Since the advent of refrigerating machinery on shipboard, marine engineers have been brought intimately in contact with the question of safe carriage and keeping of perishable goods, and by so doing have had to learn much by experience. There is, to-day, no more carefully guarded consignor than the shipper of refrigerated produce. Lloyd's have safeguarded him far more against the breakdown of refrigerating plant than is the case in almost any other kind of risk; for while a stoppage for 24 hours of the propelling machinery of a ship would not necessarily be a serious matter, a similar stoppage of the refrigerating machinery would be fatal to a refrigerated cargo. The list of spare gear to be carried for refrigerating machinery is most complete, including spares of every description, even down to a complete brine pump, pipes, tools, and duplicate fittings, etc.

It is an interesting sight to see the neat, hard frozen sheep and lambs, the solid heavy quarters, and round bodied pigs, all in clean white coverings, being shipped away in clean lime-washed holds, all packed and stowed in such a way that hardly any room is lost. The hatches are put on tight and the only indication of what is happening in the hold for weeks is furnished by the daily thermometer readings. As long as low enough temperatures are carried, there is no fear of damage to this class of cargo, it will turn out just as clean and sweet as the day it was put in. Of late years further advancement has been made, and the engineer has now in his care huge cargoes of fruit, and for this class of cargo much care and thought has to be expended if it is to be landed in as good order and condition as the bill of lading states that it was received. Only a narrow margin in temperature is allowed, no higher than, say, 35° Fah., and no lower than 33° Fah. If the fruit is newly gathered the $C.O_2$ gas given off it is apt to interfere with the air circulation, and sometimes mechanical means have to be employed to remedy this. The writer heard recently of a vessel, fitted with compressed air machinery, which had an apple cargo, and there was much trouble in keeping the correct temperature, and only by opening the doors and changing the air in the chambers occasionally, could the temperatures be lowered to the desired figure. The machine had been built to handle ordinary air, and when it was supplied with $C.O_2$ gas it gave trouble. Again, beef cargo is not always frozen. Shipments are now being made of chilled meat kept just above freezing point, the margin of temperatures between maximum and minimum being very small indeed, and demanding constant vigilance on the part of the engineers.

The ship's provision chamber gives much room for thought. Engineers get to appreciate the proper degree of temperature required for a basket of eggs, a bag of cabbage, a box of fish or a haunch of mutton, and in most vessels, nowadays, they are just as good connoisseurs with regard to such articles as is the chief steward, and the writer feels sure that cold stores on shore can seldom, if ever, show the heterogeneous collection of commodities seen in a ship's cold room. A glance down a bill of fare shows this.

Ice is made on shipboard nowadays, and engineers have had to learn how to make this article as clean and pure as possible. The great thing that ice-making emphasises is the latent heat of water. Just as the huge amount of heat liberated in the main engine condenser, in which the steam is converted from a gaseous state into a liquid, shows the latent heat of steam; so ice-making shows the latent heat extracted in turning the liquid water into solid state, as ice. It is here that the difference between the ton of refrigeration and the ton of ice made is to be observed.

The capacity of refrigerating machinery is always stated in "tons refrigeration," that is, the latent heat of water, viz., 142 x 2240 = 318080 British Thermal Units per 24 hours, the amount of heat liberated by a ton of ice melting. To make a ton of ice, however, demands many more B.T.U's. To calculate how much, assume that it is required to make a ton of ice from water at 70° to ice at 16°—

$$
\begin{aligned}
70^\circ - 32^\circ = 38 \times 2240 &= 85120 \\
142 \times 2240 &= 318080 \\
2240 \times 16 \times .5 &= 17920 \\
\hline
& 421120 \text{ B.T.U.}
\end{aligned}
$$

Without reckoning other losses, it is generally taken that the ice-making capacity of a machine is just one-half the refrigeration capacity.

The fuel consumption of auxiliary machinery is, in modern vessels, responsible for the method of driving all from a central generator by means of electricity, and in the newer vessels of the Cunard fleet electricity is used for driving the ammonia compressors. Bearing in mind that there is very little room for improvement in the actual mechanical appliances used for compressing ammonia and $C.O_2$, it seems more probable that any improvement will be in the direction of economy in motive power. Of course large installations are often driven by triple expansion condensing engines, and compound engines are common enough, but the small size refrigerator still has, as a rule, a simple steam cylinder. Brine pumps are almost invariably of the direct acting type, whereas if these pumps were made of the direct coupled centrifugal type, and the compressor, probably gear driven by motor or economical steam engine, running costs would be considerably less.

