Valve-Gear.—This subject has received much attention. About 1880 Messrs. R. and W. Hawthorn, the firm with which the writer was then connected, commenced the use of a form of the Hackworth valve-gear, of which some modification was fitted to nearly all of their subsequent engines (Proceedings Mechanical Engineers, 1880, page 430). About the same time Mr. Joy introduced his valve-gear, which is nearly if not exactly the same in principel as one of the numerous forms tried by Mr. Charles Brown. The apparent and direct advantages were: more nearly mathematically accurate distribution of steam; constant lead; and fewer parts. Indirectly these valve-gears have the advantage of shortening the engine, over the cylinders at least, because in their adaptation to the engine the valves are removed from the centre line to the front or back, whereby also they are rendered more accessible.

These advantages having turned attention to the matter, the forms of radial valve-gear became " legion." But the old-fashioned link-motion, though it seemed for a time likely to disappear, still holds its own, and in all probability will continue to do so. In the distribution of steam it may not be so mathematically accurate on paper; but practically the effect is, or can be made, as good as with the best radial valve-gear. It does not give constant lead when linking up; but constant lead is not the ideal of perfect valve-setting. A constant-lead angle of the crank is more nearly what is required, for which a diminishing lead in the valve with linking up is the necessary condition. The old link-motion lends itself readily and gracefully to any modifications which may be suggested by changes in the condition of working; the radial forms do not. Besides this, the link-motion admits of simple geometrical treatment, which is generally understood, even in the engine room, and is consequently a safer arrangement in the hands of the men found there. For high-speed engines the writer has strong objections to radial valve-gear, as to any motion not the most direct possible. It is true such gears are frequently fitted to high-speed engines; and in some horizontal engines for the navy, where space was an element of importance, they became almost a necessity. But the sudden shocks to which the parts are subjected are liable to cause considerable spring in the levers, of which such gears largely consist; and hence in some engines so designed the readings of valve settings are no guide as to what occurs when the engines are at work. Though this may be overcome by adding weight to the parts, yet when made sufficiently strong to be perfectly satisfactory, the writer ventures to say that the link-motion will be the lighter of the two.

Crank-Shaft.—For ordinary mercantile ships the solid crank-shaft has become a thing of the past. As now built up of separate pieces shrunk together, the crank-shaft is sounder and far more reliable, though it is a little heavier

Centrifugal Pumps have been more commonly adopted than formerly for circulating purposes, and with great wisdom, as they offer the advantage of keeping a cool condenser at all times, and may be used as a powerful auxiliary in case of bilging.

Steam-Pipes.—The failures of copper steam-pipes on board the "Elbe," "Lahn," and other vessels, have drawn serious attention both to the material and to the modes of construction of the pipes. The want of elastic strength in copper is an important element in the matter, and the three following remedies have been proposed, while still retaining copper as the material. First, in view of the fact that in the operation of brazing the copper may be seriously injured, to use solid-drawn tubes. This appears fairly to meet the main dangers incidental to brazing; but as solid-drawn pipes of over 7 inches diameter are difficult to procure, it hardly meets the case sufficiently. Secondly, to use electrically deposited tubes. At first, much was promised in this direction, but up to the present time it can hardly be regarded as more than in the experimental stage.

Thirdly, to use the ordinary brazed or solid-drawn tubes, and to reinforce them by serving with steel cord or steel or copper wire, or by hooping them at intervals with steel or iron bands. These have been tried, and found to answer perfectly. For economical reasons connected with winding, as well as for insuring the minimum of torture to the material during manufacture, it is important to make as few bends as possible; but in practice much less difficulty has been experienced in serving bent pipes in a machine than would have been expected.

