slightly larger than the Russian boats built by the same firm. She is fitted with twin-screws driven by petroleum motors of 450 H.P., giving a speed of 11 knots on the surface, and electric motors of 200 H.P., giving a speed of 9 knots when submerged. Three 18-in. torpedoes are carried, one bow tube only being provided. In 1908-1909 three larger boats were built at Dantzig, and in 1909- 1910 three of 600 tons displacement at the Germania works. The boats were reported to have made very long sea passages without escort.

*Japan* commenced building “ Holland ” boats in 1905. The first five were 87 ft. in length and 125 tons displacement. Two smaller boats of 86 tons were also built. In 1908 two boats of 320 tons were built at Barrow, and despatched by steamer to Japan; and three similar boats were in 1910 being built in Japan.

In 1894 *Italy* launched the “ Delfino,” a single-screw boat of 105 tons and 150 H.P. The type has not been repeated, but in 1905 a fresh start was made with three boats of the “ Glauco ” type, twin-screw boats of 150 tons on the surface, 175 tons submerged, H.P. on surface 600 to 700, speed 14. knots on surface and 8 knots submerged. In 1908 three similar out larger boats followed, the largest being the “ Foca,” 137 ft. 9 in. long, 14 ft. beam, displacement 175 tons, 900 H.P. and 15 knots speed in surface condition, 225 tons displacement, 200 H.P. and 9 knots when submerged, fitted with two 18-in. torpedo tubes. In 1910 six similar but larger boats were laid down at Spezia.

The increased interest in naval matters in *Austria* is shown by the expenditure on submarines as well as on battleships. In 1907 two boats of the “ Lake ” type 100 ft. long, 250 tons submerged, were laid down at the government dockyard at Pola; between that date and 1910 two boats of modified “ Holland ” type, 138 ft. long, 300 tons submerged and 12 knots surface speed, were built at Fiume,and two of the “ Germania ” type ordered from Kiel.

The Swedish government began by building a submarine boat, the “ Hojen,” which is understood to have resembled the early "Holland ” designs. In 1910 the “ Hvalen,” a boat similar to the latest Italian submarines, was built for the Swedish government by the Fiat San Giorgio Company at Spezia, and acquired some notoriety by making the voyage from Spezia to Stockholm without escort, including a longest run of about 700 m. from Spezia to Cartagena.

The "Dykkeren,” a submarine of the “ Laurenti ” type, but entirely electrically propelled both at the surface and submerged, was built by the Fiat San Giorgio Company at Spezia for the Danish government in 1909. She is credited with a maximum speed of 12 knots on the surface and 8 knots submerged, but, depending entirely on the energy stored in electric accumulators, her radius of action is necessarily restricted.

*Fleet Auxiliaries.—*Various types of auxiliaries are provided in the principal navies to perform services of a supplementary, though frequently important character. In many cases fighting vessels of the older classes have been converted and adapted as well as is practicable for these services, but in other cases new vessels have been built or arrangements made with owners of suitable merchant ships for the adaptation and use of those ships when required by the navies. Amongst such auxiliaries the following arc found in the British navy:—*Mine-laying vessels—*second-class cruisers of the Apollo class modified for the purpose; *fleet-repair ships—*the modified merchant-built vessels "Assistance ” of 9600 tons dis­placement and the “Cyclops” of 11,300 tons; *distilling vessel— "*Aquarius ” of 3660 tons, a modified merchant vessel, and a large number of *tank vessels* such as the “ Provider ” of 395 tons, specially built for distributing fresh water; *depot and repair ships for destroyers—*the modified cruisers "Blake," “ Blenheim,” “ Leander ” and “St George,” and the modified merchant vessels “ Hecla” and “Tyne”; *depot ships for submarines—*the modified cruisers "Bonaventure,” “ Thames,” &c., and the repair ship “ Vulcan,” as well as a new vessel the “ Maidstone,” of 3600 tons, laid down at Scott’s Yard, Greenock, in 1910; *oil tank vessels*—the merchant built vessels “ Petroleum,” of 9900 tons and “ Kharki ” of 1430 tons, and a new vessel, the "Burma ” of 3870 tons, laid down at the Greenock Dockyard Co.’s Yard in 1910. The *hospital ship* “ Maine ” of 4540 tons was fitted up for service of the United States in the Spanish-American War, and was presented to the British government in 1901 by the Atlantic Transport Co.

