel exceeds that of seven atmospheres it condenses in the double-walled receiver (B). When the greater portion of the gas has thus been driven out of the water, the apparatus is reversed, the retort (A) being cooled in a stream of cold water, whilst the liquid which it is desired to freeze is placed in the cylinder (D), placed in the interior portion (E) of the hollow cylinder. A reabsorption of the ammonia by the water now takes place, and a consequent evaporation of the liquefied ammonia in the receiver. This evaporation is accompanied by the absorption of heat which becomes latent in the gas. Thus the receiver is soon cooled down far below the freezing-point, and the liquid contained in the vessel (D) is frozen.

Messrs. Alexander Carnegie Kirk and George Thomas Beilby, of Scotland, obtained provisional protection, but afterwards abandoned their invention, which consisted essentially in placing a suitable solid substance in the absorbing-vessel instead of a liquid, as heretofore employed, for the purpose of absorbing the vaporized ammonia. The absorbent may consist of charcoal, or of chloride of silver, or of chloride of calcium, or of any solid substance having, like these, properties of absorbing large quantities of vaporized ammonia at ordinary temperatures and of giving off such ammonia again when heated to an extent short of fusing the said solid substance.

In order to prepare the apparatus for a fresh operation the absorbing-vessel is subjected to a sufficient heat in any convenient way; the evaporating-vessel being then kept cool, the ammonia is, by the heat, driven from the absorbing-vessel and is liquefied in the evaporating-vessel; the absorbing-vessel is next cooled and reabsorption takes place in it, whilst the ammonia is evaporated in the other vessel and produces the cold desired. Both the ammonia and the absorbent employed must be as free from water as possible.

This amounts to a substitution of a solid substance for the water in Carré's intermittent apparatus, and its efficiency is less, owing to the smaller quantity of ammonia which can be operated on in the same apparatus. "A given quantity of chloride of silver would produce only about the thirtieth of its bulk of liquid ammonia, and a fifth part of its bulk of ice at 0° C. In order to produce a kilogram of ice, it would be necessary to employ 27½ kilograms of the chloride; and this supposes the operation to be conducted with no loss. Water, on the other hand, dissolves, at moderate temperature, seven hundred times its volume of the gas, a quantity capable of producing two-thirds of its bulk and half its weight of liquid ammonia, and of converting into ice more than three times its own bulk. A kilogram of water employed as a solvent of ammoniacal gas will thus suffice to produce three kilograms of ice." (Barnard.)

M. Ch. Tellier covered by patents, in France and England, an invention which he afterwards patented in America on the 8th of March, 1870, and which has proved, especially by the action of a host of infringers, to be the most ready and economical plan of taking advantage in a refrigerating apparatus of the unequalled heat-absorbing power, at moderate pressures, of the volatilization of a liquid. His claim is for "the use or application, for the purpose of generating artificial cold, of pure ammoniacal gas liquefied by means of mechanical compression, substantially as described." He used the pump and condenser described in letters-patent 85,719, issued January 5, 1879; and while Tellier has continued to give the preference to methylic ether in France, this has been simply due to the greater facilities for pumping this ether. The benefits to be derived by the use of anhydrous ammonia have failed of being realized, owing to the practical difficulties of pumping it by reciprocating-pumps—difficulties which are only in a lesser degree experienced, but nevertheless encountered, in pumping other volatile agents.

In the month of May, 1877, M. Tellier issued a circular in which he propounds the merits of a new absorption machine for the use of trimethylamine in producing cold. The apparatus is similar to the ammonia-*absorption* machine, and here Tellier remarks that, without renewing the strife of seventeen years previously, he has a right to use his own invention, patented on the 25th July, 1860, as against Carré, whose patent dated 24th August, 1860, both patents being now public property.

Trimethylamine is a peculiar ammoniacal compound—a crude organic ammonia in a sense, contained in large quantity in herring-pickle, and to this it gives its peculiar odor. It is, like all agents of great value as refrigerants, readily soluble in water, and boils at 49°.6 Fahr. Moderate heat, such as that of exhaust steam, readily distils it, and the pressure in the liquefier amounts to about one atmosphere. Mr. Camille Vincent, a distinguished chemist, conceived the idea of treating in close vessels the residue of the distillation of molasses, and from this residue he has obtained an abundant supply of trimethylamine. It is not a little remarkable that this new method of producing ice for next to nothing, according to M. Tellier, was not exhibited in Paris during the recent Exposition, but as the last invention of one of the most fertile brains devoted to the study of artificial refrigeration, I have deemed it right to give the drawing and description from Tellier's British patent which has recently reached me.

He describes his improvements as follows :—

"Firstly. In employing trimethylamine, methylamine, ethylamine, or other analogous volatile products which boil at a very low temperature (about 8° or 10°), and which are soluble in water or other liquid.

"Secondly. In vaporizing one of these products for the purpose above described either by means of the heat of escape steam from a steam engine, or by means of any other suitable source of heat.

"Thirdly. In so combining and arranging the apparatus employed for this purpose as to use only a limited quantity of the refrigerating body, and to produce a current of air, gas, or uncongealable liquid carrying the cold to the place and for the purpose desired.

"For this purpose I cause the escape steam which is to be condensed, or, in short, the source of heat which I wish to utilize, to pass into a tubular boiler, preferably containing a solution of trimethylamine in water. The trimethylamine vapours, after having been washed in a concentrated solution of trimethylamine, are forced to pass through one or more worms, where they are liquefied. The liquid product is collected in a reservoir, from whence it falls in a shower, from top to bottom, into an apparatus or case containing a series of tubes enclosing a gas or an uncongealable liquid moving from the bottom upwards. The trimethylamine is vaporized in cooling the fluid in the tubes, which is then directed to cool the bodies, the temperature of which it is wished to lower.

"In order to utilize the trimethylamine vapours thus produced I can condense them by means of a compressing pump, but I prefer to effect this condensation by means of the water which contained these vapours at the commencement of the operation, and from which the application of the heat separated them. For this purpose the said water is cooled and conveyed to an apparatus or case into which also the trimethylamine vapours enter. The solution of these vapours in the water will be effected under the action of a current of cold air passing in the tubes which traverse this apparatus or condenser.

"The first solution being thus reconstituted is discharged at the outlet into the tubular steam boiler, heated by the lost vapours or otherwise, after having passed through an apparatus where it is reheated in cooling the drained solution, which is directed towards the condensing apparatus of the trimethylamine vapours. In this manner any given quantity of this liquid may be used over and over again indefinitely.

"But to make the invention better understood, I will proceed to describe the same by reference to the accompanying Drawings, in which Figure 1 shews one of the arrangements which may be employed.

"A is a steam engine of any suitable construction. The escape steam which it produces is conducted into a condenser, shewn at B, and the form of which may vary; and instead of being filled with water this condenser contains a solution of trimethylamine, obtained as hereinafter described.

"Under the effect of the heat which the condensed water steam gives off, the solution of trimethylamine is decomposed, and the trimethylamine itself being vaporized, escapes by the conduit pipe *b b*.

"As gases which separate from their solutions always carry away some water steam, and as it is necessary in this case to have the trimethylamine as pure as possible, the vapours which escape from the condenser B are rectified in the rectifier C, which contains the richest solution of trimethylamine. For this purpose the tube *b b*, is inflected in such a manner that, being doubled round on itself, it may be spread over the whole of the lower part of the rectifier C at *z*, *z*. Under these conditions the trimethylamine vapour bubbles in the strong solution contained in the rectifier C, and the vapours which escape therefrom through the tube *c*, *c*, will be found to be sufficiently pure.

"It should be remarked that it is requisite that this operation should be as complete as possible, and it may therefore be necessary to add one or more rectifiers, or to replace them by a rectifying column similar to those employed in the rectification of alcohol.

"To conclude with this part of the apparatus, the trimethylamine solution constantly arrives by the tube *a*, *b*, travels over the whole of the rectifier, escapes by the tube *a*, *c*, *a*, *c*, to run over the whole length of the condenser B, and finally escapes by the tube *a d*, which conducts it into the float space D, which allows of its expulsion.

"It will be readily seen that under these conditions a water level is no longer required, and that, just the spaces being filled with solution, the quantity of saturated methylamine which arrives by the tube expels (in consequence of the general falling back of the solution communicating itself to the condenser B) an equal part of spent solution through *d b*.

"The trimethylamine vapour which escapes by the tube *c*, *c*, enters a condenser E, consisting of a worm or coil *e*, *x*, round which circulates a current of water entering at *e*, *a*, and egressing at *e*, *b*.

"From the effect of the light pressure which is produced by the ebullition of the trimethylamine solution, a relative amount of cold is produced by the current of water, hereinbefore described, around the worm or coil *e*, *x*, *e*, *x*, and the trimethylamine is condensed; thus condensed, it escapes by the tube *e c*, which causes it to pass through a worm or coil *f*, *f*, *f*, placed in a receiver F, the object of which is hereinafter described. Finally, it is conducted by the tube *f*, *a*, to a float receiver G, which, when it contains sufficient liquid, allows the solution to escape

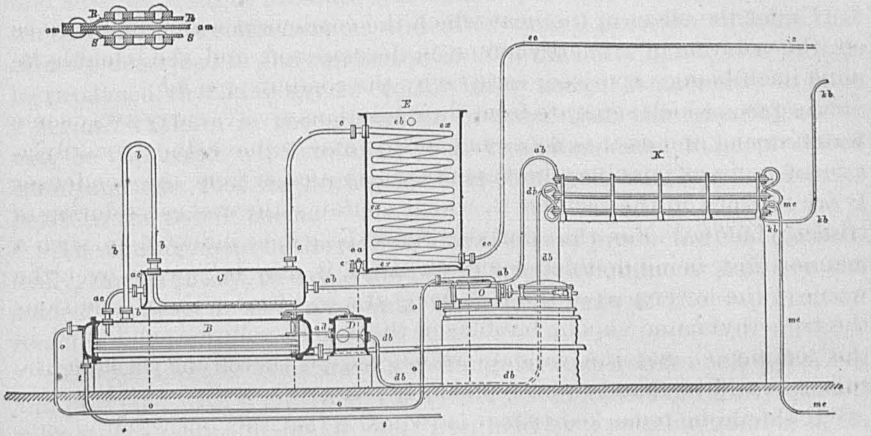


FIG. 1.

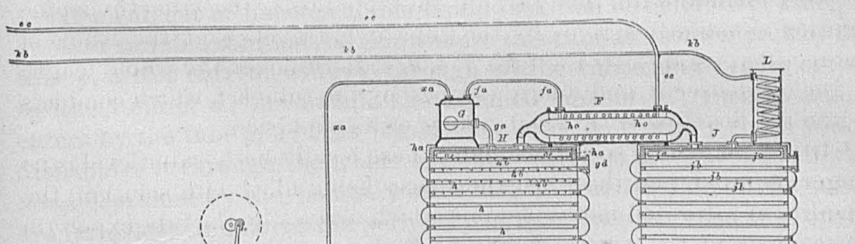


FIG. 2.

by the tube *g, a*, and consequently it arrives in a large rectangular space H, which is nothing but a refrigerator.

"Before further describing this refrigerator I will describe the use of the float space G.

"The trimethylamine is condensed at about 10°. Running water having generally a temperature of from 10° to 28°, according to the climate and seasons, a slight pressure over that of the atmosphere will be necessary to effect its condensation, and afterwards a pressure such as that already described in the condenser E. On the other hand, as cold is to be produced, that is to say 12° to 15° below zero, it is necessary to have a certain vacuum in the apparatus in order that the trimethylamine may be vaporized. It is to allow these two phenomena to be produced simultaneously that the float space G is employed, which puts a barrier between the two of them.

"The arrangement of the refrigerator allows of producing cold methodically, that is to say, to cause the purest trimethylamine to arrive on the coldest surfaces in such a manner that the energy of the vaporization remains constant.

"The refrigerator consists of a rectangular cast-iron frame *h a, h a, h a, h a*, provided with a flange on each side, which allows of tightly closing it by means of two plates of sheet iron held by a suitable number of tie pieces and nuts. Throughout its height it is furnished with a certain number of tubes *h, b*, which are joined together at their ends by elbows joining them together two and two, thus forming one continuous pipe.

"If a current of uncongealable liquid (solution of chloride of calcium or other suitable solution) be thrown into this tube at its lower part by the tube *g, c*, this current will rise through all the tubes, and finally egress by the tube *g, d;* meanwhile the liquified current of trimethylamine enters by the tube *g, a;* this liquid runs into the trough *g e, g e*, which distributes it through the whole length of tubes *h, h*. The trimethylamine deposited by the points, with which the under side of the tubes are furnished, runs over the periphery of the first tube, then that of the second tube, and so on for the following tubes, and constantly vaporizing, thereby constantly produces cold, but in so doing is impoverished, for the water which it draws with it does not vaporize; on the contrary it increases the solution in proportion as its advances and paralyses the vaporization.

