THE DOVER MEETING OF THE BRITISH ASSOCIATION.

THE final meeting of the general committee of the British Association was held on Wednesday in last week, for the purpose of receiving the report of the committee of recommendations. The list of grants made for various scientific purposes has already been given (p. 496). The committee also recommended that, in view of the opportunities of ethnographic inquiry which will be presented by the Indian census now beginning, the council of the Association be requested to urge the Government of India to make use of the census officers to obtain information with reference to particular races and tribes, and to attach photographers to the census officers to furnish a complete photographic series of typical specimens of the various races, of views of archaic industries, and of other facts interesting to ethnologists. This recommendation was accepted and ordered to be forwarded to the council. It was also resolved that the council be requested to recommend to Her Majesty's Government the importance of giving more prominence to botany in the training of Indian forest officers.

At the concluding general meeting of the Association, held on Wednesday, September 20, it was announced that the number of tickets issued was 1403. The usual votes of thanks were then put to the meeting and passed.

Sir G. G. Stokes proposed :—"That the best thanks of the Association be given to the Mayor and Corporation, to the local committee, and to the officers of the local sub-committees for their reception of the Association." Prof. Forsyth, in seconding the resolution, said that they should all carry away grateful recollections of the way in which they had been treated at Dover, and if the meeting had not been the largest it had certainly been very pleasant and highly successful.

The two local secretaries, Colonel Knocker and Mr. W. H. Pendlebury, responded for the local committee.

Sir John Evans proposed a vote of thanks to the President, Council, and Headmaster of Dover College for putting the college buildings at the service of the Association. In seconding the resolution Sir W. Thiselton-Dyer expressed, on behalf of the members of the Association, gratitude to the municipality and inhabitants of Dover for the reception which they had given to the Association. Some of the work this year had been of quite exceptional importance.

The Headmaster of Dover College (the Rev. W. C. Compton) acknowledged the vote of thanks.

Sir Norman Lockyer proposed a vote of thanks to Captain Winslow and the other officers of Her Majesty's ships, to Major-General Sir Leslie Rundle and Staff, and to all the inhabitants who had entertained members or conducted excursions, and to the heads of firms who had thrown open their works. He remarked that the fact that this vote of thanks included officers of Her Majesty's Navy and Army gave distinction to a meeting which otherwise had a distinctive character. For the first time members of the Association had met in the Sections together with French *confrères*, and the visit of the French Association had been marked by many little incidents showing a kindly feeling, which was national rather than local.

Sir W. H. White seconded the resolution, and Dr. Sebastian Evans briefly responded.

Sir John Murray moved that a cordial vote of thanks be given to Sir Michael Foster for his services as president of the Dover meeting.

Sir A. Binnie, in seconding the resolution, said that the success of this meeting was largely due to the tact and urbanity of the president. Sir Michael Foster in a few words acknowledged the compliment, and then declared the meeting adjourned till next September at Bradford.

On Wednesday afternoon the Mayor and Corporation of Canterbury received and entertained at luncheon the president and some of the chief officers of the Association, together with the president, Dr. Brouardel, and about a hundred members of l'Association française pour l'avancement des sciences.

A brief toast list followed the luncheon. The Queen and the President of the French Republic having been successively proposed from the chair, Dean Farrar gave "Our Guests and Success to the British and French Associations for the Advancement of Science," coupling with it the names of the presidents of the two Associations. In the course of his remarks he said there was no means of human knowledge which the human mind could devote itself to study with more profit or advantage than the knowledge of science. It was right to do honour to those whose efforts had illuminated darkness, removed ignorance and extended man's horizon.

Dr. Brouardel and Sir Michael Foster responded.

On Thursday, September 21, the president, officials and about three hundred members of the British Association proceeded from Dover to Boulogne to return the visit of the French Association. From the *Times* report we learn that at Boulogne they were received by leading members of the French Association, who entertained them to breakfast, and afterwards they were officially welcomed at the Town Hall by the Mayor of Boulogne. Later in the day they were entertained at a banquet in the ball-room of the casino by the municipality of the town, and speeches of compliment and welcome were delivered by the Prefect of the Pas de Calais, the Director of Primary Education as delegate of the French Government, Sir Michael Foster and Dr. Brouardel. Special commemorative medals were presented by the French Association to their president and Sir M. Foster. Subsequently the visitors were present at the unveiling of a monument of Dr. Duchesne—who died about twenty-five years ago and was distinguished by his application of electricity to nervous disorders—and of a black marble plaque upon the house in which Thomas Campbell, the poet (who devoted much time and attention to many public matters, including the University of London), died at Boulogne in 1844.

No account of the meeting which has just been concluded would be complete without a reference to two sermons on "Some of the Mutual Influences of Theology and the Natural Sciences," preached in St. Mary's Church for members of the Association by the Ven. J. M. Wilson, Archdeacon of Manchester. The enlarged conception of the study of theology, as presented by Archdeacon Wilson, will be made the subject of deep consideration by many thoughtful minds; and men of science cannot but be gratified at the liberal spirit which permeated it. No longer is it asserted that the methods and results of theology and science are antagonistic, but rather that the two exert beneficial influences upon each other, and that the scientific method should be applied to theological research. The expression of such rational views should do much to overcome the prejudice which still exists against scientific habits of thought, and to create sympathy between men engaged in advancing natural and theological knowledge. The common meeting ground is the search for truth, so far as the human mind can follow it.

SECTION E.

GEOGRAPHY.

OPENING ADDRESS BY SIR JOHN MURRAY, K.C.B., F.R.S., LL.D., PRESIDENT OF THE SECTION.

IN his opening Address to the members of the British Association at the Ipswich meeting, the President cast a retrospective glance at the progress that had taken place in the several branches of scientific inquiry from the time of the formation of the Association in 1831 down to 1895, the year in which were published the last two of the fifty volumes of Reports containing the scientific results of the voyage of H.M.S. *Challenger*. In that very able and detailed review there is no reference whatever to the work of the numerous expeditions which had been fitted out by this and other countries for the exploration of the depths of the sea, nor is there any mention of the great advance in our knowledge of the ocean during the period of sixty-five years then under consideration. This omission may be accounted for by the fact that, at the time of the formation of the British Association, knowledge concerning the ocean was, literally speaking, superficial. The study of marine phenomena had hitherto been almost entirely limited to the surface and shallow waters of the ocean, to the survey of coasts and of oceanic routes directly useful for commercial purposes. Down to that time there had been no systematic attempts to ascertain the physical and biological conditions of those regions of the earth's surface covered by the deeper waters of the ocean; indeed, most of the apparatus necessary for such investigations had not yet been invented.