Specialising is rife amongst engineers—some are mechanical, some are electrical, and so on; and it is now the general practice on all large ship-board installations to have refrigerating engineers, men who relieve the chief of a great deal of anxiety and conduce to more regular working of the plant. Smaller machines are, of course, still run by the engineer on watch amongst his other duties.

All classes of machinery have had certain eras in their lives, and it is the same with refrigerating machinery. At first engineers were satisfied to merely obtain a freezing effect; then they came to the stage when different pioneers of the industry had put forth various types and embodied the results from these in further experimental trials, from which there finally emerged almost a standardised machine, built along very similar lines by different makers. Now, engineers are expected to understand the refrigerator, just as they are the steam engine.

Specialists there must always be; no one man can expect to become an expert in electricity, steam, refrigeration, etc., and in all the various machines on ship-board, but if ordinary working principles are understood, then very little is to be feared, as common sense and experience will do the rest.

The specialist can design, erect, and start the plant to work, then he has to pass the results of his efforts on to the marine engineer to operate regularly. It is then that the owner, the man who pays for the machine, finds out whether the specialist has faithfully carried out his part of the contract.

DISCUSSION.

Mr. Norman Selfe, on being asked to open the discussion, said he spoke with some hesitation, as it was occasionally hinted that he was getting out of date. It was certainly true that it was over 50 years since he first designed Ice Machinery, as the pages of the "Engineer" will show. However, he had a good deal of pleasure in congratulating the author on the very lucid way in which he had dealt with the cycle of operations taking place in a refrigerating plant. He thought the paper would be specially useful to the younger members of the Association, who were not connected with that department of engineering dealt with, as well as to students who desired to acquire some knowledge of practical refrigeration without going into thermo-dynamic theories, for which their text-books were available. The author seemed to have a very happy way of making his meaning clear, so far as he went, but there was an omission, he thought—which might be remedied—in not dealing with the question of the transmission of heat from the brine, or the air of the chamber, to the evaporated ammonia; or from the ammonia in the condenser to the cooling water. He thought if the author amplified his paper a little in that direction it would much increase its value to the average reader. On the whole, the author was to be congratulated on having read a carefully prepared and very useful paper, and he had much pleasure in moving a hearty vote of thanks.

Mr. J. Shirra remarked that the paper was a good practical one, giving us information on many matters not touched on in text-books. We may learn, for instance, much from books about the steam engine, but unless we know something practically about such details as oil-holes and lubrication, an engine otherwise perfect, may soon come to grief, and we do not get much information on such matters from ordinary text-books.

The author says that pressures and temperatures always correspond, but this can only be true with dry saturated gas. Is the working gas not sometimes superheated? There seems some ambiguity in the use of this word "saturated." The author seems to mean "wet" gas by it sometimes. Thus he says $C.O_2$ machines are always worked with "saturated" gas, that is, gas still possessing some degree of latent heat. This seems somewhat a "derangement of epitaphs." What seems to be meant is "wet" gas, or gas containing liquid $C.O_2$, which so far from possessing latent heat, has less than none, a negative latent heat, or a tendency to absorb sensible heat and convert it into latent heat of evaporation, and so to keep down the temperature of the gas.

The explanation of critical temperatures and of how $C.O_2$ machines are affected by a high temperature of condensing water is very much to the point. In an ice-making machine on ship-board, that the speaker had experience with some 35 years ago, worked with sulphur di-oxide gas, this difficulty with high temperature water was very pronounced, as in tropical water the $C.O_2$ would not condense at all, and the machine failed when it was most wanted.

On the whole, the points referred to have been very clearly stated; and the careful way in which latent heats are stated in B.T.U's. per lb. of gas is commendable. We are often told that the latent heat of steam, for instance, is 966 degrees, a most unintelligible and confusing way of putting it.

The speaker would like to have it explained how the presence of $C.O_2$ in the air of the holds, when carrying fruit cargoes, affects the working of the machines?