Discarding copper, it has been proposed to substitute steel or iron. In the early days of the higher pressures Mr. Alexander Taylor adopted wrought-iron for steam-pipes. One fitted in the "Claremont" in February, 1882, was recently removed from the vessel for experimental purposes, and was reported upon by Mr. Magnus Sandison in a paper read before the North-East Coast Institution of Engineers and Shipbuilders (Transactions Mechanical Engineers, vol. 7, 1890-91, page 113). The following is a summary of the facts. The pipe was 5 inches external diameter, and 0·375 inch thick. It was lap-welded in the works of Messrs. A. and J. Stewart. The flanges were screwed on and brazed externally. The pipe was not lagged or protected in any manner. After eight and a half years' service the metal measured where cut 0·32 and 0·375 inch in thickness, showing that the wasting during that time had been very slight. The interior surface of the tube exhibited no signs of pitting or corrosion. It was covered by a thin crust of black oxide, the maximum thickness of which did not exceed 1-32nd inch. Where the deposit was thickest it was curiously striated by the action of the steam. On the scale being removed the origina bloom on the surface of the metal was exposed. It would thus appear that the danger from corrosion of iron steam-pipes is not borne out in their actual use, and, hence, so much of the way is cleared for a stronger and more reliable material than copper. So far the source of danger seems to be in the weld, which would be inadmissable in larger pipes; but there is no reason why these should not be lapped and riveted. There seems, however, a more promising way out of the difficulty, in the Mannesmann steel tubes which are now being "spun" out of solid bars, so as to form weldless tubes.

Cast steel has been freely used by the writer for bends, junction pieces, etc., of steam-pipes, as well as for steam valve-chests, and, except for the fact that the steel-makers' promises of delivery are generally better than their performance, the result has thus far been satisfactory in all respects. These were adopted because there existed some doubt at the time as to the strength of gun-metal under a high temperature, and as the data respecting its strength appeared of a doubtful character, a series of careful tests were made to determine the tensile strength of gun-metal when at atmospheric and higher temperatures. The test bars were all 0·75 inch diameter, or 0·4417 square inch sectional area; and those tested at the higher temperatures were broken while immersed in a bath of oil at the temperatures here stated, each line being the mean of four experiments.

TABLE 1.

Tensile Strength of Gun-metal at high temperatures.

Composition of Gun-metal.	Temperature of oil bath.	Tensile Strength per sq. inch.	Elastic Limit per sq. inch.	Elongation in length of 2 inches.
Per cent.	Fahr.	Tons.	Tons.	Per cent.
Copper 87, Tin 8, Zinc 3½, Lead 1½	50°	12·34	8·38	14·64
	400°	10·83	6·30	11·79
Copper 87, Tin 8, Zinc 5	50°	13·86	8·33	20·30
	458°	10·70	7·43	12·43

The result of these experiments was to give somewhat greater faith in gun-metal as a material to be used under a high temperature; but as steel is much stronger, it is probably the most advisable material to use, when the time necessary to procure it can be allowed.

Feed Heating.—With the double object of obviating strain on the boiler through the introduction of the feed water at a low temperature, and also of securing a greater economy of fuel, the principle of previously heating the feed water by auxiliary means has received considerable attention, and the ingenious method introduced by Mr. James Weir has been widely adopted. It is founded on the fact that if the feed water as it is drawn from the hot well be raised in temperature by the heat of a portion of steam introduced into it from one of the steam receivers, the decrease of the coal necessary to generate steam from the water of the higher temperature bears a greater ratio to the coal required without feed-heating than the power which would be developed in the cylinder by that portion of steam would bear to the whole power developed when passing all the steam through all the cylinders. The temperature of the feed is of course limited by the temperature of the steam in the receiver from which the supply for heating is drawn. Supposing, for example, a triple-expansion engine was working under the following conditions without feed-heating:—Boiler pressure, 150 lbs.; indicated horse-power in high-pressure cylinder, 398; in intermediate and low-pressure cylinders together, 790—total, 1,188; and temperature of hot well, 100° Fahr. Then with feed-heating the same engine might work as follows:—the feed might be heated to 220° Fahr., and the percentage of steam from the first receiver required to heat it would be 10·9 per cent.; the indicated horse-power in the high-pressure cylinder would be as before, 398; and in the intermediate and low-pressure cylinders it would be 10·9 per cent. less than before, or 705, and the total would be 1,103, or 93·0 per cent. of the power developed without feed-heating.

Meanwhile, the heat to be added to each pound of the feed-water at 220° Fahr. for converting it into steam would be 1,005 units against 1,125 units with feed at 100° Fahr., equivalent to an expenditure of only 89·4 per cent. of the heat required without feed-heating. Hence, the expenditure of heat in relation to power would be 89.4 ÷ 93.0 = 96·4 per cent., equivalent to a heat economy of 3·6 per cent. If the steam for heating can be taken from the low-pressure receiver, the economy is about doubled.