The difficulties connected with the exploration of the greater depths of the sea arise principally from the fact that, in the majority of cases, the observations are necessarily indirect. At the surface of the ocean direct observation is possible, but our knowledge of the conditions prevailing in deep water, and of all that is there taking place, is almost wholly dependent on the correct working of instruments, the action of which at the critical moment is hidden from sight.

It was the desire to establish telegraphic communication between Europe and America that gave the first direct impulse to the scientific exploration of the great ocean-basins, and at the present day the survey of new cable routes still yields each year a large amount of accurate knowledge regarding the floor of the ocean. Immediately before the *Challenger* Expedition there was a marked improvement in all the apparatus used in marine investigations, and thus during the *Challenger* Expedition the great ocean-basins were for the first time systematically and successfully explored. This expedition, which lasted for nearly four years, was successful beyond the expectations of its promoters, and opened out a new era in the study of oceanography. A great many sciences were enriched by a grand accumulation of new facts. Large collections were sent and brought home, and were subsequently described by specialists belonging to almost every civilised nation. Since the *Challenger* Expedition there has been almost a revolution in the methods employed in deep-sea observations. The most profound abysses of the ocean are now being everywhere examined by sailors and scientific men with increasing precision, rapidity and success.

The recognition of oceanography as a distinct branch of science may be said to date from the commencement of the *Challenger* investigations. The fuller knowledge we now possess about all oceanic phenomena has had a great modifying influence on many general conceptions as to the nature and extent of those changes which the crust of the earth is now undergoing and has undergone in past geological times. Our knowledge of the ocean is still very incomplete. So much has, however, already been acquired that the historian will, in all probability, point to the oceanographical discoveries during the past forty years as the most important addition to the natural knowledge of our planet since the great geographical voyages associated with the names of Columbus, Da Gama, and Magellan, at the end of the fifteenth and the beginning of the sixteenth centuries.

It is not my intention on this occasion to attempt anyth ng like a general review of the present state of oceanographic science. But, as nearly all the samples of marine deposits collected during the past thirty years have passed through my hands, I shall endeavour briefly to point out what, in general, their detailed examination teaches with respect to the present condition of the floor of the ocean, and I will thereafter indicate what appears to me to be the bearing of some of these results on speculations as to the evolution of the existing surface features of our planet.

Depth of the Ocean.

All measurements of depth, by which we ascertain the relief of that part of the earth's crust covered by water, are referred to the sea-surface; the measurements of height on the land are likewise referred to sea-level. It is admitted that the ocean has a very complicated undulating surface, in consequence of the attraction which the heterogeneous and elevated portions of the lithosphere exercise on the liquid hydrosphere. In the opinion of geodesists the geoid may in some places depart from the figure of the spheroid by 1000 feet. Still it is not likely that this surface of the geoid departs so widely from the mean ellipsoidal form as to introduce a great error into our estimates of the elevations and depressions on the surface of the lithosphere.

The soundings over the water-surface of the globe have accumulated at a rapid rate during the past fifty years. In the shallow water, where it is necessary to know the depth for purposes of navigation, the soundings may now be spoken of as innumerable; the 100-fathom line surrounding the land can therefore often be drawn in with much exactness. Compared with this shallow-water region, the soundings in deep water beyond the 100-fathom line are much less numerous; each year, however, there are large additions to our knowledge. Within the last decade over ten thousand deep soundings have been taken by British ships alone. The deep soundings are scattered over the different ocean-basins in varying proportions, being now most numerous in the North Atlantic and South-west Pacific, and in these two regions the contour-lines of depth may be drawn in with greater confidence than in the other divisions of the great ocean-basins. It may be pointed out that 659 soundings taken quite recently during cable surveys in the North Atlantic, although much closer together than is usually the case, and yielding much detailed information to cable engineers, have, from a general point of view, necessitated but little alteration in the contour-lines drawn on the *Challenger* bathymetrical maps published in 1895. Again, the recent soundings of the German s.s. *Valdivia* in the Atlantic, Indian, and Southern Oceans have not caused very great alteration in the positions of the contour-lines on the *Challenger* maps, if we except one occasion in the South Atlantic when a depth of 2000 fathoms was expected and the sounding machine recorded a depth of only 536 fathoms, and again in the great Southern Ocean when depths exceeding 3000 fathoms were obtained in a region where the contour-lines indicated between 1000 and 2000 fathoms. This latter discovery suggests that the great depth recorded by Ross to the south-east of South Georgia may not be very far from the truth.

I have redrawn the several contour-lines of depth in the great ocean-basins, after careful consideration of the most recent data, and these may now be regarded as a somewhat close approximation to the actual state of matters, with the possible exception of the great Southern and Antarctic Oceans, where there are relatively few soundings, but where the projected Antarctic Expeditions should soon be at work. On the whole, it may be said that the general tendency of recent soundings is to extend the area with depths greater than 1000 fathoms, and to show that numerous volcanic cones rise from the general level of the floor of the ocean-basins up to various levels beneath the sea-surface.

The areas marked out by the contour-lines of depth are now estimated as follows:—

	Fms.	Sq. geo. m.	Per cent.
Between the shore and	100	... 7,000,000	... (or 7 of the sea-bed)
,, 100 ,,	1000	... 10,000,000	... (or 10 ,, ,,)
,, 1000 ,,	2000	... 22,000,000	... (or 21 ,, ,,)
,, 2000 ,,	3000	... 57,000,000	... (or 55 ,, ,,)
Over 3000 fathoms	...	... 7,000,000	... (or 7 ,, ,,)
		103,000,000	100

From these results it appears that considerably more than half of the sea-floor lies at a depth exceeding 2000 fathoms, or over two geographical miles. It is interesting to note that the area within the 100-fathom line occupies 7,000,000 square geographical miles, whereas the area occupied by the next succeeding 900 fathoms (viz. between 100 and 1000 fathoms) occupies only 10,000,000 square geographical miles. This points to a relatively rapid descent of the sea-floor along the continental slopes between 100 and 1000 fathoms, and therefore confirms the results gained by actual soundings in this region, many of which indicate steep inclines or even perpendicular cliffs. Not only are the continental slopes the seat of many deposit-slips and seismic disturbances, but Mr. Benest has given good reasons for believing that underground rivers sometimes enter the sea at depths beyond 100 fathoms, and there bring about sudden changes in deep water. Again, the relatively large area covered by the continental shelf between the shore-line and 100 fathoms points to the wearing away of the land by current and wave action.

On the *Challenger* charts all areas where the depth exceeds

3000 fathoms have been called "Deeps," and distinctive names have been conferred upon them. Forty-three such depressions are now known, and the positions of these are shown on the map here exhibited; twenty-four are situated in the Pacific Ocean, three in the Indian Ocean, fifteen in the Atlantic Ocean, and one in the Southern and Antarctic Oceans. The area occupied by these thirty-nine deeps is estimated at 7,152,000 square geographical miles, or about 7 per cent. of the total water-surface of the globe. Within these deeps over 250 soundings have been recorded, of which twenty-four exceed 4000 fathoms, including three exceeding 5000 fathoms.