Mr. W. H. German said that The Colonial Sugar Refining Coy. manufacture $C.O_2$ at their distillery, and, for bottling it in liquid form, had adopted 3-stage compressors, the gas being filtered between the first and second stage.

In the summer, when the cooling water from the harbour rose to over 70° Fah., the machines became somewhat inefficient, as the liquefying pressure then rose to between 11/1200 lbs., but he thought it would interest members to know that an ammonia refrigerator has been used for cooling the condensing water, thus making the $C.O_2$ compressors more efficient, as it reduced the liquefying, or bottling pressure to between 6/700 lbs.

Mr. A. E. Lea desired to say that the thanks of the members of this Association were due to Mr. Sinclair for the able manner in which he had put the paper before them.

Having had practical experience of the working of $C.O_2$ machines, both at sea and ashore, he would say that the gas in this type of machine does not readily liquefy at a higher temperature than 86° Fah.

With regard to the export of fruit from these States it was only during the last five years that it had been carried witn any great success, and it was not only due to the refrigerating, but to the improvement in handling the $C.O_2$ that is given off from the fruit. In former years, this gas was simply taken from the hold and discharged into the atmosphere. This system is now altered and the gas is circulated in the chambers by means of fans, and, being heavier than air, it consequently descends to the floor, from where it is then drawn by means of a trunk or duct to the fans. He mentioned this matter, as, perhaps, most of the members were unaware, that this system is applied in the carriage of fruit.

He thought it would be agreed that Mr. Sinclair had given many details of the ammonia system to prove its general excellence for practical use, and yet some of the largest steamers are fitted with the old type cold air machines, which produce air saturated with moisture. This air is circulated directly amongst the products, often causing mould and thereby deteriorating the value of the cargo. It is a surprise to him that many owners still use this old type of machine, working at greater cost in coal consumption than an ammonia machine of the same capacity.

Mr. Russell Sinclair said that he had much pleasure in hearing the paper read, and complimented the author on the clear way in which he had brought the matter before them. He wished that the author had put more stress on the necessity for those responsible for the installation of refrigerating plant on board steamers, laying down the conditions more clearly and definitely than they did as a rule. In too many cases refrigerating plants on board a ship are looked upon as an excrescence, rather than as a vital part of the economy of a steamer; and often the most cramped and hottest corner of a vessel is where the freezing machine is placed, instead of being given full consideration for the important work it has to do. Too often, also, the details of the installation were left to be carried out in the cheapest manner possible. He would also have liked the author to have mentioned in the paper, more about the necessity, the vital importance, of having the thermometer equipment of any refrigerating plant in very good order. Just as a doctor relies on the thermometer indicating the condition of a patient, so must the refrigerating engineer depend on the thermometers to give him correct information as to how the plant is working, and the importance of keeping thermometers in perfect working order, and always registering correctly, cannot be too strongly emphasised. Many times he had found, when called in to advise on a plant, as to the reason of its falling off in efficiency, that it was impossible to discover what was the matter until the thermometers were put right, all being either broken or reading inaccurately, or placed in such positions that it was almost impossible to see them. Mr. Selfe, in speaking, had referred to the advantage it would be to have some information as to the amount of piping in insulated chambers, but it would be difficult to lay down any hard and fast rule as to the transference of heat through piping, because what would apply in one case would not apply in another, e.g., if pipes become covered with snow, the transference of heat is greatly interfered with, and the ratio of transfer alters, but it would be an advantage if the author added to his paper a few figures giving the average proportion which has been found suitable for the piping of chambers.

Referring to Mr. German's remarks, re the difficulty experienced with $C.O_2$ machines. There seems to be no question but that machines using $C.O_2$ are not suited for continuous tropical running. The critical temperatures of $C.O_2$, i.e., the point at which it will liquefy, is about 87°. Above that temperature no liquefaction could take place, and the benefit of the latent heat of vaporization could not be fully availed of, but the machine would still go on doing refrigerating work, because the gas, though not becoming liquid, would be in a very dense condition, and the efficiency drops under these conditions to a very low point.