Other feed-heaters, more or less upon the same principle, have been introduced. Also others which heat the feed in a series of pipes within the boiler, so that it is introduced into the water in the boiler practically at boiling temperature; this is economical, however, only in the sense that wear and tear of the boiler is saved. In principle the plan does not involve economy of fuel.

Auxiliary Supply of Fresh Water.—Intimately associated with the feed is the means adopted for making up the losses of fresh water due to escape of steam from safety-valves, leakage at glands, joints, etc., and of water discharged from the air-pumps. A few years ago this loss was regularly made up from the sea, with the result that the water in the boilers was gradually increased in density, whence followed deposit on the internal surfaces, and consequent loss of efficiency, and danger of accident through overheating the plates. With the higher pressures now adopted, the danger arising frum overheating is much more serious, and the necessity is absolute of maintaining the heating surfaces free from deposit. This can be done only by filling the boilers with fresh water in the first instance, and maintaining it in that condition. To do this two methods are adopted, either separately or in conjunction. Either a reserve supply of fresh water is carried in tanks, or the supplementary feed is distilled from sea water by special apparatus provided for the purpose.

In the construction of the distilling or evaporating apparatus advantage has been taken of two important physical facts, namely :—that, if water be heated to a temperature higher than that corresponding with the pressure on its surface, evaporation will take place ; and that the passage of heat from steam at one side of a plate to water at the other is very rapid. In practice the distillation is effected by passing steam, say from the first receiver, through a nest of tubes inside a still or evaporator, of which the steam space is connected, either with the second receiver or with the condenser. The temperature of the steam inside the tubes being higher than that of the steam either in the second receiver or in the condenser, the result is that the water inside the still is evaporated, and passes with the rest of the steam into the condenser, where it is condensed, and serves to make up the loss. This plan localizes the trouble of deposit, and frees it from its dangerous character, because an evaporator cannot become overheated like a boiler, even though it be neglected until it salts up solid; and if the same precautions are taken in working the evaporator which used to be adopted with low-pressure boilers when they were fed with salt water, no serious trouble should result. When the tubes do become incrusted with deposit, they can be either withdrawn or exposed, as the apparatus is generally so arranged, and they can then be cleaned.

Screw Propeller.—In Mr. Marshall's paper of 1881 it was said (page 476) that "the screw propeller is still to a great extent an unsolved problem." This was at the time a fairly true remark. It was true the problem had been made the subject of general theoretical investigation by various eminent mathematicians, notably by Professor Rankine and Mr. William Froude, and of special experimental research by various engineers.

As examples of the latter may be mentioned the extended series of investigations on the French vessel, "Pelican," and the series made by Mr. Isherwood on a steamlaunch about 1874.

These experiments, however, such as they were, did little to bring out general facts and to reduce the subject to a practical analysis.

Since the date of Mr. Marshall's paper, the literature on this subject has grown rapidly, and has been almost entirely of a practical character. The screw has been made the subject of most careful experiments. One of the earliest extensive series of experiments was made under the writer's direction in 1881 with a large number of models, the primary object being to determine what value there was in a few of the various twists which inventive ingenuity can give to a screw blade. The results led the experimenters to the conclusion that in free water such twists and curves are valueless as serving to augment efficiency. The experiments were then carried further with a view to determine quantitative moduli for the resistance of screws with different ratios of pitch to diameter, or "pitch ratios;" and afterwards with different ratios of surface to the area of the circle described by the tips of the blades or "surface ratios." As these results have to some extent been analysed and published, no further reference need be made to them now. In 1886 Mr. R. E. Froude published in the Transactions of the Institution of Naval Architects (page 250) the deductions drawn from an extensive series of trials made with four models of similar form and equal diameter, but having different pitch ratios. Mr. S. W. Barnaby has published some of the results of experiments made under the direction of Mr. J. I. Thornycroft; and in his paper read before the Institution of Civil Engineers in 1890 (vol. cii, page 74), he has also put Mr. R. E. Froude's results into a shape more suitable for comparison with practice. Nor ought Mr G. A. Calvert's carefully planned experiments to pass unnoticed, of which an account was given in the Transactions of the Institution of Naval Architects in 1887 (page 303). These experiments were made on rectangular bodies with sections of propeller blade form, moved through the water at various velocities in straight lines, in directions oblique to their plane faces, and from their results an estimate was formed of the resistance of a screw.