Depths exceeding 4000 fathoms (or four geographical miles) have been recorded within eight of the deeps, viz. in the North Atlantic within the Nares Deep; in the Antarctic within the Ross Deep; in the Banda Sea within the Weber Deep; in the North Pacific within the Challenger, Tuscarora, and Supau Deeps; and in the South Pacific within the Aldrich and Richards Deeps. Depths exceeding 5000 fathoms have been hitherto recorded only within the Aldrich Deep of the South Pacific, to the east of the Kermadecs and Friendly Islands, where the greatest depth is 5155 fathoms, or 530 feet more than five geographical miles, being about 2000 feet more below the level of the sea than the summit of Mount Everest in the Himalayas is above it. The levels on the surface of the lithosphere thus oscillate between the limits of about ten geographical miles (more than eighteen kilometres).

Temperature of the Ocean-floor.

Our knowledge of the temperature on the floor of the ocean is derived from observations in the layers of water immediately above the bottom by means of deep-sea thermometers, from the electric resistance of telegraph cables resting on the bed of the great ocean-basins, and from the temperature of large masses of mud and ooze brought up by the dredge from great depths. These observations are now sufficiently numerous to permit of some general statements as to the distribution of temperature over the bottom of the great oceans.

All the temperatures recorded up to the present time in the sub-surface waters of the open ocean indicate that at a depth of about 100 fathoms seasonal variation of temperature disappears. Beyond that depth there is a constant, or nearly constant, temperature at any one place throughout the year. In some special positions, and under some peculiar conditions, a lateral shifting of large bodies of water takes place on the floor of the ocean at depths greater than 100 fathoms. This phenomenon has been well illustrated by Prof. Libbey off the east coast of North America, where the Gulf Stream and Labrador Current run side by side in opposite directions. This lateral shifting cannot, however, be called seasonal, for it appears to be effected by violent storms, or strong off-shore winds bringing up colder water from considerable depths to supply the place of the surface drift, so that the colder water covers stretches of the ocean's bed which under normal conditions are overlaid by warmer strata of water. Sudden changes of temperature like these cause the destruction of innumerable marine animals, and produce very marked peculiarities in the deposits over the areas thus affected.

It is estimated that 92 per cent. of the entire sea-floor has a temperature lower than 40° F. This is in striking contrast to the temperature prevailing at the surface of the ocean, only 16 per cent. of which has a mean temperature under 40° F. The temperature over nearly the whole of the floor of the Indian Ocean in deep water is under 35° F. A similar temperature occurs over a large part of the South Atlantic and certain parts of the Pacific, but at the bottom of the North Atlantic basin and over a very large portion of the Pacific the temperature is higher than 35° F. In depths beyond 2000 fathoms, the average temperature over the floor of the North Atlantic is about 2° F. above the average temperature at the bottom of the Indian Ocean and South Atlantic, while the average temperature of the bed of the Pacific is intermediate between these.

It is admitted that the low temperature of the deep sea has been acquired at the surface in Polar and sub-Polar regions, chiefly within the higher latitudes of the southern hemisphere, where the cooled surface water sinks to the bottom and spreads slowly over the floor of the ocean into equatorial regions. These cold waters carry with them into the deep sea the gases of the atmosphere, which are everywhere taken up at the surface according to the known laws of gas absorption. In this way myriads of living animals are enabled to carry on their existence at all depths in the open ocean. The nitrogen remains more or less constant at all times and places, but the proportion of oxygen is frequently much reduced in deep water, owing to the processes of oxidation and respiration which are there going on.

The deep sea is a region of darkness as well as of low temperature, for the direct rays of the sun are wholly absorbed in passing through the superficial layers of water. Plant-life is in consequence quite absent over 93 per cent. of the bottom of the ocean, or 66 per cent. of the whole surface of the lithosphere. The abundant deep-sea fauna, which covers the floor of the ocean, is therefore ultimately dependent for food upon organic matter assimilated by plants near its surface, in the shallower waters near the coast-lines, and on the surface of the dry land itself.

As has been already stated, about 7,000,000 square geographical miles of the sea-floor lies within the 100-fathom line, and this area is in consequence subject to seasonal variations of temperature, to strong currents, to the effects of sunlight, and presents a great variety of physical conditions. The planktonic plant-life is here reinforced by the littoral sea-weeds, and animal-life is very abundant. About 40 per cent. of the water over the bottom of this shallow-water area has a mean temperature under 40° F., while 20 per cent. has a mean temperature between 40° and 60° F., and 40 per cent. a temperature of over 60° F.

It follows from this that only 3 per cent. of the floor of the ocean presents conditions of temperature favourable for the vigorous growth of corals and those other benthonic organisms which make up coral reefs and require a temperature of over 60° F. all the year round. On the other hand, more than half of the surface of the ocean has a temperature which never falls below 60° F. at any time of the year. In these surface-waters with a high temperature, the shells of Pelagic Molluscs, Foraminifera, Algæ, and other planktonic organisms are secreted in great abundance, and fall to the bottom after death.

It thus happens that, at the present time, over nearly the whole floor of the ocean we have mingled in the deposits the remains of organisms which had lived under widely different physical conditions, since the remains of organisms which lived in tropical sunlight, and in water at a temperature above 80° F., all their lives, now lie buried in the same deposit on the sea-floor together with the remains of other organisms which lived all their lives in darkness and at a temperature near to the freezing point of fresh water.

Marine Deposits on the Ocean-floor.

The marine deposits now forming over the floor of the ocean present many interesting peculiarities according to their geographical and bathymetrical position. On the continental shelf, within the 100-fathom line, sands and gravels predominate, while on the continental slopes beyond the 100-fathom line, Blue Muds, Green Muds, and Red Muds, together with Volcanic Muds and Coral Muds, prevail, the two latter kinds of deposits being, however, more characteristic of the shallow water around oceanic islands. The composition of all these Terrigenous Deposits depends on the structure of the adjoining land. Around continental shores, except where coral reefs, limestones, and volcanic rocks are present, the materials consist principally of fragments and minerals derived from the disintegration of the ancient rocks of the continents, the most characteristic and abundant mineral species being quartz. River detritus extends in many instances far from the land, while off high and bold coasts, where no large rivers enter the sea, pelagic conditions may be found in somewhat close proximity to the shore-line. It is in these latter positions that Green Muds containing much glauconite, and other deposits containing many phosphatic nodules, have for the most part been found; as, for instance, off the eastern coast of the United States, off the Cape of Good Hope, and off the eastern coasts of Australia and Japan. The presence of glauconitic grains and phosphatic nodules in the deposit at these places appears to be very intimately associated with a great annual range of temperature in the surface and shallow waters, and the consequent destruction of myriads of marine animals. As an example of this phenomenon may be mentioned the destruction of the tile-fish in the spring of 1882 off the eastern coast of North America, when a layer six feet in thickness of dead fish and other marine animals was believed to cover the ocean floor for many square miles.