"To withdraw all that part of the trimethylamine that may vaporize when this liquid arrives at the lower part of the refrigerator H, it is discharged by the tube *i a* into a tabular receiver I, which is in fact a vaporizer, in the tubes of which circulates the current of chloride of calcium which has been to convey the cold, and in consequence is there at its highest temperature. Under the effect of this temperature, proportionately raised, the last possible vapours of trimethylamine escape; they are conducted by the tube *i, b* into the refrigerator H, where they are reunited with those which are already formed there. But in order that the operation may continue, the vapours must be removed as fast as they are formed. To effect this they can be absorbed by a current of water.

"It is preferable to abstract a current of spent solution from the boiler, and to conduct this current into the apparatus shewn at J, in which the vapours may be absorbed. This apparatus is exactly similar in its general arrangement to that shewn at H, and is in free communication with the same, by means of the vessel F and its two tubes *h* and *j*, consequently the vapours which are formed in H arrive freely in the apparatus J. To absorb them, the spent solution coming from the vaporizing condenser B is conducted into the gutter *j a*, *j a*, and to the passage of which I will hereinafter refer. This gutter, perforated similar to the gutter *g e*, *g e*, with a multitude of holes, discharges over the length of the top tube *j b* the solution from the first tube; it falls on to the second, and so on, thus offering a very large surface for the absorption of the vapours which arrive from the apparatus H. But to effect this absorption it is not sufficient merely to offer the absorbing surfaces to the gas to be absorbed, it is necessary that the liquid should be cold, and moreover that the heat produced by the condensation of the trimethylamine vapours should be carried off, the absorption being in direct proportion to the temperature. To obtain this double result the spent solution which escapes from the float vessel D is caused to pass through the tube *d*, *b*, *d*, *b*, *d*, *b*, through an apparatus shewn at K, which may be called an exchanger, and the action of which is hereinafter described. At the outlet *k*, *a* of this exchanger the solution escapes by the tube *k*, *b*, *k*, *b*, which conducts it to a worm L, which, constantly surrounded with cold water, effects the cooling of the said solution, which then enters the apparatus J at a temperature identical with that of the water which was employed to cool it in the worm L.

"With regard to the caloric which is disengaged during the condensation of the trimethylamine vapours in the absorber J, it is carried off by a current of water, which is caused to arrive by the cock *j*, *c*, and which, running through all the tubes *j b*, *j b*, *j b*, carries off the caloric as fast as it is formed.

"To assist the distribution of the liquids over the changer from H and J, they may be coated with a light tissue of cotton netting.

"Should water be scarce in the country where the apparatus is working, the water which has been used in the absorber J may be used for the condensation in the condenser E, which is a very important consideration. Only slight excess of pressure in the trimethylamine generating apparatus will result from this state of things, and consequently it is always easy to set them up.

"Referring again to the absorption, a portion of the vapours will have been able to escape at the condensation. To avoid this inconvenience the vapours and the condenser liquid which has been used in the absorber J are caused to descend through the tube *j f*, *j f*, which conducts the whole into M.

"It will be easily seen that the whole arrives through the whole length of M by the perforated tube *j m*, *j m*. The combination will thus be effected under the best conditions, which are still more favoured by the current of cooling water, which, entering at *j c*, first runs over the surface of M through the worm *m a*, *m a*, before entering the tubes of the absorber J, and here the production of the solution which was to be formed is finished.

"As will be easily understood, it is necessary to carry it out of the absorber, and cause it to give back the trimethylamine, which should again produce the freezing action, and thus render it permanent.

"To obtain this latter result it must be reconducted to the vaporizing condenser. For this purpose the tube *m e*, *m e*, *m e*, *m e*, passes from the absorbing vessel M to the said vaporizing condenser. By following the course of the tube *m e*, *m e*, *m e*, *m e*, it will be seen that instead of going direct to the vaporizer B, it is at first drawn in by the pump N, which is necessary, since there is only a very low pressure in the absorber J, and a higher pressure in the vaporizer B, and that moreover it is caused to pass through the series of plates of the changer K; and I will now describe this apparatus.

"It has been seen that very hot liquid was sent out of the vaporizing condenser B, and that, on the contrary, very cold liquid was discharged from M, and which should be returned into the vaporizer B. It is then requisite to exchange the temperatures, that is to say, to impart the heat to the liquid which is to enter the vaporizer B, and the cold to the liquid which is to enter the absorber J, and it is for this purpose that the exchanger K is employed. It consists simply of three plates of sheet iron united together at their peripheries by one or two rows of rivots. This arrangement is shewn in Figure 2, on a preceding page.

"The plate *a m* is the exchange plate.

"In the space R, R, circulates the liquid to be reheated, which may escape through the tube *r m*; in the space S, S, on the other hand, comes the liquid which is to impart the heat.

"As will be easily seen by referring to K, the two liquids run in opposite directions, and consequently exchange their heat. The liquid which enters the rectifier C by the tube *a b*, *a b*, is as hot as possible; and that which leaves by the tube *k b*, *k b*, and enters the absorber J after having run through the worm L, is as cold as possible.

"It remains to describe some of the parts which are necessary to insure the working of the apparatus. These consist of six pumps placed round the steam engine A, viz:

"1. An air pump, shewn at O.

"2. Another similar air pump placed behind the pump O, and on a level with it, and is consequently not seen in the Drawing, but which I will call pump No. 2.

"3. A chloride of calcium pump P.

"4. A feed pump N, moved by an excentric *n a*, keyed on the shaft Q.

"5. A pump similar to the chloride pump, but placed at the opposite end of the shaft Q; this pump is not seen in the drawing, but it shall be called pump No. 5.

"Another feed pump similar to the pump N, not seen in the drawing, called pump No. 6.

"I will now describe the working of these different pumps.

"The pump O is used for withdrawing, by means of the tube *o, o, o, o*, the air brought by the water steam into the tubes of the condenser B, and therefore insures the proper working of the same.

"The pump No. 6, identical in its action to the pump N, takes, by means of the tube *t, t, t*, the condensed water in the condenser B, and conducts it into the boiler, which furnishes the steam to the cylinder of the engine A, and which may be placed in any suitable position.

"The pump No. 2, which is an air pump similar to the pump O, draws in through the tube *v* all the air which may be in the apparatus J and H; it therefore allows the trimethylamine which arrives there to evaporate at low pressure and carries off at the same time the air which by chance might enter into the apparatus. A cock placed at *v w*, allows of regulating this action, as will be understood. The pump No. 2 may be so fixed that it may be disconnected when required. As the air which it draws in is charged with methylamine, it does not send it directly into the atmosphere, but into a receiver containing water, and in which the trimethylamine may be absorbed. This receiver is shown at X. As will be easily seen, it is provided with three tubes, one at *x*, which communicates with the pump No. 2; one at *x a*, which communicates with the purifier; and one at *x t*, which communicates with the interior. Finally, a cock *x m* allows of drawing off the saturated liquid.

"The working of the chlorure pump P has been hereinbefore described.

"With regard to the pump No. 5, it draws up water from any suitable source, and raises it into the upper reservoir to distribute it either around the condenser E, or round the cooler L, and finally in the absorber J, to be employed in the absorption.

"The motive power furnished by the cylinder engine A needs no description; it is used in the ordinary way.

"The current of cooled chlorure of calcium which escapes through *g, d* may he utilized for producing ice or cold.

"The operation of the changer K will be readily understood.

"The vapours which escape from H through *h* are very cold, but the trimethylamine which runs through the worm *h o, h o*, is slightly warm, thus causing them to circulate in opposite directions; the greatest amount of cold is extracted to carry it back to H."

P.—AIR-MACHINES.

The opinion has widely prevailed that the simple expansion of compressed air produces cold, and that the effect is analogous to the change of physical state from the liquid to the gaseous. Joule originally declared that *no change of temperature occurs when air is allowed to expand in such a manner as not to develop mechanical power.* Later experiments by Joule and Sir William Thomson indicate, nevertheless, a slight cooling effect.

Some remarkable natural phenomena are attributable, however, to conditions under which air may be compressed and forced through obstructions, so that its heat may be transformed into mechanical energy, and thus it cools wells or actually freezes water in subterranean caverns. The frozen well at Brandon, Vt.,* has been examined by Prof. John M. Ordway, and is an interesting example of this description. Cold air is constantly flowing upward in it. At the opening of the well the thermometer indicated 43°.5 Fahr., the temperature of the external air being 78° at the time of the examination. Five feet below the mouth, the thermometer stood at 43°, and 12 feet down, at 40°. Water drawn out from the bottom without stopping to cool the bucket was at 34°, and at other times it contained lumps of ice detached from the ice-coating lining the well for some 5 feet above the surface of the water. Professor Ordway says: "We had hardly begun to make close observations before it occurred to us that we were dealing with a case of compressed air, which might be accumulated by some natural subterranean tromp (Wassertrommel) or "Catalan blower," and which passing through the gravel effects the gradual refrigeration and actual freezing of a considerable quantity of wet gravel."

To Dr. John Gorrie (American Journal of Science and Art, vol. x, page 39) we owe the earliest determinations of the quantity of heat evolved from atmospheric air by mechanical compression with a view to the production of ice by machinery. He directed attention to the discrepant statements of Colladon, Gay-Lussac, Dalton, and others, and having secured the coöperation of capitalists for the erection of air-compressing appliances in New Orleans, he chanced to adopt the only method by which any success, by this method, in artificial refrigeration was possible. The compressed air was allowed to discharge into an engine which worked expansively through a valve so constructed as to permit of cutting off the communication with the reservoir at any portion of the stroke. The air, in this way, independently of the safety-valve, was prevented from attaining more than a certain degree of pressure. Dr. Gorrie anticipated later patents in which the injection of water to cool the air in the compressing-pump has been practised. Indeed, he studied the subject with skill and in a true philosophic spirit, complaining that "owing to defects of mechanical contrivance and unskilful workmanship, incidental, perhaps, to every new device and a novitiate intercourse with practical mechanics, the machine was not capable of performing all its duties with the accuracy the natural laws involved called for."

* Ann. Sci. Discoveries, 1856, p. 190; 1860, p. 316.

It is foreign to my purpose to quote the tables and experiments relating to the differences in temperature between the air and the water at their influx and egress; but a crucial experiment which he performed was conclusive and interesting: "During an experiment of an hour's duration the water of injection, instead of being supplied, as usual, by the city hydrant, was taken from and returned to a butt of about 130 gallons capacity, containing about 1,100 pounds of water. At the commencement of the experiment the temperature of the water was 77° Fahr. (the atmosphere being 79° Fahr.); at the end it was 112° Fahr., the engine working twenty revolutions a minute. The quantity of ice which the heat thus disengaged would melt is equal to $(1100 \times 32 \div 140 =)$ 275 pounds; or for 24 hours, 6,600 pounds. There was but very little diminution in the rate at which the temperature of the water was increased.

"The quantity of heat which the condensed air in its expansion is capable of absorbing, or, in other words, the quantity of ice it is capable of producing, proves that there has been no material error of observation or calculation.

"The quantity of heat generated by compressing air to half its volume is sufficient to elevate the temperature of an equal weight of water 74° Fahr., and of its own body 277° Fahr. When it was reduced to one-fourth of its volume, the increase of heat became, for water, 105° Fahr., and for air, 395° Fahr.; and when condensed to one-eighth of its original volume, the heat was, for water, 125°, and for air 472° Fahr.

"According to these observations and deductions, while the densities of air increased in the geometrical progression 2, 4, 8, the heat evolved corresponded nearly to the arithmetical series 3, 4, 5. But the ratio in the differences of temperature between the assigned densities follows a very different rate of progression from either: thus, for the densities 2, 4, 8, atmospheric pressure, the corresponding differences of heat evolved were, in the decreasing number, nearly (277, 118, 80) 3.5, 1.5, 1."

I need not further refer to Mr. C. W. Siemens's idea of compressing air and expanding it in an engine as noticed elsewhere. Mr. Alexander Carnegie Kirk was the first and most successful inventor of a practical air-machine for making ice. He wished to supersede an ether-machine at the Bathgate Paraffin Works, owing to its being too small and dangerous. He had to cool the oils to a temperature of from 35° to 40° Fahr., to crystallize the paraffin. On his first trial air was compressed into a receiver and allowed to expand by driving a small engine—a plan which had been proposed and tried—but it offered little encouragement. The next trial was with an apparatus similar to Stirling's air-engine, with which, after many modifications, mercury was frozen. Mr. Kirk designed a machine, patented on the 25th April, 1862, for the application and use to and in the production of cold of a vessel containing air or other elastic fluid or gas alternately in a state of compression and expansion, and provided with a piston and regenerator. On the piston being moved to one end of the vessel, the enclosed air may pass freely to the other end, giving out its heat to or absorbing heat from the regenerator as it passes through it. The piston is caused to move in such a manner that the air whilst being compressed will always be at one end of the vessel, and whilst being expanded be always at the opposite end of the same, the regenerator preventing the conveyance of heat or cold by the air from one end of the vessel to the other. The heat generated during compression is removed by exposing that part of the vessel to a current of cold air, water, or other cooling medium, whilst the cold produced at the other end by expansion is used to refrigerate any liquid or substance which may be brought in contact therewith.