Besides the foregoing, arrangements are made for fitting up fast vessels such as the "Mauretania ” and “ Lusitania ” with a number of 6-in. or other Q.F. guns for service as merchant cruisers in time of war, when they would be used as ocean-going scouts, or for the protection of trade routes. Corresponding arrangements are made by several other countries, while in Russia and Japan special mercantile cruisers have been built under the title of Volunteer steamers. A full account of the Russian Volunteer Fleet is to be found in a paper read by Mr H. Rowell at the Institute of Naval Architects 1905, later vessels being described in *Engineering,* 11th March 1910, and an account of the Japanese Volunteer vessels will be found in *International Marine Engineering,* June 1909. The writer is indebted to Mr J. H. Narbeth, M.V.O., for valuable assistance in preparing this article. (P. Wa.)

SHIPBUILDING. When ships were built of wood and propelled by sails their possible size and proportions were limited by the nature of the structural material, while the type of structure had been evolved by long experience and was incapable of any radical modification. Speed depended so much on circumstances independent of the design of the vessel, such as the state of the wind and sea, that it was impossible to include a definite speed over a voyage or measured distance as one of the essential requirements of a design; and the speed actually obtainable was low even under the most favourable conditions when judged by modern standards. Stability depended principally on the amount of ballast carried, and this was determined experimentally after the completion of the vessel. Under these conditions there was no room for any striking originality of design. One vessel followed so closely on the lines of another, that the qualities of the new ship could be determined for all practical purposes by the performance of an almost identical vessel in the past. The theoretical science of shipbuilding, the object of which is to establish quantitative relations between the behaviour and performance of the ship and the variations in design causing them, was generally neglected.

With the introduction of iron, and later of steel, as a structural material for the hulls of ships, and of heat engines for their propulsion, the possible variation of size, proportions and propelling power of ships was enormously increased. In order to make the fullest use of these new possibilities, and to adapt each ship, as closely as may be, to the special purpose for which it is intended, theoretic knowledge has become of paramount im­portance to the designer. He has been forced to investigate closely those branches of the abstract physical sciences that bear specially on ships and their behaviour, and these mathe­matical and experimental investigations constitute the study of Theoretical Shipbuilding. It embraces the consideration of problems and questions upon which the qualities of a ship depend and which determine the various features of the design, having regard to the particular services that the ship will be required to perform; *i.e.* the requirements that must be fulfilled in order that she may make her various passages economically and with safety in all conditions of wind and sea, the best form for the hull with regard to the resistance offered by the water and the engine power requisite in order to attain the speed desired, the nature of waves and their action upon the ship, and the structural arrangements necessary in order that she may be sufficiently strong to withstand the various stresses to which she will be subjected. The determination of the most suitable dimensions to fulfil certain conditions involves the consideration of a different set of circumstances for almost every service; and here the experience gained in vessels of similar type, together with the known effect of modifications made to fulfil new conditions of each particular design, can be used as a guide. The requirements of economical working, safety, &c., determine the length, breadth, depth and form. The length has a most important bearing on the economy of power with which the speed is obtained ; and on the breadth, depth and height of side, or freeboard, depend to an important degree the stability and seaworthiness of the vessel.

While, however, the importance to the ship designer of mathe­matical theories based on first principles and experiment can hardly be overrated, it should be observed that the circumstances and conditions postulated are invariably much less complex than those which surround actual ships. The applicability of the theories depends on the closeness with which the assumed circumstances are realized in practice. The ultimate guide in the design of new ships must, therefore, still remain practical experience. To this experience theory is a powerful assistance, but can by no means replace it.

Theoretical Shipbuilding

Stability.

When a ship floats at rest in still water, the forces acting upon her must be in equilibrium. These consist of the weight of the