In all the Terrigenous Deposits the evidences of the mechanical action of tides, of currents, and of a great variety of physical conditions, may almost everywhere be detected, and it is possible to recognise in these deposits an accumulation of materials analogous to many of the marine stratified rocks of the continents, such as sandstones, quartzites, shales, marls, greensands, chalks, limestones, conglomerates, and volcanic grits.

With increasing depth and distance from the continents the deposits gradually lose their terrigenous character, the particles derived directly from the emerged land decrease in size and in number, the evidences of mechanical action disappear, and the deposits pass slowly into what have been called Pelagic Deposits at an average distance of about 200 miles from continental coast-lines. The materials composing Pelagic Deposits are not directly derived from the disintegration of the continents and other land-surfaces. They are largely made up of the shells and skeletons of marine organisms secreted in the surface waters of the ocean, consisting either of carbonate of lime, such as Pelagic Molluscs, Pelagic Foraminifera, and Pelagic Algæ, or of silica, such as Diatoms and Radiolarians. The inorganic constituents of the Pelagic Deposits are for the most part derived from the attrition of floating pumice, from the disintegration of water-logged pumice, from showers of volcanic ashes, and from the débris ejected from submarine volcanoes, together with the products of their decomposition. Quartz particles, which play so important a *rôle* in the Terrigenous Deposits, are almost wholly absent, except where the surface waters of the ocean are affected by floating ice, or where the prevailing winds have driven the desert sands far into the oceanic areas. Glauconite is likewise absent from these abysmal regions. The various kinds of Pelagic Deposits are named according to their characteristic constituents, Pteropod Oozes, Globigerina Oozes, Diatom Oozes, Radiolarian Oozes, and Red Clay.

The distribution of the deep-sea deposits over the floor of the ocean is shown on the map here exhibited, but it must be remembered that there is no sharp line of demarcation between them; the Terrigenous pass gradually into the Pelagic Deposits, and the varieties of each of these great divisions also pass insensibly the one into the other, so that it is often difficult to fix the name of a given sample.

On another map here exhibited the percentage distribution of carbonate of lime in the deposits over the floor of the ocean has been represented, the results being founded on an extremely large number of analyses. The results are also shown in the following table:—

		Sq. Geo. Miles.	Percentage.
Over 75% $CaCO_3$	...	6,000,000	5·8
50 to 75% ,,	...	24,000,000	23·2
25 to 50% ,,	...	14,000,000	13·5
Under 25% ,,	...	59,000,000	57·5
		103,000,000	100

The carbonate of lime shells derived from the surface play a great and puzzling *rôle* in all deep-sea deposits, varying in abundance according to the depth of the ocean and the temperature of the surface waters. In tropical regions removed from land, where the depths are less than 600 fathoms, the carbonate of lime due to the remains of these organisms from the surface may rise to 80 or 90 per cent.; with increase of depth, and under the same surface conditions, the percentage of carbonate of lime slowly diminishes, till, at depths of about 2000 fathoms, the average percentage falls to about 60, at 2400 fathoms to about 30, and at about 2600 fathoms to about 10, beyond which depth there may be only traces of carbonate of lime due to the presence of surface shells. The thin and more delicate surface shells first disappear from the deposits, the thicker and denser ones alone persist to greater depths. A careful examination of a large number of observations shows that the percentage of carbonate of lime in the deposits falls off much more rapidly at depths between 2200 and 2500 fathoms than at other depths.

The Red Clay, which occurs in all the deeper stretches of the ocean far from land, and covers nearly half of the whole sea-floor, contains—in addition to volcanic débris, clayey matter, the oxides of iron and manganese—numerous remains of whales, sharks and other fishes, together with zeolitic crystals, manganese nodules, and minute magnetic spherules, which are believed to have a cosmic origin. One hawl of a small trawl in the Central Pacific brought to the surface on one occasion, from a depth of about two and a half miles, many bushels of manganese nodules, along with fifteen hundred sharks' teeth, over fifty fragments of earbones and other bones of whales. Some of these organic remains, such as the *Carcharodon* and *Lamna* teeth and the bones of the Ziphioid whales, belong apparently to extinct species. One or two of these sharks' teeth, earbones, or cosmic spherules, may be occasionally found in a Globigerina Ooze, but their occurrence in this or any deposits other than Red Clay is extremely rare.

Our knowledge of the marine deposits is limited to the superficial layers; as a rule, the sounding-tube does not penetrate more than six or eight inches, but in some positions the sounding-tube and dredge have been known to sink fully two feet into the deposit. Sometimes a Red Clay is overlaid by a Globigerina Ooze, more frequently a Red Clay overlies a Globigerina Ooze, the transition between the two layers being either abrupt or gradual. In some positions it is possible to account for these layers by referring them to changes in the condition of the surface waters, but in other situations it seems necessary to call in elevations and subsidences of the sea-floor.

If the whole of the carbonate of lime shells be removed by dilute acid from a typical sample of Globigerina Ooze, the inorganic residue left behind is quite similar in composition to a typical Red Clay. This suggests that possibly, owing to some hypogene action, such as the escape of carbonic acid through the sea-floor, a deposit that once was a Globigerina Ooze might be slowly converted into a Red Clay. However, this is not the interpretation which commends itself after an examination of all the data at present available; a consideration of the rate of accumulation probably affords a more correct interpretation. It appears certain that the Terrigenous Deposits accumulate much more rapidly than the Pelagic Deposits. Among the Pelagic Deposits, the Pteropod and Globigerina Oozes of the tropical regions, being made up of the calcareous shells of a much larger number of tropical species, apparently accumulate at a greater rate than the Globigerina Oozes in extra-tropical areas. Diatom Ooze being composed of both calcareous and siliceous organisms, has again a more rapid rate of deposition than Radiolarian Ooze. In Red Clay the minimum rate of accumulation takes place. The number of sharks' teeth, of earbones and other bones of Cetaceans and of cosmic spherules in a deposit may indeed be taken as a measure of the rate of deposition. These spherules, teeth and bones are probably more abundant in the Red Clays, because few other substances there fall to the bottom to cover them up, and they thus form an appreciable part of the whole deposit. The volcanic materials in a Red Clay having, because of the slow accumulation, been for a long time exposed to the action of sea-water, have been profoundly altered. The massive manganese-iron nodules and zeolitic crystals present in the deposit are secondary products arising from the decomposition of these volcanic materials, just as the formation of glauconite, phosphatic, and calcareous and barytic nodules accompanies the decomposition of terrigenous rocks and minerals in deposits nearer continental shores. There is thus a striking difference between the average chemical and mineralogical composition of Terrigenous and Pelagic Deposits.