Mr. Kirk afterwards found an advantage in using damp air instead of dry air, and in his paper on the Mechanical Production of Cold, read in 1874, before the Institute of Civil Engineers in London, he established the following comparison:

In dry-air machine:

Indicated horse-power, 7.08.

Rejected heat = 1,409 pounds of water heated 1° Fahr. per minute.

Absorbed heat, 1,106 pounds of water cooled 1° Fahr. per minute.

In wet-air machine:

Indicated horse-power, 7.8.

Rejected heat, 2,271.2 pounds of water heated 1° Fahr. per minute.

Absorbed heat, 1,795.2 pounds of water cooled 1° Fahr. per minute.

The professed improvements of Messrs. Windhausen, of Germany, and Paul Giffard, of Paris, relate to matters of detail of secondary importance, and it is well recognized now that where water-power can be had and condensing-water is abundant, a cold-air machine may be used, but it is much too cumbersome and wasteful for such purposes as have recently been suggested for ice-machines in steamers for the transport of provisions or for sanitary purposes.

Q—GAS ICE-MACHINES OF NEW TYPE.

The difficulties which I first encountered, with reference to the special object for which I wanted to use artificial cold, were the unsuitable character of absorption (Carré) machines for ships' use; the unwieldy and power-absorbing nature of air-machines; the explosive character of ether-machines.

In dealing with pump-machines such as the Harrison sulphuric-ether and the Tellier methylic-ether apparatuses, the greatest objections I discovered were, the explosive character of the materials, and the quantity of these to be stored in a machine which might leak and distribute a very inflammable gas in a vessel, especially in hot latitudes, where even sulphuric ether is in the gaseous state at atmospheric pressure.

M. Tellier has always spoken of the explosiveness of ether as of secondary importance, and has declared that it is needless discussing the question when alcohols, essences, gases, petroleum oils, &c., are entrusted, to ignorant people and children, under conditions when real danger might be apprehended. But two blacks do not make a white; and the binary engine of Count du Trembley would have continued running had there not been immense difficulty and peril in using ether in reciprocating engines and pumps.

It occurred to me to introduce a form of condenser and refrigerator consisting of tubes within tubes, as described further on, which reduced the volume of ether, distributed over a wide surface within a narrow compass, and enabled me to construct an apparatus of great solidity and safety. At the same time, one inconvenience attending the ether-machines was that the brine used, common salt and water, was apt to freeze up in the refrigerator-tubes and burst them. This I overcame by the use of an aqueous solution of glycerine, and later on I have economized by using chlorine of magnesium and water, with some glycerine added, according to the temperature at which it is proposed to work.

Without attempting a detailed history of improvements suggested from time to time, my main object for years was to overcome the then inevitable use of a reciprocating-pump in which liquefiable gases were alternately liquefied and volatilized, to the detriment of efficiency. This was found one of the most objectionable features in the use of sulphurous acid and ammonia, inasmuch as a film of liquid remains after every stroke between the piston and the cylinder-cover, and expands on the return stroke so as to interfere with the suction of a fresh charge.

I must enlarge somewhat on this subject of

R.—ENGINES AND PUMPS.

In all freezing-machines, except those depending on absorption of a gas by water and its distillation, it has been a matter of primary importance to secure an economical engine, and a pump capable of producing a vacuum, or compressing a liquefiable gas.

All kinds of engines have been used—upright and horizontal high-pressure and compound engines. The inevitable waste, attending the production of steam, and its imperfect utilization, in the best form of reciprocating engines, have been regarded as really incurable evils, in the production of artificial ice by means of pump-machines.

The method of transmitting power has necessarily attracted considerable attention, and in one machine the crank-shaft has been the seat of all strain, whereas in other cases, with an engine placed on a bed-plate on a line with the pump, the pressure on the engine-piston was greatest when there was least resistance, and *vice versa*.

But the difficulties of the engines, common to all machines using steam, appeared of less importance than the imperfections of the reciprocating pump. Whether single or double acting, the change in the direction of motion at every stroke, the universal clearance or imperfect discharge of the gas from the pump at each revolution; the cumbersome and noisy valves, which are frequently broken by striking; the leaky stuffing-boxes, and the ample surface of the piston-rod, for exposing a layer of gas to atmospheric contact, as many times per minute as the piston runs its course, led me in early days, when seeking practical improvements in ice-machines, to search for a continuous-motion or rotary pump, without clearance, capable of passing gases of great tenuity, at all pressures.

The obstacles in my way have been well understood by engineers, and I cannot do better than indicate them by a sweeping declaration at page 367 of Professor Thurston's History of the Growth of the Steam Engine. He says: "The rotary engine is gradually coming into use for various special purposes, where small power is called for, and where economy of fuel is not important; but it has never yet competed, *and may perhaps never in the future compete*, with the reciprocating-piston engine where large engines are required, or where even moderate economy of fuel is essential."

I had grown to believe not a little as Professor Thurston expresses himself, when in the summer of 1876 I was told by Mr. Siebe, son of the celebrated Daniel Siebe who first built the successful Harrison ether-machine, that what I had so long searched for had at last been invented by a Lancashire engineer. Mr. Siebe had seen an engine and pump working, in the compression of air, up to 60 pounds, and drawing a vacuum up to 28 inches; and this same apparatus I shortly afterwards purchased from Mr. William Eli Sudlow, the inventor and patentee.

Familiarity in working turbines of various kinds, in connection with cotton and woollen mills in Mexico, led Mr. Sudlow to a close study of the methods whereby steam could be used in a revolving engine. In Central America he failed with his first castings, and, with the genuine enthusiasm of a pioneer, he threw up his lucrative position to return to England and complete his work. He first built a five-cylinder engine, which was exhibited at the Peel Park Manchester Exhibition in 1874. Both "Engineer" and "Engineering" favorably noticed this effort of striking novelty, but the unwieldy nature of the apparatus led to its being superseded, by a series of progressive improvements. To such perfection had Mr. Sudlow brought his air-pumps and steam-engine in 1877, that I asked him to accompany me to America, with an apparatus which is the most perfect gas-pumping arrangement that I believe has ever been produced.

It consists of two pumps capable of passing 90 cubic feet of gas per minute at atmospheric pressure, the pumps being driven by an engine which is placed on the same shaft.

Both engines and pump are of identical construction, except as to the arrangement of valves. They rest in line on a common bed-plate, and the description of one cylinder will serve for all.

The cylinder is extended upwards by a rectangular block, and is provided at its ends with closely-fitting covers having ample stuffing-boxes, suitably packed.

On removing an end cover an internal piston-cover, circular in form, comes into view. This piston-cover fits into a recess where it is packed by metallic rings like an ordinary piston. Above this cover is a rectangular flat piece of metal screwed to the rectangular block, and which, on removal, is found to close the space in which a slide moves vertically. The removal of four screws from the circular cover exposes the end of the piston, wich is arranged eccentrically to the shaft. The inner covers at either end practically complete the piston, but their main function is to equalize the wearing surface, and effectually to prevent leakage.

This is a vital point, and it is necessary to understand that one cause of serious imperfection, in most rotary engines and pumps, has been the unequal wear at the ends of eccentric pistons, which naturally travelled farther at their peripheries than at their centres. Once the inner covers are bolted to the piston this detrimental condition is obviated.

At the greatest distance from the shaft a slot is cut into the piston and into this is fitted a steel bar, packed automatically against the cylinder through a channel communicating with the pressure-side of the steam or gas.

In the vertical slot above the piston is a broad slide of equal length with piston and cylinder. It divides the whole into two chambers and rides on the eccentric piston. Its lower edge is convex and its upper surface is perforated by two ports which lead through to the pressure-side of either engine or pump.

The slide fits snugly in its socket and its weight exerts some influence to maintain it in contact with the piston. Corresponding to the upper orifices in the slide are the valve-openings for the inlet or exit, as the case may be, in the engine and pump. Immediately on the low-pressure side of the slide, midway in the length of the cylinder, is the induction-port provided in the pump with a valve to prevent recoil of gas.

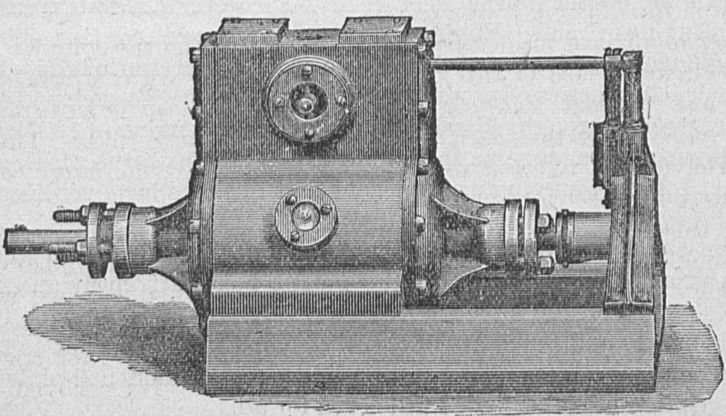


FIG. 1.

The first or lateral view appropriately indicates the compact and solid aspect of this apparatus, and indicates the manner in which the cylinder is fixed to the bed-plates, the nature and position of the outer covers with their stuffing-boxes.

The upper opening is the outlet for gas in the pump, and when used on an engine the inlet for steam. The large central flanged opening is here shown provided with an induction valve as used in the pump in order to prevent the reflux of gases towards the refrigerator. The lower aperture communicates with the water-jacket.

At the right-hand side of the drawing a bracket supports one end of a small shaft used only in the engine as a means of moving the cut-off by the action communicated to it by the spiral cam on the shaft below.

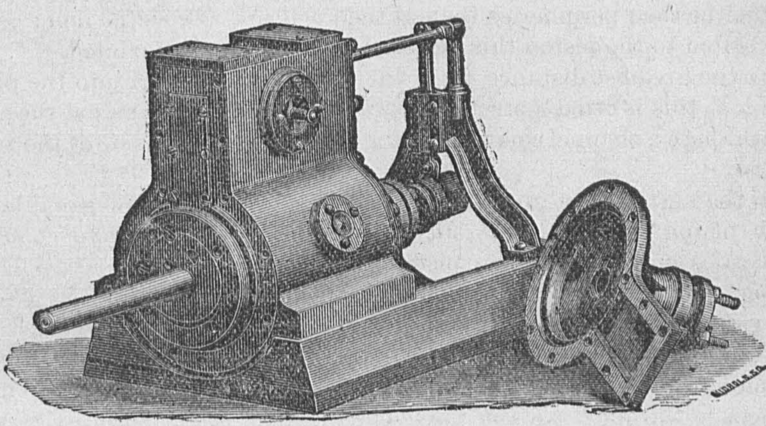


FIG. 2.

The second illustration shows one end, cover removed and exposing to view an internal cover or piston-head, which is fixed by the screws shown in the drawing to the piston within. This circular cover is seen to work in a recess formed by a projecting ridge; on the cylinder in the outer circumference of this circular piston-head is a cast-iron ring to pack and prevent leakage. Above the piston-head is a rectangular plate which closes the space occupied internally by the slide. The other parts have been referred to above, but the form of the outer cover is well shown on the right-hand side of this drawing.

The third engraving shows the internal arrangement after removal of the inner covers. The eccentric piston with the packing-bar at its periphery and the slide pressing on it above. This slide winds up and down according to the position of the eccentric piston. The slide is provided with two channel or ports communicating with two top openings, one of which is uncovered and the "mushroom" valve removed. This cover and valve are drawn on the right-hand side as shown above.

Sufficient has been said to point out very definitely the special advantages of both engine and pump of this novel design.

First. The combined engine and pump are very compact and perfectly self-contained.

Second. The position of the inlet and outlet ports at separate and distant points, so that on the heat-engine side the hot steam passes into the warmer and issues from the colder port, instead of the same channels being used alternately for the entrance and exit, as in a reciprocating engine.