He would like to refer to one remark made by Mr. **Shirra,** in questioning the authors correctness in referring to the benefit of latent heat of saturated gas in the compressor. He would like to say that he thought the author was quite correct in the use of the term "latent heat" in this connection, because in a compressor working on the principle of using saturated gas, such as ammonia, the gas is evaporated in the refrigerating coils t such a pressure that the temperature corresponding to that pressure of gas will be such that the heat taken up from the surrounding object is not sufficient to completely raise the gas to its dew point. The gas, therefore, comes back to the compressor not totally vaporized, then after it is sucked into the compressor, and during the process of compression, the heat due to the mechanical action of compression, which would, if the gas were not in a saturated condition, cause a rapid rise in the sensible temperature, becomes latent and prevents the increase in temperature. In other words, the unvaporized portion of the refrigerant in the gas becomes vaporized by the rising temperature due to compression, and the latent heat thus taken advantage of prevents a rise in the sensible temperature. Thus, in this way, neither $C.O_2$ compressors nor ammonia compressors, working on the saturated gas system, require to have any water jacket round their compressors. The proper regulation of the flow of gas in these machines is easily gauged by the engineer in charge feeling the temperature of the discharge from the compressor by his hand, the average condition being that the discharge temperature should not be greater than the hand can bear.

Mr. J. C. Brand remarked that he desired to add his quota of praise to that of the previous speakers.

Mr. Sinclair had treated the important subject of refrigeration in an exhaustive and practical manner. He (the speaker) would like to ask the author if he could enlighten them on the subject of the suitability, or otherwise, of Australian pine in the insulation of the walls of refrigerated chambers.

Some time ago, whilst in England, at a discussion before one of the learned institutes, he averred that our local woods were suitable, and that in several installations he had inspected, the wood showed no sign of decay from moisture, after ten years' use.

Mr. Sinclair very rightly drew attention to the necessity of piping chambers differently according to their dimensions, and not from their cubic capacity. This is of extreme importance, especially in ship-board installations.

The author has made no mention of the Absorption system of ammonia refrigeration, which is especially interesting from an economic point of view. In Liverpool and Yarmouth this system has been fitted to utilise the exhaust steam from the engines of the compressor plants. As there are no moving parts, with the exception of the liquor circulating pumps, these plants are economical in upkeep, and need little skilled attention.

In passing, the author mentioned the difficulty experienced in $C.O_2$ machines when the temperature of the sea was above normal. The speaker remembers one such installation, of which he was in charge, which, when passing over the equator with a sea temperature of 84° Fah. recorded a pressure of 1350 lbs. per square inch on the pressure gauge of the compressor, with the accompanying troubles with compressor pistons and glands.

Messrs. Hall and Coy. now fit condensers of very large surface in their plants, especially for use in tropical climates.

He would conclude with the expression that the paper is an extremely valuable one, in a community such as theirs, where refrigeration bulks so large in their professional life.

REPLY.

In replying to the different points raised in the discussion, Mr. Sinclair explained, by means of a blackboard sketch, the principle of the compound compressor, showing how a small clearance in the low pressure end was of great importance, and how the space between the pistons was in connection with the low pressure side of the plant. He stated that the question of saturated and dry gas was a much debated point, and he preferred not to touch on it. With regard to the $C.O_2$ gas generated from fruit, interfering with the efficient working of a plant, he would explain that the gas, being heavier than air, lay in masses in the lower parts of holds and interfered with the proper circulation of the air, necessitating the fitting of menhanical appliances to stir the air about.

With regard to $C.O_2$ machines, he would say that their efficiency fell greatly with high temperatures of cooling water, compared with ammonia machines. Professor Siebel gives the following table in his "Compend":—

Temperature before expansion valve deg. F...	54°	63°	72°	81°	90°
Excess of efficiency of ammonia over CO_2 plants	17%	23%	31%	47%	101%

In reply to Mr. Brand's inquiry, he would say that refrigerated air has no effect on timber. It is found that almost in all cases where double linings are used it is the inner lining that shows decay first, and this is brought about by the absence of air circulation. In many modern buildings, one lining only is now adopted, with paper fitted to seal the insulation.

As stated in the paper, the relation between temperature and pressure of ammonia gas was a constant quantity, and as high condensing pressures invariably followed high temperature of cooling water, it was found that in most cases exhaust steam did not possess sufficient heat to raise ammonia gas to the necessary temperature and pressure and to raise the exhaust pressure to give additional heat destroyed all the economy.