It would be extremely interesting to have a detailed examination of one of those deep holes where a typical Red Clay is present, and even to bore some depth into such a deposit if possible, for in these positions it is probable that not more than a few feet of deposit have accumulated since the close of the Tertiary period. One such area lies to the south-west of Australia, and its examination might possibly form part of the programme of the approaching Antarctic explorations.

Life on the Ocean-floor.

It has already been stated that plant-life is limited to the shallow waters, but fishes and members of all the invertebrate groups are distributed over the floor of the ocean at all depths. The majority of these deep-sea animals live by eating the mud, clay or ooze, or by catching the minute particles of organic matter which fall from the surface. It is probably not far from the truth to say that three-fourths of the deposits now covering the floor of the ocean have passed through the alimentary canals of marine animals. These mud-eating species, many of which are of gigantic size when compared with their allies living in the shallow coastal waters, become in turn the prey of numerous rapacious animals armed with peculiar prehensile and tactile organs. Some fishes are blind, while others have very large eyes. Phosphorescent light plays a most important *rôle* in the deep sea, and is correlated with the prevailing red and brown colours of deep-sea organisms. Phosphorescent organs appear sometimes to act as a bull's-eye lantern to enable particles of food to be picked up, and at other times as a lure or a warning. All these peculiar adaptations indicate that the struggle for life may be not much less severe in the deep sea than in the shallower waters of the ocean.

Many deep-sea animals present archaic characters; still the deep sea cannot be said to contain more remnants of faunas which flourished in remote geological periods than the shallow and fresh waters of the continents. Indeed, king-crabs, Lingulas, Trigonias, Port Jackson sharks, *Ceratodus*, *Lepidosiren*, and *Protopterus*, probably represent older faunas than anything to be found in the deep sea

Sir Wyville Thomson was of opinion that, from the Silurian period to the present day, there had been as now a continuous deep ocean with a bottom temperature oscillating about the freezing point of fresh water, and that there had always been an abyssal fauna. I incline to the view that in Palæozoic times the ocean-basins were not so deep as they are now; that the ocean then had throughout a nearly uniform high temperature, and that life was either absent or represented only by bacteria and other low forms in great depths, as is now the case in the Black Sea, where life is practically absent beyond 100 fathoms, and where the deeper waters are saturated with sulphuretted hydrogen. This is not, however, the place to enter on speculations concerning the origin of the deep-sea fauna, nor to dwell on what has been called "bipolarity" in the distribution of marine organisms.

Evolution of the Continental and Oceanic Areas.

I have now pointed out what appears to me to be some of the more general results arrived at in recent years regarding the present condition of the floor of the ocean. I may now be permitted to indicate the possible bearing of these results on opinions as to the origin of some fundamental geographical phenomena; for instance, on the evolution of the protruding continents and sunken ocean-basins. In dealing with such a problem much that is hypothetical must necessarily be introduced, but these speculations are based on ascertained scientific facts.

The well-known American geologist, Dutton, says: "It has been much the habit of geologists to attempt to explain the progressive elevation of plateaus and mountain platforms, and also the folding of strata, by one and the same process. I hold the two processes to be distinct, and having no necessary relation to each other. There are plicated regions which are little or not at all elevated, and there are elevated regions which are not plicated." Speaking of great regional uplifts, he says further: "What the real nature of the uplifting force may be is, to my mind, an entire mystery, but I think we may discern at least one of its attributes, and that it is a gradual expansion or a diminution of density of the subterranean magmas. . . . We know of no cause which could either add to the mass or diminish the density, yet one of the two must surely have happened. . . . Hence I infer that the cause which elevates the land involves an expansion of the underlying magmas, and the cause which depresses it is a shrinkage of the magmas; the nature of the process is at present a complete mystery." I shall endeavour to show how the detailed study of marine deposits may help to solve the mystery here referred to by Dutton.

The surface of the globe has not always been as we now see it. When, in the past, the surface had a temperature of about 400° F., what is now the water of the ocean must have existed as water vapour in the atmosphere, which would thereby—as well as because of the presence of other substances—be increased in density and volume. Life, as we know it, could not then exist. Again, science foresees a time when low temperatures, like those produced by Prof. Dewar at the Royal Institution, will prevail over the face of the earth. The hydrosphere and atmosphere will then have disappeared within the rocky crust, or the waters of the ocean will have become solid rock, and over their surface will roll an ocean of liquid air about forty feet in depth. Life, as we know it, unless it undergoes suitable secular modifications, will be extinct. Somewhere between these two indefinite points of time in the evolution of our planet it is our privilege to live, to investigate, and to speculate concerning the antecedent and future conditions of things.

When we regard our globe with the mind's eye, it appears at the present time to be formed of concentric spheres, very like, and still very unlike, the successive coats of an onion. Within is situated the vast nucleus or *centrosphere*; surrounding this is what may be called the *tektosphere* (τηκτός, molten), a shell of materials in a state bordering on fusion, upon which rests and creeps the *lithosphere*. Then follow *hydrosphere* and *atmosphere*, with the included *biosphere* (βίος, life). To the interaction of these six geospheres, through energy derived from internal and external sources, may be referred all the existing superficial phenomena of the planet.

The vast interior of the planetary mass, although not under direct observation, is known, from the results of the astronomer and physicist, to have a mean density of 5·6, or twice that of ordinary surface rock. The substances brought within the reach of observation in veinstones, in lavas, and hypogene rocks—by the action of water as a solvent and sublimant—warrant the belief that the centrosphere is largely made up of metals and metalloids with imprisoned gases. It is admitted that the vast nucleus has a very high temperature, but so enormous is the pressure of the superincumbent crust that the melting point of the substances in the interior is believed to be raised to a higher value than the temperature there existing—the centrosphere in consequence remains solid, for it may be assumed that the melting point of rock-forming materials is raised by increase of pressure. Astronomers, from a study of precession and nutation, have long been convinced that the centrosphere must be practically solid.

Recent seismological observations indicate the transmission of two types of waves through the earth—the condensational-rarefactional and the purely distortional—and the study of these tremors supports the view that the centrosphere is not only solid, but possesses great uniformity of structure. The seismological investigations of Profs. Milne and Knott point also to a fairly abrupt boundary or transition surface, where the solid nucleus passes into the somewhat plastic magma on which the firm upper crust rests.

In this plastic layer or shell—named the *tektosphere*—the materials are most probably in a state of unstable equilibrium and bordering on fusion. Here the loose-textured solids of the external crust are converted into the denser solids of the nucleus or into molten masses, at a critical point of temperature and pressure; deep-seated rocks may in consequence escape through fissures in the lithosphere. Within the lithosphere itself, the temperature falls off so rapidly towards the surface as to be everywhere below the melting point of any substance there under its particular pressure.