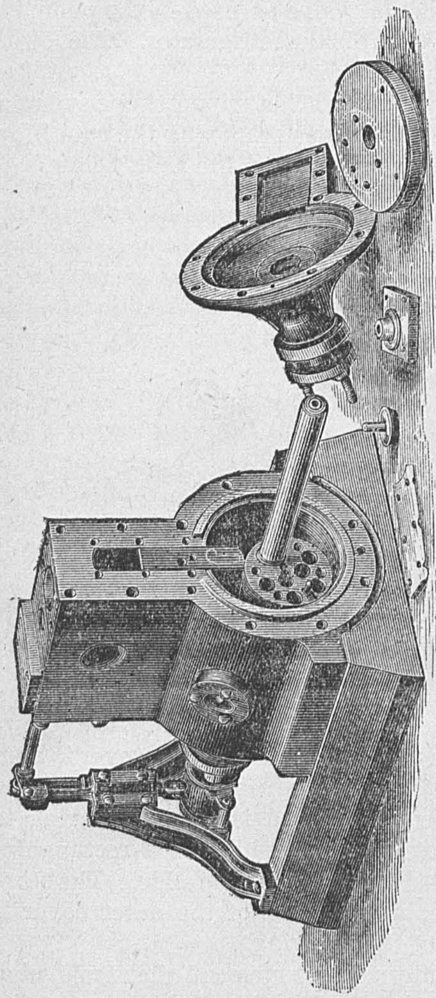


FIG. 3.

Third. The steam or gas admitted does not exert its pressure on the whole area of the piston at the initial point, but the surface increases up to the half-stroke and then diminishes, so that at the end of the stroke or point of maximum pressure, in forcing out a gas, the resisting surface is reduced. By this contrivance, the strain and friction are controlled.

Fourth. Slow valve-motion, the valves moving only once in a complete revolution.

Fifth. Permanent opening of the exhaust of the engine, so as to expel the entire contents of the cylinder, whether liquid or gaseous.

Sixth. Absolute tightness, all parts being pressure-packed.

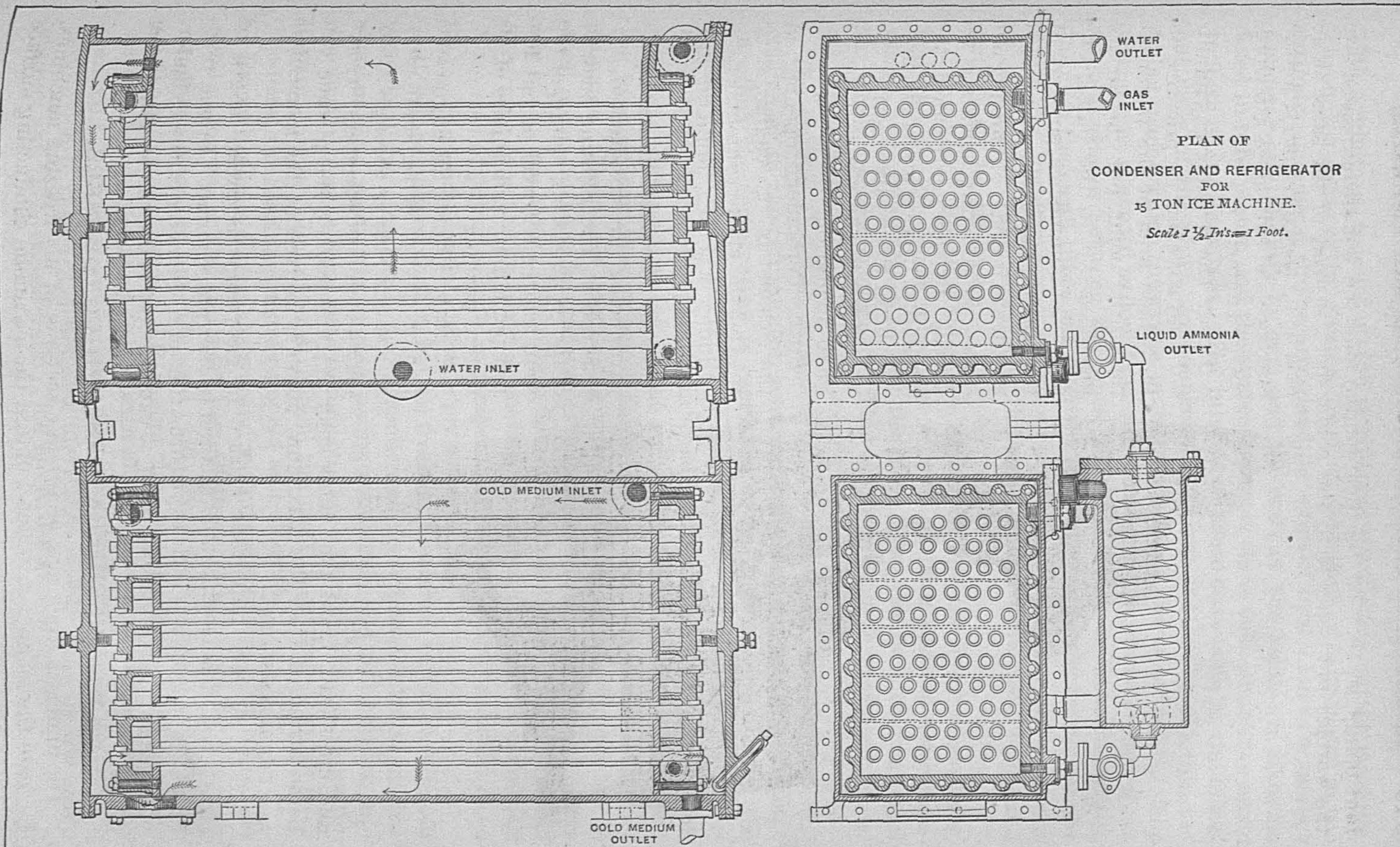
Seventh. The rotating instead of the reciprocating motion of the shaft causes a travel of but few feet per minute and admits of effectual packing.

Eighth. Placing the engine and pumps on the same shaft obviates severe strains through many joints, such as gibs, cotters, brasses and crosshead, crank-pin, crank-shaft, &c. Moreover, the pistons can be so arranged that the maximum power is exerted at the moment of maximum resistance.

Ninth. A very important feature in gas-pumps is great length of stroke, and this is admirably secured in the rotary pump. In one revolution the travel is a little over three times the diameter of the cylinder, whereas in a reciprocating pump it can only be twice the length of the crank.

R.—REFRIGERATORS AND CONDENSERS.

The annexed drawings, of tubular sections of my freezing machines, indicate the manner in which I obtain the maximum conducting surface



PLAN OF

CONDENSER AND REFRIGERATOR
FOR
15 TON ICE MACHINE.

Scale 1 ½ In's.=1 Foot.

with a minimum amount of the refrigerant circulating in the machine. Through a series of long tubes, fixed at their ends in tube-plates in the ordinary manner, I run a corresponding series of tubes, but of a smaller diameter and slightly longer; and the ends of the latter are likewise fixed in tube-plates, and the spaces between these tube-plates are made to form closed chambers. The interior of these chambers, at the different ends of the pipes, are connected with one another by the thin annular spaces which intervene between the inner and outer tubes. The refrigerant is caused to flow from one chamber to the other through these annular spaces between the pipes, while the liquid to be cooled passes through the small tubes and over the outer ones. In the condenser the warm gas, under compression, occupies the annular space, and a current of condensing water flows freely through the bore of the small tubes and outside the larger ones.

The ends of the outer tubes are expanded into the inner tube-plates, and the smaller inner tubes are secured at both ends in outer tube-plates by stuffing-boxes, so that the inner tubes can be withdrawn and the whole apparatus cleaned. This is an advantage possessed by no other machine.

The smaller chamber, occupied by a vertical coil leading from the condenser to the refrigerator, represents my supplementary condenser, in which the temperature is regulated so as to determine at will the pressure at which the machine is to be operated. This manifest improvement, in any form of apparatus in which gases are liquefied by compression, was suggested to me by the varying conditions observed in working freezing-machines on board ships sailing from temperate to tropical climates. The warm condensing water available at the equator led to such pressures as to interfere most materially with the economical working of the machines. By using a flow of the cooled, uncongealable liquid returning from the ice-boxes or cooling chambers, it is easy to obtain, at some cost of power, a regular temperature of 32° Fahr. or under, so as to prevent undue and dangerous pressures.

It will be noticed that so far, all freezing machines in which a liquid is volatilized, circulated, and recondensed by a pump, consist of four fundamental parts, viz, engine, pump, condenser, and refrigerator, and the improvements from time to time on Jacob Perkins's machine are improvements in detail of construction, the most important of which have rendered the machines more compact and efficient.

Every machine so far has worked with most economy, the colder the condensing water and the more perfect the arrangements for complete liquefaction, on the one side, and ready evaporation, by supply of heat, on the refrigerator side. All, except the Carré machine, which presents serious drawbacks as compared with any apparatus in which anhydrous ammonia is alternately liquefied and volatilized, have been wasteful in proportion to the inefficiency and inevitable loss of heat by the steam engine, and these considerations led me to design my

S.—THERMO-GLACIAL ENGINE.

This is based on the ascertained fact that a liquefiable gas or vapor may be cooled and liquefied by the transformation of its heat into mechanical energy. I avail myself of this by causing the gas or vapor in its passage to the refrigerator—or that portion of the apparatus where it acts upon the substance to be refrigerated—to exert its energy against a resisting body, such as the piston of an engine, whereby it parts with its heat and is liquefied to a great extent, if not entirely; in which condition it passes from the engine to the refrigerator, where it acts as the refrigerating agent. In the refrigerator it is, by the heat, abstracted from the substance to be cooled, again converted into vapor or gas, which is, by a pump or compresser (driven by the engine above named) returned to the starting point and there supplied with sufficient additional heat to overcome inertia and friction, so as to cause it again to pass on to the engine and through the same cycle of operations.

The apparatus requisite to effectuate the foregoing method of operation consists of the following leading parts:

I. A heater or boiler, in which the gas or vapor is raised to the proper degree of heat. If we suppose that the material employed be anhydrous or pure liquid ammonia—a substance which I prefer, and in practice use—then the heater or boiler is heated by suitable means to raise the ammonia to, say 125° Fahr., which will give a pressure of about 300 pounds to the square inch.

II. An engine, preferably a rotary engine, in which the piston has a continuous rotary movement on its axis in one direction. The gas from the boiler is through a suitable conduit led to the engine, where it is worked expansively, through the instrumentality of a proper cut-off, to drive the piston. In this way the heat is used up by conversion into mechanical energy, and the gas thus freed from heat assumes the liquid form more or less completely, according to the extent to which the heat has been transformed into energy. I prefer to use a double engine; that is to say, one having two cylinders. The gas enters the first or high-pressure cylinder and is there worked expansively, so as to abstract much of its heat. It thence exhausts into the second or low-pressure cylinder, where it is worked expansively still further. The expansion in each case is determined by the usual cut-off, which can be regulated by the engineer, according to conditions of use and the nature of the liquefiable gas or vapor employed, in such manner as to admit at each stroke or revolution, as far as practicable, only that amount of gas whose heat can be all, or nearly so, transformed into mechanical energy, the object being to bring the gas to a liquid condition by the time it has done its work in the second cylinder.

III. A refrigerator, into which the liquefied gas or vapor is led from the engine, and where it is brought into contact with or caused to act directly or indirectly upon the object to be cooled or frozen. The refrigerating agent here, by abstraction of heat from the body to be cooled, reassumes a gaseous or vaporous form.

IV. A compressor, or pump, which draws off from the refrigerator the vapor or gas as it forms, and returns it to the boiler or heater. I prefer to use for this purpose a double pump, analogous to the double engine, and driven by the engine. The vapor is returned to the heater or boiler against the pressure of the gas therein, and it is for this purpose that I prefer the double pump, in which the compression is effected by steps or successive stages, and not all at once. The vapor is compressed to a certain extent in the first cylinder; it thence passes to the second cylinder, where it is still further compressed and forced back into the boiler. The pump is provided with the usual puppet or check valve, for preventing back-pressure; said valves opening only at the concluding part of each revolution or stroke of their respective pistons.

V. Between the pumps and the boiler, heat may be rejected in a surface condenser in which water is the circulating medium, and the liquefied ammonia at the temperature of the surrounding water may then be forced by an injector or by a special force-pump into the ammonia heater.

VI. By the use of a steam-engine aiding the compression and practically lifting the ammonia directly from the refrigerator to the ammonia heater, no direct heat need be applied to the latter, and the amount equivalent to the energy developed by the steam-engine takes its place.

Subject strictly to thermodynamic law, a maximum economy can by these means be obtained for the abstraction of heat from surrounding objects.

It is evident, inasmuch as the heat abstracted from the agent to be cooled is availed of, comparatively little additional heat is required to bring the vapor or gas to the condition for imparting motion to the engine piston.

I propose to distinguish the apparatus in which this cycle of operations can be conducted by the name of "Thermo-glacial Engine."

T.—DRY COLD AIR AS A PRESERVATIVE.