One of the most important results deduced from experiments on model screws is that they appear to have practically equal efficiencies throughout a wide range, both in pitch ratio and in surface ratio, so that great latitude is left to the designer in regard to the form of the propeller. Another important feature is that, although these experiments are not a direct guide to the selection of the most efficient propeller for a particular ship, they supply the means of analysing the performances of screws fitted to vessels, and of thus indirectly determining what are likely to be the best dimensions of screw for a vessel of a class whose results are known. Thus a great advance has been made on the old method of trial upon the ship itself, which was the origin of almost every conceivable erroneous view respecting the screw propeller. The fact was lost sight of that any modification in form, dimensions, or proportions, referred only to that particular combination of ship and propeller, or to one similar thereto; and so something like chaos was the result. This, however, need not be the case much longer.

In regard to the material used for propellers, steel has been largely adopted for both solid and loose-bladed screws; but unless protected in some way the tips of the blades are apt to corrode rapidly and become unserviceable. One of the stronger kinds of bronze is often judiciously employed for the blades, in conjunction with a steel boss. Where the first extra expense can be afforded, bronze seems the preferable material; the castings are of a reliable character, and the metal does not rapidly corrode; the bronze blades can therefore with safety be made lighter than steel blades, which favours their springing, and accommodating themselves more readily to the various speeds of the different parts of the wake. This might be expected to result in some slight degree of efficiency, of which, however, the writer has never had the opportunity of satisfactorily determining the exact extent. Instances can be brought forward where bronze blades have been substituted for steel or iron with markedly improved results; but in cases of this kind which the writer has had the opportunity of analysing. the whole improvement might be accounted for by the modified proportions of the screw when in working condition. In other words, both experiment and practical working alike go to show that, although cast-iron and steel blades as usually proportioned are sufficiently stiff to retain their form while at work, bronze blades being made much lighter are not; and the result is that the measured or set pitch is less than that which the blades assume while at work. Some facts relative to this subject have already been given in a recent paper by the writer (North-East Coast Institution of Engineers and Shipbuilders, vol. 7, 1890-1, page 179)

Twin Screws.—The great question of twin-screw propulsion has been put to the test upon a large scale in the mercantile marine, or rather in what would usually be termed the passenger service. While engineers, however, are prepared to admit its advantages so far as greater security from total breakdown is concerned, there is by no means thorough agreement as to whether single or twin screws have the greater propulsive efficiency.

What is required to form a sound judgment upon the whole question is a series of examples of twin and single-screw vessels, each of which is known to be fitted with the most suitable propeller for the type of vessel and speed; and until this information is available, little can be said upon the subject with any certainty.

So far the following large passenger steamers have been fitted with twin screws:—

TABLE 2.

Passenger Steamers fitted with Twin Screws.

Vessels.	Length between perpendiculars.	Beam.	Cylinders, two sets in all cases. Diameters.	Stroke.	Boiler Pressure per sq. inch.	Indicated Horse-Power.
	Feet.	Feet.	Inches.	Inches.	Lbs.	I.H.P.
City of New York / City of Paris	525	63¼	45,71,113	60	150	20,000
Majestic / Teutonic	565	58	43,68,110	60	180	18,000
Normannia	500	57½	40,67,106	66	160	11,500
Columbia	463½	55½	41,66,101	66	160	12,500
Empress of India / Empress of Japan / Empress of China	440	51	32,51,82	54	160	10,125
Orel	415	48	34,54,85	51	160	10,000
Scot	460	54½	34½,57½,92	60	170	11,656

It appears to be a current opinion that the twin-screw arrangement necessitates a greater weight of machinery. This is not necessarily so, however; on the contrary the opportunity is offered for reducing the weight of all those parts of the engines, of which the weight relatively to power is inversely proportional to the revolutions. This can be reduced in the proportion of 1 to $\sqrt{2}$, that is to 71 per cent. of their weight in the single-screw engine; for since approximately the same total disc-area is required in both cases with similarly proportioned propellers, the twins will work at a greater speed of revolution than the single screw.

From a commercial point of view there ought to be littl disagreement as to the advantage of twin screws, so long as the loss of space incurred by the necessity for double tunnels is not important; and for the larger passenger vessels now built for ocean service the disadvantage should not be great. Besides their superiority in the matter of immunity from total break-down, and in greatly diminished weight of machinery, they also offer the opportunity of reducing to some extent its cost.