Now, as the solid centrosphere slowly contracted from loss of heat, the primitive lithosphere, in accommodating itself—through changes in the tektosphere—to the shrinking nucleus, would be buckled, warped, and thrown into ridges. That these movements are still going on is shown by the fact that the lithosphere is everywhere and at all times in a slight but measurable state of pulsation. The rigidity of the primitive rocky crust would permit of considerable deformations of the kind here indicated. Indeed, the compression of mountain chains has most probably been brought about in this manner, but the same cannot be said of the elevation of plateaus, of mountain platforms, and of continents.

From many lines of investigation it is concluded, as we have seen, that the centrosphere is homogeneous in structure. Direct observation, on the other hand, shows that the lithosphere is heterogeneous in composition. How has this heterogeneity been brought about? The original crust was almost certainly composed of complex and stable silicates, all the silicon dioxide being in combination with bases. Lord Kelvin has pointed out that, when the solid crust began to form, it would rapidly cool over its whole surface; the precipitation of water would accelerate this process, and there would soon be an approximation to present conditions. As time went on the plastic or critical layer—the tektosphere—immediately beneath the crust would gradually sink deeper and deeper, while ruptures and readjustments would become less and less frequent than in earlier stages. With the first fall of rain the silicates of the crust would be attacked by water and carbon dioxide, which can at low temperatures displace silicon dioxide from its combinations. The silicates, in consequence, have been continuously robbed of a part, or the whole of their bases. The silica thus set free goes ultimately to form quartz veins and quartz sand on or about the emerged land, while the bases leached out of the disintegrating rocks are carried out into the ocean and ocean-basins. A continuous disintegration and differentiation of materials of the lithosphere, accompanied by a sort of migration and selection among mineral substances, is thus always in progress. Through the agency of life, carbonate of lime accumulates in one place; through the agency of winds, quartz sand is heaped up in another; through the agency of water, beds of clay, of oxides of iron and of manganese are spread out in other directions.

The contraction of the centrosphere supplies the force which folds and crumples the lithosphere. The combined effect of hydrosphere, atmosphere and biosphere on the lithosphere gives direction and a determinate mode of action to that force. From the earliest geological times the most resistant dust of the continents has been strewn along the marginal belt of the sea-floor skirting the land. At the present time, the deposits over this area contain on the average about 70 per cent. of free and combined silica, mostly in the form of quartz sand. In the abysmal deposits far from land there is an average of only about 30 per cent. of silica, and hardly any of this in the form of quartz sand. Lime, iron and the other bases largely predominate in these abysmal regions. The continuous loading on the margins of the emerged land by deposits tends by increased pressure to keep the materials of the tektosphere in a solid condition immediately beneath the loaded area. The unloading of emerged land tends by relief of pressure to produce a viscous condition of the tektosphere immediately beneath the denuded surfaces. Under the influence of the continuous shakings, tremors and tremblings always taking place in the lithosphere, the materials of the tektosphere yield to the stresses acting on them, and the deep-seated portions of the terrigenous deposits are slowly carried towards, over or underneath the emerged land. The rocks subsequently re-formed beneath continental areas out of these terrigenous materials, under great pressure and in hydrothermal conditions, would be more acid than the rocks from which they were originally derived, and it is well known that the acid silicates have a lower specific gravity than the intermediate or basic ones. By a continual repetition of this process the continental protuberances have been gradually built up of lighter materials than the other parts of the lithosphere. The relatively light quartz, which is also the most refractory, the most stable and the least fusible among rock-forming minerals, plays in all this the principal *rôle*. The average height of the surface of the continents is about three miles above the average level of the abysmal regions. If now we assume the average density of the crust beneath the continents to be 2·5, and of the part beneath the abysmal regions to be 3, then the spheroidal surface of equal pressure—the tektosphere—would have a minimum depth of eighteen miles beneath the continents and fifteen miles beneath the oceans, or if we assume the density of the crust beneath the continents to be 2·5, and beneath the abysmal regions to be 2·8, then the tektosphere would be twenty-eight miles beneath the continents and twenty-five miles beneath the oceans. The present condition of the earth's crust might be brought about by the disintegration of a quantity of quartz-free volcanic rock, covering the continental areas to a depth of eighteen miles, and the re-formation of rocks out of the disintegrated materials.

Where the lighter and more bulky substances have accumulated there has been a relative increase of volume, and in consequence bulging has taken place at the surface over the continental areas. Where the denser materials have been laid down there has been flattening, and in consequence a depression of the abysmal regions of the ocean-basins. It is known that, as a general rule, where large masses of sediment have been deposited, their deposition has been accompanied by a depression of the area. On the other hand, where broad mountain platforms have been subjected to extensive erosion, the loss of altitude by denudation has been made good by a rise of the platform. This points to a movement of matter on to the continental areas.

If this be anything like a true conception of the interactions that are taking place between the various geospheres of which our globe is made up, then we can understand why, in the gradual evolution of the surface features, the average level of the continental plains now stands permanently about three miles above the average level of those plains which form the floor of the deep ocean-basins. We may also understand how the defect of mass under continents and an excess of mass under the oceans have been brought about, as well as deficiency of mass under mountains and excess of mass under plains. Even the local anomalies indicated by the plumb-line, gravity and magnetic observations may in this way receive a rational explanation. It has been urged that an enormous time—greater even than what is demanded by Darwin—would be necessary for an evolution of the existing surface features on these lines. I do not think so. Indeed, in all that relates to geological time I agree, generally speaking, with the physicists rather than with the biologists and geologists.

Progress of Oceanic Research.

I have now touched on some of the problems and speculations suggested by recent deep-sea explorations; and there are many others, equally attractive, to which no reference has been made. It is abundantly evident that, for the satisfactory explanation of many marine phenomena, further observations and explorations are necessary. Happily there is no sign that the interest in oceanographical work has in any way slackened. On the contrary, the number of scientific men and ships engaged in the study of the ocean is rapidly increasing. Among all civilised peoples and in all quarters of the globe the economic importance of many of the problems that await solution is clearly recognised.

We have every reason to be proud of the work continually carried on by the officers and ships attached to the Hydrographic Department of the British Navy. They have surveyed coasts in all parts of the world for the purposes of navigation, and within the past few years have greatly enlarged our knowledge of the sea-bed and deeper waters over wide stretches of the Pacific and other oceans. The samples of the bottom which are procured, being always carefully preserved by the officers, have enabled very definite notions to be formed as to the geographical and bathymetrical distribution of marine deposits.

The ships belonging to the various British telegraph cable companies have done most excellent work in this as well as in other directions. Even during the present year Mr. R. E. Peake has in the s.s. *Britannia* procured 477 deep soundings in the North Atlantic, besides a large collection of deep-sea deposits, and many deep-sea temperature and current observations.