We learn, from Turner's Embassy to Thibet,* that the flesh of animals is preserved frost-dried—not frozen—and it keeps without salt. He says: "I had supplies of this prepared meat during all the time I remained at Teshoo Loomboo, which had been cured in the preceding winter. It was perfectly sweet, and I was accustomed to eat heartily of it, without any further dressing, and at length grew fond of it. It had not the appearance of being raw, but resembled in color that which has been well boiled. It had been deprived of all ruddiness by the intense cold."

Frozen meat, unless losing actively in weight by evaporation owing

* 4°, London, 1806, p. 301. Quoted by Samuel Parker in his Chemical Essays. Bohn, 1841. London.

to the dryness of circumambient air, will, like frozen fish, decompose on exposure to warmth. The decomposition is activated by atmospheric impurity, and it is easy to understand how, in the mountains of Thibet, the rarefied air, of great dryness, mobility, and freedom from putrefactive germs, would satisfy the conditions for abstracting sufficient moisture, even from frozen meat, whilst effectually precluding decay. Pure dry air, either hot or cold, being an admirable desiccant, is, under suitable conditions, an excellent preservative. The charqui of South America, salted, it is true, is a product of sun-drying; and the desiccation of carcasses without decomposition, on the plains, has been a matter of common observation.

In preserving meat in England by the use of antiseptic gases, I encountered no difficulty, especially as to temperature; but in sending meats to different parts of the world, I soon learned that close packages favored mould, whereas a very mild preservative, with desiccation, would keep meat at all temperatures. Some mutton that I brought over to America with me from England in January, 1868, having been well preserved by means of carbonic oxide and sulphurous acid, arrived in New York mouldy, from having been packed in canvas and wooden boxes. The mould was scraped off and the meat proved excellent, some being eaten in Chicago as late as September of 1868, having been preserved about ten months. The meat was fresh and juicy. In Chicago and Texas the difficulties of high temperature were encountered, and in the early part of 1869 I first attempted the cooling of meat, for its after chemical preservation, by blowing air through a chamber in which bullocks and other animals were hung. I adopted two plans: one with ice in the room, the air-current being produced by a Root's blower; the other was by passing the air through a coil surrounded by frigorific mixtures. These experiments satisfied me that dry cold-air currents were indispensable to the preservation of meats in the South, and I was thus led to study the Carré ice-machines in New Orleans. Thence I returned home, by way of Washington, and devoted myself to the study of artificial refrigeration. The best machine for my purpose at that time was Harrison's ether-machine, as constructed by Messrs. Siebe & West, and I erected one, shortly after my return home, for the purpose of completing my investigations. Three concrete chambers were built with a metal roof, over which the cooled brine flowed and passed into an air-cooler composed of pipes, through which the air passed and around which the brine flowed back to the machine. As in Texas, I used a Root's blower, and established a continuous current, using the same air over and over again, so as to dry and cool the meat. I used burnt air and sulphurous acid to complete the preservation, and shipped large quantities of meat to all parts. The result of all these costly and varied experiments may be summed up under two heads:

First. All meat packed in hermetically-sealed cans, in wooden boxes, in salt and oat-hulls, like hams for the China trade, became mouldy and rotten. Desiccation had been slight and the antiseptics had been used in moderate doses, to avoid adventitious flavor.

Secondly. Meat in canvas shipped anywhere, but most frequently to the Brazils, and on one memorable occasion, by the steamship Somersetshire, to the port of Melbourne, Australia, arrived in excellent condition. Indeed, the mutton on board the Somersetshire was served one day in each week to the passengers, and proved better than the mutton newly killed on board. It was juicy and tender.

The inference was manifest—slight but progressive desiccation at any temperature protected the meat from mould.

In 1857, that most fertile inventor and distinguished physicist, Mr. C. W. Siemens, had conceived the idea, of blowing cold air into a cellar or chamber, for the obvious purpose of preserving perishable material. He only sought provisional protection for the process of compressing air, cooling it, and then expanding it in a cylinder or engine, immersed in brine or a solution of chloride of calcium, so as to obtain low temperatures.

Shortly before the Franco-German war in 1870, I erected appliances in Paris, to show my method of meat-preservation, and I used ice and salt to dry and cool the air so as to avoid the expense of an ice-machine for the simple purposes of demonstration. The Emperor Napoleon was to have witnessed my experiments, but I returned to London, the war broke out, and some of the meat remained hung up in the open air till the first siege of Paris, when it proved most acceptable.

I have purposely entered into these details, since whatever may have been conceived by others was unknown to me, and I believe I was at least one of the first to erect an ice-machine with an adequate apparatus to utilize pure, dry, cold air for the preservation of meat. The summer of 1870 showed me that atmospheric air did no harm to the cured meats; but, on the contrary, that the more we attempted to check its circulation by enveloping the meat the more difficult was its transportation across the seas.

It is also certain that all the methods of producing cold-air currents around meat for transport were practically anticipated by me early in 1869, and the person of all others who deserves the most credit for the development of the meat-trade with England by the dry cold-air process, using ice, is Mr. T. C. Eastman, of New York. His enterprise, wealth, and trade facilities enabled him to adopt a patented process, that of Mr. Bates, which demanded much courage and capital for its development. Its success has been one of the most important commercial victories of the current decade.

Mr. Eastman writes me on the 25th of December, 1878:

"We commenced the shipment of beef from this country to England, September 29, 1875, and shipped during the balance of that year 299 cattle, 125 sheep, 25 lambs, and 20 pigs.

"In the year 1876, 17,099 cattle, 6,657 sheep, 1,935 pigs.

"In the year 1877, 38,466 cattle, 20,773 sheep.

"In the year 1878, 56,850 cattle, 45,641 sheep, 2,219 pigs.

"The shipments for the year 1878 are not complete, as we will ship about 1,500 more cattle, 1,200 sheep, and 600 pigs, before the 1st of January, 1879.

"As to our method of carrying these meats you understand perfectly. We shipped very light of dressed meat during the summer months of 1878, as the large shipments of live cattle interfered with dressed meats, which we think will be the case in the summer of 1879. We will ship for the next four months an average of about 1,800 cattle, 2,200 sheep, and 600 pigs weekly, but will reduce our shipments very much about the first of April, and ship heavily of live cattle during the warm season.

"We commenced this business in a small way on the start, and have increased from time to time till our outlay in refrigerator boxes and machinery has amounted to $175,000. I shipped the first beef that was shipped to Europe as an article of commerce. In fact, all small experimental shipments, which amounted to very little, were failures."

What Mr. Eastman has done for meat others can do with fish, and I am informed that Mr. Eugene Blackford shipped American salmon some years since, the only drawback to the business being the want of cold storage to keep the fish in good order in London.

On the 4th of May, 1870, the Baltimore and Texas Steam Transportation Company was organized, and in its prospectus it is stated that fresh beef, mutton, and game had been conveyed from London to Rio in the steamer Rio de Janeiro fitted with the Tellier machine, and after a voyage of 21 days they were found in perfect condition. During said trip, and whilst on the equator and in its vicinity, the temperature in the refrigerating-room was kept at from 32° to 33° Fahr., while outside it ranged from 105° to 107°, and the water itself stood at 80° to 90°.

On the 6th of December, 1870,* M. Ch. Tellier addressed a note to the Academy of Sciences relating that he had kept rooms at 0° C., or at most at—1° C., and had preserved beef, mutton, game (with fur, feathers, and entrails), and fish for seven and nine weeks. He said: "What I employ is a current of cold air, below 0° C., or currents of liquids between —8° C. and—10°. · · · A slight and gentle desiccation amounting to 10 per cent. of the weight of meats in six weeks is attended with preservation of the product." The abstraction of 18 or 20 per cent. of the moisture at low temperatures *in vacuo* will cure meats. In a second note addressed to the Academy of Sciences on the 27th of December, 1870, M. Tellier says that he first attempted desiccation *in vacuo* in 1867. By the aid of chloride of calcium a piece of meat was made to lose 25 per cent. of its moisture. Pasteur had recognized that from 25° to 40° C. (from 77° to 104° Fahr.) was the most favorable range of temperature for putrefaction. Thirty-two degrees Fahr., or 0° C., and 212° Fahr., or 100° C., completely prevent it. Tellier says practice accords with science. At

* Conservation de la Viande, &c. Par Ch. Tellier. Paris. 1871.

0° C. putrefaction-germs are inert and at 212° they are boiled. He goes on to say that *Mycodermia cervisiæ* is inert at 0°, vegetates at 7°, 8°, and 10° C., and above this temperature multiplies with enormous activity, but then other parasitic ferments appear. *Mycodermia aceti* requires a temperature from 20° to 25° C. The lactic ferment is produced from 25° to 30° C. In beer-yeast, *Mycodermia cervisiæ* or *vini* vegetates at 7° or 8°, whereas temperatures of 15° or 18° are required in raisin-yeast. Rotifera remain inert for an indefinite period if dried; in water, they move, live, and have an active existence. Yeast dried and pressed is inert; moistened, it forthwith manifests activity. Augustus Smith found that below 10° C. blood does not readily decompose; above this temperature, changes occur which are very rapid at 22° C. At 16° C., the putrefaction of half a litre of blood will yield 100 cubic centimetres of carbonic acid in 24 hours. At 22° C., the same quantity, in the same time, will yield 400 cubic centimetres, viz, four times more by a rise of only 6° C.

M. Poggiale, the distinguished inspector-general of military pharmacy in Paris, presented a report on the 31st of March, 1874, to the Academy of Medicine of Paris, and which report was made to the "Conseil de Salubrité de la Seine."* Poggiale remarked that since 1850 he had had frequent occasion to study for the war department the various processes of meat-preservation, such as salting, drying, the use of sulphurous acid, carbolic acid, and creosote; coatings of gelatine, sugar, or glycerine; vacuum, artificial atmospheres, hydrochloric acid and sodium bisulphite, meat-extract, cooking in closed vessels, &c. None but the method Appert (the now common method of cooking in hermetically-sealed tinned cans) solved the problem. He then goes on to say that M. Tellier believes he has discovered the right process. To obtain this result it suffices to maintain at 0° C. or at —1° C. the temperature of the chamber in which the meat is placed. To be precise, I shall quote literally: "Pour produire le froid il n'emploie pas la glace, qui donne de l'humidité et qui n'abbaisse pas suffisamment ni régulièrement la température de la viande. Il prefère un courant d'air froid ou plutôt des courants liquides à —8°. ou —10°, qui, congelant l'humidité de l'atmosphére, la dessèchent et en abaissent la température. L'operation consiste donc à établir des magasins frigorifiques dont la température sort de 0° à —1°."

He goes on to describe Tellier's methylic ether process of producing artificial cold, and his isolated room with powdered coal between the walls. In this chamber there were four tanks with a wooden pipe for the circulation of cooled calcic chloride solution. He adds: "Pour que l'action frigorifique soit uniforme dans toutes les parties de la chambre, on y a établi un ventilateur qui prend l'air à l'une de ses extrémités, le fait passer dans le conduit contenant les bassins froids et le force à sortir par le côté opposé de cette même chambre. L'air est donc constamment renouvelé, bien que ce soit toujours le même air."

* Importation en France des Viandes fraiches conservées par le froid. Paris, Imprimerie de J. Claye, 1874.

M. Poggiale observed two partridges which had been placed in the chamber on the 1st of February, had been taken out on the 5th of March in excellent state of preservation, and weighing 786 grammes. Half a sheep, kept at 0° C. for 37 days, presented all the characters of fresh meat; the weight, which had been 8.8 kilos, had fallen to 7.5 kilos; the loss was, therefore, about 12 per cent. in 37 days. He concludes his report by saying that M. Tellier proposed to convey meat from Montevideo, in 25 or 30 days, to Paris, by Rouen, and there placed in cold store for sale. He considered M. Tellier's experiments as of great interest as a matter of public hygiene, and that he deserved to be encouraged.

So important was this question considered that Professor Bouley, member of the French Institute, and Inspector-general of Veterinary Schools in France, was called upon to make two reports: the first on the 28th of September, 1874, to the "Comité Consultatif d'Hygiène publique de la France," and the second on the 5th of October, 1874, to the French Academy of Sciences. These reports bear out M. Poggiale's statement, but contain a few facts and observations which merit record here. Having described the methylic-ether machine and the method of cooling the rooms, he points out, according to Tellier's experiments, that meats which lose 10 per cent. of weight the first 30 days, viz, 3.33 grammes per kilogram per day, only waste 5 per cent. the second 30 days, or 1.65 grammes per kilogram per day. Beyond this, the drying continues very slowly, and at the end of eight months the interior of the meat is still moist. The duration of the preservative influence of cold may be regarded as indefinite; but, whilst meats really improve, during the first 40 or 45 days, they deteriorate somewhat, for the purposes of sale, beyond that time; they become too tender, and there is a fatty flavor, "une sensation gustative qui rappelle l'idée d'une matière grasse." M. Pasteur was invited by Professor Bouley to his home to taste some meat, and he inquired if the quarter of beef could be preserved as well as a quarter of mutton, and whether some change would not occur near the bone. A hind quarter of beef weighing 140 pounds had a thermometer plunged into its most fleshy portion at a depth of 18 centim. (about six inches), which took three days to fall from 36°.6 C. to 0° C. But this did not in the least interfere with its preservation, because the air is purified in circulation and the low temperature deprives the germs of activity.

The experiment at M. Tellier's place at Auteuil has proved that the temperature may vary from —2° to 3° C., viz, from 28°.4 to 37°.4 Fahr. During the hot month of June, 1874, the temperature rose in the cold room to 8° C. or 46°.4 Fahr., owing to the ice-machine having to be stopped for 36 hours; but a haunch of beef, weighing 140 pounds which was in the room during these oscillations for 51 days, was admirably preserved, and all who ate of it recognized that it was better than meat killed 24 or 48 hours before being cooked.

The experiments which the reporters had to refer to were conducted from the 29th of November, 1873, to the 7th of July, 1874.

Professor Bouley remarks, in his report to the Academy of Sciences, that "the knowledge of the preservative action of cold on organic bodies is, without doubt, as old as humanity itself, and every day one has recourse to this preservative influence for the preservation of alimentary substances. M. Tellier cannot, therefore, pretend to this invention. But that which is new in this process, which he has brought before the Academy, and which constitutes a real invention, is the idea of creating a dry and cold atmosphere, in which organic matters may be preserved permanently; atmosphere which is circulating without ceasing from the cold room to the refrigerating apparatus and back to the room in order to maintain the required temperature and abstract the moisture." "Grâce à ce circulus, on bénéficie de l'abaissement de température une fois acquis, et l'air revient à la chambre froide, desséché et purifié." This, he says, is the ingenious process of preservation of organic matters, and particularly of meats, which M. Tellier has communicated to the Academy. "Your commission has recognized its efficacy under the conditions under which it has been applied. But they must practise every reserve as to the industrial application that may be made of it. Experience alone can determine its economic value."

That M. Tellier had only then developed his practical methods may be gleaned from his English patent dated the 11th of August, 1874, No. 2,770. He says: "My process has for its object a slow desiccation combined with the action of cold exerted at temperatures approaching to 32° Fahr., but without congelation for organic substances under 32° Fahr., with congelation for amorphous substances, such as butter. Such desiccation requires to be graduated according to the nature of the articles to be preserved; and particularly with regard to meat, it must be slight when it is required to preserve the meat in the ordinary condition of butcher's meat, in which case a desiccation equivalent to a loss in weight of one-quarter to one-third per cent. per day is all that is necessary." He moreover says that the air may be dried by passing through the refrigerator of any suitable machine, and the desiccating property may be increased by causing the air to pass over dry chloride of calcium or other agent absorbing moisture readily.

M. Tellier had evidently been developing his idea over a period of four or five years, but he was neither alone in these efforts nor was he unanticipated.

To those who have known the nature and extent of my experiments since 1865, and especially from the autumn of 1869 to June, 1870, with the many efforts made in 1871, 1872, and 1873 to carry out, on a large scale, the transport of meats in dry cold air, I need not address a word. I saw Professor Low's ship, with a carbonic-acid refrigerating-machine on board, in 1869. Had he been fortunate enough to use more manageable chemicals he might have succeeded; but, like Mr. Mort, of Sidney, Mr. Harrison, of Victoria, and many others, he proposed to freeze meat, and that system I then, and ever after, condemned. In 1873, after having made various improvements in freezing-machines, I published a pamphlet, in which I said:

"Frozen meat has kept for ages, and during the Russian or North American winters the people are compelled to put up with it. Freezing is, however, prejudicial to the meat, and commercially impracticable, since it necessitates the construction not only of ordinary ice-houses, but of *freezing-chambers* at the ports of shipment and landing, and there are innumerable impediments in the way of getting the frozen produce delivered untainted to the consumer. Experimentally the process is simple and quite successful, but not as a means of supplying the nation's food.

"PRESENT PROPOSAL.—Since my return from America my labors have been constant, and my chief difficulty has arisen from the imperfect construction of all the machines employed in refrigeration. Not only did I find that the method of promptly cooling a large body of meat—say, two or three hundred bullocks at a time—was unknown, but the machines at our disposal could not be depended on. This difficulty I have now completely overcome, and in designing a steamer provided with a compound tubular freezing-machine, I have held in view the following points:

"1. The preservation of meat for seven or eight days, and even longer, insured by cooling the carcasses down to 40° or 45° Fahr. immediately after slaughter.

"2. Meat moulds and deteriorates in a *still* and *damp* atmosphere, but if the air be circulated and kept dry the meat retains a firm and florid aspect, and the currents of dry cold air may be so regulated as to keep the meat for an indefinite time.

"3. Not only for the transportation of fresh meat, but likewise for the transportation of fish, fruit, vegetables, eggs, cheese, &c., steamers, the holds of which can be kept by an economical system at 40° or 45° Fahr., or even as high as 50° Fahr., will command a large trade.

"The machine which I have perfected especially during the past two years enables us, by the use of ether, to have a body of liquid in a tank at the upper part of a ship's hold, corresponding to any number of pounds or tons of ice required to maintain a steady temperature in the hold. Brewers have taught us by prolonged experience that it may be economical to cool down to 40° or 45° Fahr., whereas freezing or the production of ice would be most costly and wasteful. With a compound tubular refrigerating-machine the temperature required is maintained, and it presents the immense advantage of enabling us to *cool*, *dry*, and *purify* the air that is made to circulate in the hold.

"COOLING THE AIR.—A perforated tube of adequate dimensions runs along the bottom of the hold and communicates with a fan or air-pump. From this fan or pump a tube delivers the air into the tubes passing through the cold liquid in the refrigerator. When the fan is set in motion the air is passed round and round continuously, so as to keep the meat dry and fresh.

"DRYING THE AIR.—The liquid in the tank surrounding the tubes through which the air is blown can be readily kept at a point a little above freezing, and the tubes are so placed on an incline that the moisture condensed from the circulating air trickles back and is drawn off at will. Condensation by cold surfaces is the cheapest and best method of drying air. The evaporation from the hot meat helps to abstract the animal heat, and when the meat is cold the continuous draughts of cold dry air are most beneficial.

"PURIFYING THE AIR.—One effect of the constant circulation of the air of the ship's hold through damp cold tubes is that it gets completely purified, and germs of decay and of mould are arrested. The atmosphere is sweet and pure, as well as cold, and this is one of the most desirable results attained by the plan now devised."

U.—DOES ICE DRY AIR?

I then believed, as I do now, that great económics and certainty would attend the use of antiseptics in conjunction with moderately cold air-currents for long voyages, and, since I have been in America a second time, I perceive that the crude ice method might have been attended with less loss and difficulty, had the persons engaged in the business acted under competent scientific advisers. So uncertain are they of the principles under which they work that some believe ice dries, and others that it wets air, whereas the truth is that ice condenses moisture from damp air warmer than itself, but will give up moisture to dry air at any temperature. Evaporation goes on from a surface of ice or snow at 32° Fahr. In the open air, and in a perfectly still night, the moisture amounts to nearly one ounce for every square metre exposed per hour. At 0° Fahr. nearly a quarter of an ounce of watery vapor rises per square metre per hour, and at 32° below 0° Fahr. more than two pounds of invisible vapor ascend into the air from every acre of surface. Thirteen to fourteen hundred pounds of watery vapor pass into the atmosphere for every square mile of snow or ice.

V.—PROPOSED IMPROVEMENT IN FREEZING FISH.

It is to be regretted that immense sums are invested in carrying out crude methods in the arts, and the introduction of rational and economical processes are then resisted by those who like to leave well alone. This would indicate the advantages to be derived by a careful exposition of the state of knowledge, in this case of the art of fish preservation, and, having laid down the principles involved in all known processes, a solid basis for further improvement might be established. Moreover, trials of new devices, under carefully-noted conditions, without involving very large outlay, might speedily enlarge the area of trade to the fisheries of this or any other country. It is of course difficult, for a person engaged in a large business, to change any system fairly meeting his requirements;

but in the case of the beef-trade to-day an average of 80 tons of ice per 100 tons of meat has to be carried, where a machine, occupying a ten-ton measured space, would insure better results, and guarantee the shipper against the consequences of delays at sea, from broken shafts or other causes.

Again, in the fish business the practice of freezing fish hard, and stacking them like cords of wood, may turn out to be an indispensable method for certain purposes; but the ice and salt process which I saw in 1868 in this country continues to-day, whereas it is easy to demonstrate that the art of artificial freezing should not amount to 25 per cent. of the cost of using ice at $3 to $4 per ton, and salt at best market prices, with all the labor of breaking and mixing.

Enterprising business men may justly state that up to this time promises have been scarcely fulfilled by the inventors of ice-machines, and, that the bold assertions in illustrated pamphlets, issued by persons interested in the sale of machines, have been hypothetical, often positively untrue, and no means were afforded to enable, even competent engineers, to determine on the probable issue of any costly trials. With this position of matters fairly in view, the laws and data controlling the practical production of artificial cold have been stated as fully as possible in a memoir of necessarily limited extent; and whilst it is not claimed that the subject has been in any sense exhausted, the intention has been of stating nothing but the truth, and of completing the task hereafter.

It is not, therefore, too much to hope that the more enlightened fish-culturists, who may have a knowledge of physics and chemistry to test and extend the information given, will contribute, by their influence and encouragement, to favor the development of rational and economical means, for the accomplishment of the various objects herein briefly unfolded.

W.—PRESERVATION OF BAIT AND FISH.

The proper storage and preservation of sound bait is one, if not the most important, part of a fisherman's business. Mr. Brown Goode has stated the problems to be solved on this question as follows:

1. To provide means by which a Grand Bank cod-schooner can carry 100 barrels of bait, in a compact mass, and in such a state of congelation that it can be used for eight or ten weeks.

2. To provide means for the refrigeration and preservation, for six months or more, of a quantity of bait amounting to at least 100,000 or 150,000 barrels.

Prof. Goode, moreover, informs me that it is difficult to estimate the total amount of bait consumed by the Gloucester fleet. Large quantities are salted for use in the mackerel, cod, and halibut fishery. About 35,000 barrels of "round fish" are cut up and salted for this purpose.

The George's Bank cod-fleet consume annually, something like 80,000 barrels of iced bait, chiefly menhaden in summer and herring in the colder weather. The herring are brought from Nova Scotia and Newfoundland, where they are bought frozen at the rate of 30 cents to $1 per hundred. Probably thirty voyages are made from Gloucester each winter for the purpose of getting these fish. Mr. Goode has not at hand an estimate of the quantity brought in each cargo, but it cannot well be less than 100,000 herring. The quantity thus brought in amounts to between three and four millions of herring, for which at least $15,000 are paid. Canada alone, exclusive of Newfoundland, sent in 1876 to the United States 4,361,000 pounds of herring (fresh), valued at $53,989. Besides the fish brought in the winter, a large quantity of herring are bought on the coasts of Newfoundland by the Grand Bank fleet, of which Gloucester has nearly 100 vessels. These vessels require for a season's fishing something like 100 barrels each of fresh bait. This they buy at the rate of about $2 a barrel, or somewhat more when they take them in frozen for the first spring trip. The necessity of going into port for bait uses up certainly half of the time of their four months' absence, besides which each vessel pays out from $200 to $500 for bait.

Mr. Goode estimates that Gloucester pays something like $40,000 annually for 20,000 to 25,000 barrels of herring. These herring and other fish, like the alewives, closely resembling them, occur in immense schools on the Atlantic coast during cold weather. The whole demand of Gloucester would doubtless be supplied by 120,000 to 200,000 barrels of fish, or perhaps 25,000,000 to 50,000,000 fish, frozen in such a manner as always to be available for use as bait. These fish, Mr. Goode says, if packed solid would occupy a space, approximately of 30,000 to 50,000 cubic feet. If proved good for bait, from 50 cents to $1 would readily be obtained per barrel.

The nature and extent of the bait-preserving question may likewise be inferred from the following note by Mr. J. K. Smidth.* In his paper on the Fisheries among the ancient Greeks and Romans, he states, after Oppian, that the "lycostome" (a sort of herring) were the best bait for catching the "sargus." As soon as a certain quantity has been thrown into the water they came in large swarms to eat it, and the fishermen then seized the opportunity to enclose them in their nets, and thus frequently caught large numbers. This use of bait, Mr. Smidth remarks, "in net-fishing, reminds us of the sardine-fisheries on the coast of Brittany, as carried on in our time. But here the roe of the codfish is used as a bait for the sardines. To give an idea of the enormous quantity of roe used for sardine-fishing, he mentions that 30,000 kegs of roe are exported annually from Norway to France. Each of these kegs contains about 140 kilograms, making a total of about 4,500,000 kilograms, or about 9,000,000 pounds, valued at about 3,000,000 francs. Several owners of large fisheries have assured me that the buying of this roe deprives them of half the profits of their sardine-fisheries."