The French have been extending the valuable work of the *Talisman* and *Travailleur*, while the Prince of Monaco is at the present moment carrying on his oceanic investigations in the Arctic Seas with a large new yacht elaborately and specially fitted out for such work. The Russians have recently been engaged in the scientific exploration of the Black Sea and the Caspian Sea, and a special ship is now employed in the investigation of the Arctic fisheries of the Murman coast under the direction of Prof. Knipowitsch. Admiral Makaroff has this summer been hammering his way through Arctic ice, and at the same time carrying on a great variety of systematic observations and experiments on board the *Yermak*—the most powerful and most effective instrument of marine research ever constructed. Mr. Alexander Agassiz has this year recommenced his deep-sea explorations in the Pacific on board the U.S. steamer *Albatross*. He proposes to cross the Pacific in several directions, and to conduct investigations among the Paumotu and other coral island groups. Prof. Weber is similarly employed on board a Dutch man-of-war in the East Indian Seas. The Deutsche Seewarte at Hamburg, under the direction of Dr. Neumayer, continues its praiseworthy assistance and encouragement to all investigators of the ocean, and this year the important German Deep-Sea Expedition, in the s.s. *Valdivia*, arrived home after most successful oceanographical explorations in the Atlantic, Indian and Great Southern Oceans.

The *Belgica* has returned to Europe safely with a wealth of geological and biological collections and physical observations, after spending, for the first time on record, a whole winter among the icefields and icebergs of the Antarctic. Mr. Borchgrevink in December last again penetrated to Cape Adare, successfully landed his party at that point and is now wintering on the Antarctic continent. The expeditions of Lieut. Peary, of Prof. Nathorst, of Captain Sverdrup, and of the Duke of Abruzzi, which are now in progress, may be expected to yield much new information about the condition of the Arctic Ocean. Mr. Wellman has just returned from the north of Franz Josef Land with observations of considerable interest.

Some of the scientific results obtained by the expeditions in the Danish steamer *Ingolf* have lately been published, and these, along with the results of the joint work pursued for many years by the Swedes, Danes and Norwegians, may ultimately have great economic value from their direct bearing on fishery problems and on weather forecasting over long periods of time.

Largely through the influence of Prof. Otto Pettersson, an International Conference assembled at Stockholm a few months ago, for the purpose of deliberating as to a programme of conjoint scientific work in the North Sea and northern parts of the Atlantic, with special reference to the economic aspect of sea-fisheries. A programme was successfully drawn up, and an organisation suggested for carrying it into effect; these proposals are now under the consideration of the several States. The Norwegian Government has voted a large sum of money for building a special vessel to conduct marine investigations of the nature recommended by this conference. It is to be hoped the other North Sea Powers may soon follow this excellent example.

The various marine stations and laboratories for scientific research in all parts of the world furnish each year much new knowledge concerning the ocean. Among our own people the excellent work carried on by the Marine Biological Association, the Irish Fisheries Department, the Scottish Fishery Board, the Lancashire Fisheries Committee, the Cape and Canadian Fisheries Departments, is well worthy of recognition and continued support. Mr. George Murray, Mr. H. N. Dickson, Prof. Cleve, Prof. Otto Pettersson, Mr. Robert Irvine and others have, with the assistance of the officers of the Mercantile Marine, accumulated in recent years a vast amount of information regarding the distribution of temperature and salinity, as well as of the planktonic organisms at the surface of the ocean. The papers by Mr. H. C. Russell on the icebergs and currents of the Great Southern Ocean, and of Mr. F. W. Walker on the density of the water in the Southern Hemisphere, show that the Australian Colonies are taking a practical interest in oceanographical problems.

Proposed Antarctic Explorations.

The great event of the year, from a geographical point of view, is the progress that has been made towards the realisation of a scheme for the thorough scientific exploration in the near future of the whole South Polar region. The British and German Governments have voted or guaranteed large sums of money to assist in promoting this object, and princely donations have likewise been received from private individuals, in this connection the action of Mr. L. W. Longstaff in making a gift of 25,000*l.*, and of Mr. A. C. Harmsworth in promising 5000*l.*, being beyond all praise.

There is an earnest desire among the scientific men of Britain and Germany that there should be some sort of co-operation with regard to the scientific work of the two expeditions, and that these should both sail in 1901, so that the invaluable gain attaching to simultaneous observations may be secured. Beyond this nothing has, as yet, been definitely settled. The members of the Association will presently have an opportunity of expressing their opinions as to what should be attempted by the British expedition, how the work in connection with it should be arranged, and how the various researches in view can best be carried to a successful issue.

I have long taken a deep interest in Antarctic exploration, because such exploration must necessarily deal largely with oceanographical problems, and also because I have had the privilege of studying the conditions of the ocean within both the Arctic and Antarctic circles. In the year 1886 I published an article on the subject of Antarctic Exploration in the *Scottish Geographical Magazine*. This article led to an interesting interview, especially when viewed in the light of after events, for, a few weeks after it appeared in type, a young Norwegian walked into the *Challenger* office in Edinburgh to ask when the proposed expedition would probably start, and if there were any chance of his services being accepted. His name was Nansen.

When at the request of the President I addressed the Royal Geographical Society on the same subject in the year 1893, I made the following statement as to what it seemed to me should be the general character of the proposed exploration: "A dash at the South Pole is not, however, what I advocate, nor do I believe *that* is what British science at the present time desires. It demands rather a steady, continuous, laborious and systematic exploration of the whole southern region with all the appliances of the modern investigator." At the same time I urged further, that these explorations should be undertaken by the Royal Navy in two ships, and that the work should extend over two winters and three summers.

This scheme must now be abandoned, so far at least as the Royal Navy is concerned, for the Government has intimated that it can spare neither ships nor officers, men nor money, for an undertaking of such magnitude. The example of Foreign Powers—rather than the representations from our own scientific men—appears to have been chiefly instrumental in at last inducing the Government to promise a sum of 45,000*l.*, provided that an equal amount be forthcoming from other sources. This resolve throws the responsibility for the financial administration, for the equipment and for the management of this exploration on the representative scientific societies, which have no organisation ready for carrying out important executive work on such an extensive scale. I am doubtful whether this state of matters should be regarded as a sign of increasing lukewarmness on the part of the Government towards marine research, or should rather be looked on as a most unexpected and welcome recognition of the growing importance of science and scientific men to the affairs of the nation. Let us adopt the latter view, and accept the heavy responsibility attached thereto.