* United States Commissioner of Fish and Fisheries Report, Part III, 1876, p. 7.

Coupled with Mr. Goode's statement that half the time available for fishing is consumed by the Gloucester fishermen's excursions after bait, Mr. Smidth's last remark is of great interest, as showing how vital the question of bait-preservation is to the fisheries.

Two processes are in vogue: the one which may be termed rough salting, and the other more careful handling and thorough cleaning of the fish, washing out blood and dirt, with a view to a milder salting. Salt bait is not so good as fresh bait, and there is a difference of opinion as to the relative value of whole and cleaned, or split salted fish. Since the soundness of bait thus used depends mainly on the condition of the fish when first salted, it may be desirable, even where salting is continued, to have means for the prompt cooling and drying of the fresh fish, and their more deliberate packing in barrels, as at present practised.

This seemed to have the preference, and the difficulties in its use depend (1) on the limited time it can be kept frozen and secured in a fishing-schooner; (2) on the time and distance required to secure it—*a priori*, it is not easy to understand how this form of bait can have any advantage over partially desiccated bait, and on carefully considering all I have learned from Professor Baird, Mr. Milner, and Mr. Brown Goode, it is my opinion that the best method of curing bait will be by drying at low temperatures.

A paper was read some years ago at the Society of Arts in London by Mr. Buchanan, on the preservation of vegetables by cold-air currents, and in justice to this gentleman I must say that the specimens prepared of cabbage, Brussels sprouts, onions, &c., were all that could be desired. This bore out my views as to the preservation of meats, and although absolute desiccation was essential for the prolonged packing of vegetable matter, animal produce may be made to preserve all its purity and delicate flavor by prompt and partial drying at lower temperatures, and effected in shorter time than by Mr. Buchanan's process. He placed his vegetables on trays, or an endless band, and maintained active currents of air in a confined box at ordinary temperatures, removing the moisture by chloride of calcium. This moisture could, of course, be better and more economically abstracted by metal surfaces lowered below 32° Fahr., and the dry cold air would always be preferable to temperatures varying, say, from 50° to 70°, and over. It is true that when relying on simple movement of the atmosphere the temperature may be varied at different stages of the process, and whereas it might be wise to dry slowly when the whole of the moisture in the vegetables, combined with high temperature, might lead to decay, so soon as a large percentage of the water had been removed, a higher temperature, even up to 100° Fahr., might be advantageously used to expedite the process. All aromatic substances retain their natural and unaltered characters only if dried at the lower available temperatures. It is with great confidence that I propose an extended trial of cold-dried bait.

Any quantity can be profitably and inexpensively cured by this process. Protracted preservation on land or at sea demands only moderate care to keep the bait dry. The method of packing can be such as to economize both room and cost, as compared with barrels. The fish used as bait, if properly handled, would retain form, color, and flavor. No extraneous material requires to be used in the preservation but what can readily be had at the fishing centres. The appliances necessary for this process are—

First. Cold storage to take in cargoes of fresh bait in bulk.

Second. Vacuum cylinders for promptly drying the cooled bait.

Third. Suitable canvas and facilities for packing in bales of convenient size.

Fourth. On each boat a convenient receptacle or cabin, through which air is made to pass continually at external temperatures by an automatic process; or if a closed and dry chamber is more easily secured, a drying-box containing a small quantity of chloride of magnesium or crude chloride of calcium may be employed without any through current of air. Common salt may, in the absence of the chlorides, sufficiently dry the chamber to prevent mould.

The cold-storage system I have described elsewhere, and I need only dilate on vacuum process of drying. The good to be derived from this is that slower drying is almost sure to be attended with some change in the flavor from the action of the air on the fish. A Sudlow air-pump such as I use for pumping ammonia gas, will create and maintain a vacuum in wrought-iron cylinders with adjustable covers, so that in two or three days from 15 to 25 per cent. of moisture is abstracted from the bait. The less it is dried the better, perhaps, except for keeping-properties, and here is the only question demanding experiment. I would propose a supply in suitable boxes of bait dried to the extent of 15, 20, and 25 per cent., and if the abstraction of the smaller amount of moisture were not inconsistent with preservation, in bales enclosed in a drying-chamber, it would be useless expense and an actual disadvantage to attempt further desiccation.

The *barrel* system of packing would favor mould, and thus affect the flavor and freshness of the bait; but coarse canvas, admitting of the escape of moisture, however slight this may be, will constitute a solid and sufficient covering for the bait. My experience as to packing the carcasses of mutton and quarters of meat, to hang them up in any convenient place where they can be kept dry on shipboard, indicates that with the most ordinary precautions the bait can thus be stowed away. Should an accident lead to their getting immersed in sea-water, the bales may be hung up like sails to dry in the rigging, and will keep sound and sweet at any temperature.

The *chamber* or *receptacle* on the schooner should be under lock and key and under the skipper's control. The only condition required is dryness, but if the regulations, as to the maintenance of purity and cleanliness in the bait-houses, are not preserved, a sea may be shipped, swamping the bait-house, and great trouble thus caused by damaged bait. I do not believe cold-dried bait will demand any more care than salt or frozen bait, but the chances of its prompt, beneficial and economical introduction depend on care and foresight in the first trials, and until the fishermen become familiar with its use. The nearest approach to live bait will be the carefully-preserved dry fish, which, on being submerged, may promptly regain plumpness, should drying have to be continued so long as to shrink them perceptibly.

X.—PRESERVATION OF SALMON, COD, HALIBUT, &c.

Appert's method of cooking in hermetically-sealed tin cans has proved a great boon to fisheries. The salmon-canneries on the Columbia and Sacramento Rivers, not to speak of the sardine-trade in France and elsewhere, the canned oysters of Baltimore, canned lobsters, &c., indicate how indispensable a cheap mode of fish-preservation is found in supplying the people's food. This subject deserves attention, and it would be well to know why canned fish, like canned meats and fruits, tend in the long run to nauseate, or, at all events, not to be eaten with the same relish as on first trials. I believe it will be an immense advantage if the cost and inconveniences of tinning can be set aside; and on sanitary grounds this may be very desirable. The contents of cans, containing cooked fish of all sorts, should be subjected to analysis, making a selection of different dates, so as to ascertain what the influence may be of protracted preservation in contact with metals. In the Chemical News of July 5, 1878, page 5, Mr. Albert E. Menke, of the chemical laboratory, King's College, London, writes as follows: "In opening a tin can of pine-apples I found that at the place where the tin had been soldered corrosion had taken place, which induced me to test for tin, having found indications of it, and made a quantitative analysis with the following results: I first poured the syrup off, and squeezed the juice from the fruit, then oxidized with chlorate of potash and hydrochloric acid, boiled, and then reduced the tin to the stannous state with sulphate of soda; sulphuretted hydrogen was then passed through the liquid, the tin sulphide was then filtered off, dissolved in strong hydrochloric acid, largely diluted and titrated with potassium permanganate. 0.151335 gramme of tin was found in a tin of pine-apple which weighed 1¾ pounds. I next tried lobster and apples, and found in the lobster 0.010089 gramme, and in the apples, 0.00672 gramme of tin, showing that the pine-apple was the worst, which would support the theory that it was due to corrosion."

Salting, *smoking*, and *drying* by the sun or at ordinary temperatures, are the commonest methods of fish-preservation, which are attended with great difficulties in the summer season, when unexpectedly large catches demand more hands, more time and conveniences than have been usually provided. Thus a successful haul is sometimes a cause of loss rather than profit. Cold houses, for the temporary preservation of fish, are, therefore, even for these purposes, invaluable.

It is not my object to dilate on those used for the process of *freezing*, as adopted by some of the more enterprising dealers in fish. If, as I have before said, it be found best to freeze fish under certain circumstances, the most economical plan admits of very ready description.

Mr. Frank Buckland informed me some years since that he had received in London, from Glasgow, a mass of fish frozen in a block of ice; that they looked well, but could not be separated for the trade without thawing the ice. This experiment, often repeated, indicates how effectually not only one but many fish may be frozen *en masse*. It may be incidentally remarked that certain kinds of hardy fresh-water fish may be frozen alive in a block of ice, and kept there for a time not yet well defined, but extending, at all events, over many days or weeks, and on thawing the ice the fish prove to have been unharmed. What temperature they will withstand is not known, and, in relation to fish-culture, this is another field for inquiry of the highest interest. It is just possible that some fish may be transported frozen to stock rivers or seas more easily than they can be carried in a water-tank, and whether a sole or turbot will resist such usage I cannot say; the experiments have yet to be made; and all we know is that some fish, like pike, may survive the process. It would not be difficult to try the experiment, inasmuch as a flat metal can containing the fish could be very rapidly frozen by a surrounding solution of glycerine and water from a freezing-machine, and, by selecting the proper cryogen, a temperature not much below 32° Fahr. might be readily maintained in a tub, containing the said metal can, on its passage across the Atlantic. The information at my disposal is so scanty that, apart from the fact that fish have survived freezing in a solid block of ice, I know nothing. It occurs to me, however, that in all probability the temperature of 32° Fahr. is low enough for most fishes, and the obvious use of common salt and ice might be attended by too low a temperature to insure success. Many failures may be anticipated; but without these, good work was rarely performed.

The present practice of freezing each individual fish solid and then keeping a quantity on hand from seasons of plenty to those of scarcity, is, of course, more feasible because less costly by the use of an ice-machine than by ice and salt. The uncongealable liquid would take the place of the brine, and very little, if any, alteration in plant, beyond the addition of a machine, would probably be required. The sooner the fish are frozen after being caught the better, and they must not be allowed to thaw until the time for cooking them. Frozen fish are packed in fine sawdust and closely boxed to be sent two or three hundred miles, thawing out slowly in transit; they are then dropped in water to complete the thawing, and are ready to cook.

Professor Goode informs me that "the total amount of iced halibut brought annually to the port of Gloucester is not far from 10,000,000 pounds. More than two-thirds of this, say 7,500,000 pounds, is brought from the Banks, or the coast of Nova Scotia, in vessels fitted out for the halibut-trade. Of these, there are about thirty which pursue the fishing part of the year, at least. The Bank halibut are brought in cargoes of from 15,000 to 80,000 pounds. The average weight of halibut is not far from 50 pounds, though individuals of 150 pounds are by no means uncommon. The length of a trip to the Banks for halibut is usually about three weeks, about half the time being consumed in making the passage to and fro.

"The remainder of the supply, which is perhaps something more than 2,000,000 pounds, is brought in small lots of 2,000 or 3,000 pounds by the vessels which fish for cod on the George's Banks. There are over one hundred of these vessels, which make one or two trips per month each throughout the year.

"The halibut as soon as they are caught are packed in broken ice in the hold of the vessel, which is divided up for that purpose into bins about eight feet each in dimensions.

"When they are brought on board the vessel their temperature is probably not much greater than that of the water in which they were caught, say 38° to 40°, the bottom temperature being about 33° to 34° Fahr. They are very cold when landed on the wharf at Gloucester, usually colder than 45° or 48°.

"They are immediately packed for shipment in pine boxes holding about 450 pounds; their abdominal cavities being filled with chopped ice, which is also plentifully bestowed in the crevices between their bodies.

"The weekly receipts of halibut probably range from 100,000 to 700,000 pounds per week, and sometimes the quantity is greater."

A halibut-schooner carries from 18 to 50 tons of ice on a trip; the largest quantity in summer. The amount annually consumed by the fleet does not fall much below 8,000 tons. This includes a certain amount allowed proportionally to the George's fleet.

Prof. Goode says the problem here to solve is how "to provide for the refrigeration and preservation on shore for one or two weeks of 10,000 or 15,000 halibut, weighing perhaps 50 or 60 pounds each."

It is well in all industries to depart as little as possible at first from established customs. Pending adequate experiments, it is quite certain that the boxed halibut must be placed in a room at 30° Fahr., in which the ice used at sea would not melt. The lids might be removed, to be replaced when the fish have to be shipped; but I see a positive advantage in resorting to the least possible disturbance, or handling of the fish, whilst insuring their preservation for so limited a time. Moisture is as great a factor, if not a greater, than heat in developing putrefaction; and a current of dry air at low temperature would check all mould or other parasitic vegetation; and a little fresh ice when the boxes are shipped would meet the very simple requirement of equalizing supply and demand by a preservation of one or two weeks.

There is a manifest difficulty in the way of resorting to any but the least costly process of transporting the fresh fish from the boat where it must be iced to the consumers. Any plan of preservation available for greater delays in transit, such as the supply of European markets might, in time, supersede the more precarious process hitherto in use.

It might be desirable to have cold chambers on the fishing-schooners, so that the ice should not melt in the boxes; and in time suitable refrigerators may be introduced amongst the fishermen. The prompt and practical remedy, however, lies in disturbing as little as possible the course of the trade; and so far as my experiments with fish have extended I have not found any preservative so good as ice; its only disadvantage is the melting, and to prolong its effects with a minimum deterioration of the fish is simply to keep the whole at a temperature which will fail to freeze the fish but will preserve the ice and insure dryness. The more complete the desiccation, so long as ice is around the fish, the more certain the result.

It is not improbable that this combination of using ice and artificial refrigeration may settle the problem of shipping fish to the English markets, and it is my intention to further by all means in my power the establishment of cold storage in England for the reception of all kinds of American produce, including fish. The obstacles I have met so far in this have resulted from the difficulties in inducing the agents in England to anticipate any preparations without coöperation by American exporters, and in America such men as Mr. Eastman in the beef business have little confidence in investing capital except under their own eyes, but when they see, there appears to be no limit to their enterprise.

With the lead taken in fish-culture in America, it is to be hoped this matter of making provision at the European centres of consumption for the reception and preservation of fish may meet with fewer obstacles than I have encountered in ten years with all the suggestions, admitted to be sound, in relation to the meat-trade.

Y.—DRY COLD WITHOUT ICE.

This plan so successful with the meat can be made to succeed with fish, but I hesitate to develop a complete plan on the slender knowledge I have of the possibilities in the fish-trade.

One thing is certain, viz, that drying without salt or smoke, so as to keep a split fish in the most perfect condition for some weeks, to be restored by a few hours' immersion in pure cold water, is practicable. Water can be abstracted and replaced from and into the most delicate animal tissues without the slightest deterioration or the development of adventitious flavor. This is undoubtedly the process which will supersede canning to a large extent on the Columbia and Sacramento Rivers, and it were well if, with the progress of fish-culture, these methods were made the subject of experiment and demonstration, so as to encourage capitalists to ship fish as nearly like grain in bulk, without incurring needless outlay, and spending money either to destroy the texture or the flavor of the materials preserved.

Where ice is at hand and ice-machines cannot be obtained, the use of a very simple refrigerator maintained just below 32° will keep the air dry, whilst its rapid circulation insures the more or less active shrinking and preservation of the fish. It is most economical almost anywhere to use an artificial process of producing the cold, for a building 70 feet long by 40 feet wide, divided into two or more floors, can be kept in a suitable state by a machine capable of producing only a couple of tons of ice daily, at a cost not exceeding, under proper conditions, $100 per month.

Z.—THE GLACIARIUM.

I cannot refrain here from pointing out the great importance in such cities as New York, Boston, Philadelphia, Baltimore, New Orleans, San Francisco, and a host of minor ones—indeed, all above 25,000 inhabitants—of establishing places where refrigerating-machines may serve to produce pure and cheap ice, preserve provisions, favor such industries as fishing and the inland transport of food, and provide, especially in the South, the means of getting pure water from the sea instead of rain-water, or ministering to the comfort of the inhabitants in hot weather by providing cool chambers at a temperature between 60° and 70° for purposes of recreation and athletic exercise. When I first constructed an ice skating-floor, it was simply with a view to encourage people in the idea that if engineers had been baffled by the difficulties of the subject, they were not insurmountable; but from the success in maintaining such sheets of ice during the hottest weather in summer, and even in an iron boat—the floating swimming-bath on the river Thames—led to a clear perception of the field there was in the future for the processes, perhaps too tardily developed. Ice-men only think of making ice, and in England the scanty use of ice in the largest cities retards the introduction of one of the most powerful aids to the promotion of heath, comfort, and economy, viz, the artificial production of cheap cold.

To recapitulate, a glaciarum includes—

First. The manufacture of pure, transparent crystal ice, containing as low as one-tenth of one per cent. of matter in solution or suspension, and hence absolutely free of all known impurities calculated to render water or ice unwholesome.

Second. The manufacture of ice in bottles—the carafes frappées of the Parisian cafés.

Third. Cold stores for meats, preserved provisions, fish, game, fruits, vegetables, &c.

Fourth. Storerooms for the protection of all articles attacked by insects during the summer, and which insects are killed, or arrested in their process of reproduction and development, by temperatures approaching the freezing-point of water. Thus, furs, feathers, woollen and other goods may be preserved in a state of perfect purity and freshness, free from moths, &c.

The destruction of fever-germs, such as the poison of yellow fever, at or below 32° Fahr., indicates that articles of wearing-apparel and furniture placed in such chambers, with absolutely dry cold air, 20° to 30° below the freezing-point of water, would constitute an invaluable adjunct to the means employed by sanitary authorities for effectual disinfection. The air blown, over metal surfaces and through antiseptic sprays, can be made to operate on every part of infected fabrics, without damage, however delicate they may be.

Fifth. The wholesale manufacture of ice-creams, ice-puddings, &c., constituting in some large cities a most profitable industry.

Sixth. The maintenance, especially during the winter season, of sheets of ice for skating and curling purposes. The pastime of skating may be indulged under cover in an atmosphere warmed suitably to avert colds and chills; and the ice being frozen by submerged pipes, retains its hardness under the most trying circumstances.

With the altered views amongst medical men as to the treatment of fever and many inflammatory diseases, ice becomes a positively essential therapeutic agent in warm latitudes.

Z*.—ON RENDERING SEA-WATER POTABLE.

The fact is generally appreciated, that Nature adopts two processes of water-purification for the requirements of mankind. The most universal is distillation or evaporation, and recondensation in the form of rain; and some towns, like New Orleans, are compelled to make use of rain-water, owing to the gross impurities of other sources of supply. In many cities, the rivers whence palatable water is obtained are polluted by sewage; and where wells have been common, the infiltration of soil by excreta, and other surface impurities, have been active agents in the propagation of filth diseases, such as typhoid fever and Asiatic cholera. Rain and distilled water are insipid and unpalatable. They are set aside for bright, sparkling, hard waters, which are often surcharged with organic germs; and throughout the South and Southwest many towns exist where a pure palatable water would be regarded as an unqualified boon, hitherto beyond reach.

The formation of ice, or crystallization of water, effectually removes all suspended or dissolved impurities calculated to engender disease. Ice-water is one of the necessaries of life in America, and if the ice were made so as to remove the discharged effete matter, its general employment would tend materially to reduce the prevalence of some of the maladies of towns. The natural ice supplied now always contains much dirt, which can be obtained in quantities from the bottoms of ice-jugs.

By means of a thermo-glacial engine, the cost of purifying, and rendering palatable, one hundred gallons of water, will not exceed fifty cents;

and this at once indicates the wide application of an entirely new system of supplying communities with pure water, where under existing circumstances none can be had.

Professor Baird, in the letter requesting me to furnish information at my disposal on the manufacture of ice and the preservation of fish, has directed my special attention to the dearth of water in places on the seacoast, such as Gloucester, Mass. This opens up a wide field of operations wherever ice-machines are established for the use of fisheries; and without attempting to determine the extent and actual form of appliances required in practice, the data at our disposal indicate the feasibility of making ice from sea-water and supplying a town with drinking-water of great purity.

M. Tellier, having described the congealer in his 1869 patent, goes on to say that another application, hitherto vainly attempted, is the preparation of fresh water at sea by means of congelation. It is a well-known fact that the water of the sea, when congealed, casts off the salts which it holds in solution, and that water is thus obtained quite as fresh as that produced by distillation, with this difference, however, in favor of the congealing process, that while a glass of distilled water can hardly be swallowed, there is no pleasanter drink than melted ice. Let the congealer be filled with sea-water, allow sufficient time for congelation to take place, and then run out the liquor laden with salts; the fresh water, in the shape of ice, will remain in the apparatus. This ice, being allowed to melt, will furnish, either alone or mixed with distilled or other water, excellent drinking-water, fit for any purpose.

Messrs. Henri Merle & Co., at Giraud, on the Mediterranean coast of France, adopted M. Carré's ammonia-machines soon after they were first constructed, at their salines, covering 25,000 acres.* Four-fifths of the chloride of sodium is removed from the sea-water by solar heat. A mixture of sulphate of magnesia and chlorides of magnesium and potassium remains in the mother-water, and this, on being subjected to —18° C., or a little below 0° Fahr., yields, by a double decomposition of common salt and sulphate of magnesia, sulphate of soda, which deposits in crystals, and a solution of magnesium chloride. The sulphate of magnesia is almost entirely withdrawn from the water, and the sulphate of soda which is obtained is a valuable commercial product, being the material from which carbonate of soda is prepared. The waters are now subjected to evaporation over the fire, and the remaining common salt which they contain is deposited in the form of the most beautiful fine salt. The chlorides of magnesium and potassium still remain in solution; but when the concentration has reached the specific gravity 1.31, the solution is allowed to flow over a broad surface of concrete (béton), where, in cooling, it parts with all the potash it contains in the form of a double chloride of potash and magnesium. The remaining water, containing only chloride of magnesium, is rejected. This waste salt may hereafter prove of great value as a cryogen, and I have used its watery solution exten-

* General Survey of the Paris Universal Exhibition, 1867. Washington, 1868.

sively, in the place of the aqueous solution of glycerine, as an uncongealable liquid in connection with ice-machines.

The double chloride of potash and magnesium, washed with half its weight of cold water, yields three-quarters of its potash in the form of chloride of potassium; and the remaining quarter, still held in solution in the water used in this final operation, is returned to the boiler. The commissioners of the United States who reported on this process in 1867 remarked that "the separation of potash from sea-water, thus effected, is one of the most important and valuable results which science has, in modern times, contributed to the industrial arts. Though potash is the most useful of the alkalies, the natural sources from which it is possible to obtain it economically are very few in number. Hitherto the supply has been chiefly derived from the ashes of land-plants, from which it is separated by lixiviation. This resource, which continually grows more precarious as civilization advances and as forests disappear, is destined, doubtless, to give way to the process just described, and which has already been for a number of years in active and successful operation."

Messrs. Merle have applied the treatment above described to mother-waters amounting to 100,000 cubic metres per annum, with an annual product of 4,000 tons of anhydrous sulphate of soda, 1,000 tons of chloride of potassium, and 12,000 tons of refined table-salt.

The waters leaving the refrigerators do not form incrustations in the boilers, owing to the almost complete decomposition of the sulphate of magnesia during refrigeration, the removal of sulphuric acid, in the sulphate of soda, and the increase in the quantity of magnesium chloride.

By a process of downward freezing, such as I have described, pure ice forms on the cooled metal surface and the salt-crystal deposit. Professor Guthrie has in this way obtained ice containing only 0.4052 of solid residue per cent. He experimented with sea-water from Dover, having, after filtration at 760^{mm}, the boiling-point of 100°.6 C., while the temperature of its vapor was 100°.2. This sea-water began to freeze at 2° C., for two hours the percentage of solid residue was 6.5786. A large beaker of this sea-water was cooled to 0° C. A tin vessel was supported inside the beaker, so that its bottom just touched the surface of the water, and a freezing-mixture was placed in the tin vessel. When about one one-hundredth of the whole had solidified, the solid was removed and divided into two parts: one was allowed to melt, and its percentage of solid matter was determined as above; the other was broken up and frequently pressed between linen and flannel in a screw-press, being allowed to melt as little as possible. The percentage of solid matter in this was also determined. The following numbers show the result of this examination:

	Per cent. at 100° of solid residue.
Sea-water	6.5786
Frozen sea-water	5.4209
Frozen and pressed sea-water	0.4925

"It appears, then," says Professor Guthrie, "that under these conditions the freezing of sea-water is little more than the freezing of ice, and that the almost undiminished saltness of the unpressed ice is due, as suggested by Dr. Rae, to the entanglement amidst the ice-crystals of a brine richer in solid constituents than the original water itself. Such brine, which is here squeezed out in the press, drains in nature down from the upper surface of the ice-floe by gravitation, and also is replaced by osmic action by new sea-water which again yields up fresh ice; so that while new floes are porous and salt, old ones are more compact and much fresher, as the traveller observed. . . . The degree of saltness of a floe depends not only upon its age, but also upon the rapidity with which it was at first formed, and upon the lowest temperature to which it has subsequently been exposed."

Mr. Guthrie justly supposed that the ice of the sea is mainly formed at or near the surface by radiation from the surface into space, and by contact with the colder air. He imitated this by hanging a blackened tin pan, containing a freezing-mixture, within one-eighth of an inch of the surface of the sea-water and thus obtained the ice which, on being pressed, contained a minimum solid residue.

CONCLUSION.

It had been my intention to enter into practical details concerning refrigerators, refrigerator-cars, and the methods of making pure ice economically. The time and space occupied preclude this now, but the opportunity for giving a connected history of the numerous efforts made of late years to extend the benefits of refrigeration for man's wants will not be neglected, if only in the fishing interests.

WASHINGTON, October, 1879.