Any one who will take the trouble to read, in the *Proceedings* of the Royal Society of London, the account of the discussion which recently took place on "The Scientific Advantages of an Antarctic Expedition," will gather some idea of the number and wide range of the subjects which it is urged should be investigated within the Antarctic area; the proposed researches have to do with almost every branch of science. Unless an earnest attempt be made to approach very near to the ideal there sketched out, widespread and lasting disappointment will certainly be felt among the scientific men of this country. The proposed expedition should not be one of adventure. Not a rapid invasion and a sudden retreat, with tales of hardships and risks, but a scientific occupation of the unknown area by observation and experiment should be aimed at in these days.

I have all along estimated the cost of a well-equipped Antarctic expedition at about 150,000*l.* I see no reason for changing my views on this point at the present time, nor on the general scope of the work to be undertaken by the proposed expedition, as set forth in the papers I have published on the subject. There is now a sum of at most 90,000*l.* in hand, or in view. If one ship should be specially built for penetrating the icy region, and be sent south with one naturalist on board, then such an expedition may, it will be granted, bring back interesting and important results. But it must be distinctly understood that this is not the kind of exploration scientific men have been urging on the British public for the past fifteen or twenty years. We must, if possible, have two ships, with landing parties for stations on shore, and with a recognised scientific leader and staff on board of each ship. Although we cannot have the Royal Navy, these ships can be most efficiently officered and manned from the Mercantile Marine. With only one ship many of the proposed observations would have to be cut out of the programme. In anticipation of this being the case, there are at the present moment irreconcilable differences of opinion among those most interested in these explorations, as to which sciences must be sacrificed.

The difficulties which at present surround this undertaking are fundamentally those of money. These difficulties would at once disappear, and others would certainly be overcome, should the members of the British Association at this meeting agree to place in the hands of their President a sum of 50,000*l.*, so that the total amount available for Antarctic exploration would become something like 150,000*l.* Although there is but one central Government, surely there are within the bounds of this great Empire two more men like Mr. Longstaff. The Government has suddenly placed the burden of upholding the high traditions of Great Britain in marine research and exploration on the shoulders of her scientific men. In their name I appeal to all our well-to-do fellow-countrymen in every walk of life for assistance, so that these new duties may be discharged in a manner worthy of the Empire and of the well-earned reputation of British Science.

SECTION G.

MECHANICAL SCIENCE.

OPENING ADDRESS BY SIR WILLIAM WHITE, K.C.B., LL.D., F.R.S., PRESIDENT OF THE SECTION.

IN this Address it is proposed to review briefly the characteristic features of the progress made in steam navigation; to glance at the principal causes of advance in the speeds of steamships and in the lengths of the voyages on which such vessels can be successfully employed; and to indicate how the experience and achievement of the last sixty years bear upon the prospects of further advance.

There is reason to hope that this choice of subject is not inappropriate. From the beginning of steam navigation the British Association in its corporate capacity, by the appointment of special committees, and by the action of individual members, has greatly assisted the scientific treatment of steamship design. Valuable contributions bearing on the resistance offered by water to the motion of ships, the conduct and analysis of the results of steamship trials, the efficiency of propellers and cognate subjects have been published in the Reports of the Association. Many of these have largely influenced practice, and most of them may be claimed as the work of this Section.

On this occasion no attempt will be made either to summarise or appraise the work that has been done. It must suffice to mention the names of three men to whom naval architects are deeply indebted, and whose labours are ended—Scott Russell, Rankine, and William Froude. Each of them did good work, but to Froude we owe the device and application of the method of model experiment with ships and propellers, by means of which the design of vessels of novel types and unprecedented speeds can now be undertaken with greater confidence than heretofore.

As speeds increase, each succeeding step in the ascending scale becomes more difficult, and the rate of increase in the power to be developed rapidly augments. Looking back on what has been achieved, it is impossible to overrate the courage and skill displayed by the pioneers of steam navigation, who had at first to face the unknown, and always to depend almost entirely on experience gained with actual ships, when they undertook the production of swifter vessels. Their successors of the present day have equal need to make a thorough study of the performances of steamships both in smooth water and at sea. In many ways they have to face greater difficulties than their predecessors, as ships increase in size and speed. On the other hand, they have the accumulated experience of sixty years to draw upon, the benefit of improved methods of trials of steamships, the advantage of scientific procedure in the record and analysis of such trials and the assistance of model experiments.

Steamship design to be successful must always be based on experiment and experience as well as on scientific principles and processes. It involves problems of endless variety and great complexity. The services to be performed by steamships differ in character, and demand the production of many distinct types of ships and propelling apparatus. In all these types, however, there is one common requirement—the attainment of a specified speed. And in all types there has been a continuous demand for higher speed.

Stated broadly, the task set before the naval architect in the design of any steamship is to fulfil certain conditions of speed in a ship which shall not merely carry fuel sufficient to traverse a specified distance at that speed, but which shall carry a specified load on a limited draught of water. Speed, load, power and fuel supply are all related; the two last have to be determined in each case. In some instances other limiting conditions are imposed affecting length, breadth or depth. In all cases there are three separate efficiencies to be considered: those of the ship as influenced by her form; of the propelling apparatus, including the generation of steam in the boilers and its utilisation in the engines; and of the propellers. Besides these considerations, the designer has to take account of the materials and structural arrangements which will best secure the association of lightness with strength in the hull of the vessel. He must select those types of engines and boilers best adapted for the service proposed. Here the choice must be influenced by the length of the voyage, as well as the exposure it may involve to storm and stress. Obviously the conditions to be fulfilled in an ocean-going passenger steamer of the highest speed, and in a cross-Channel steamer designed to make short runs at high speed in comparatively sheltered waters, must be radically different. And so must be the conditions in a swift sea-going cruiser of large size and great coal endurance, from those best adapted for a torpedo boat or destroyer. There is, in fact, no general rule applicable to all classes of steamships: each must be considered and dealt with independently, in the light of the latest experience and improvements. For merchant ships there is always the commercial consideration—Will it pay? For warships there is the corresponding inquiry—Will the cost be justified by the fighting power and efficiency?

Characteristics of Progress in Steam Navigation.

Looking at the results so far attained, it may be said that progress in steam navigation has been marked by the following characteristics:—

(1) Growth in dimensions and weights of ships, and large increase in engine-power, as speeds have been raised.

(2) Improvements in marine engineering accompanying increase of steam pressure. Economy of fuel and reduction in the weight of propelling apparatus in proportion to the power developed.

(3) Improvements in the materials used in shipbuilding; better structural arrangements; relatively lighter hulls and larger carrying power.

(4) Improvements in form, leading to diminished resistance and economy of power expended in propulsion.

These general statements represent well-known facts—so familiar, indeed, that their full significance is often overlooked. It would be easy to multiply illustrations, but only a few representative cases will be taken.

Transatlantic Passenger Steamers.

The Transatlantic service naturally comes first. It is a simple case, in that the distance to be covered has remained practically the same, and that for most of the swift passenger steamers cargo-carrying capacity is not a very important factor in the design.

In 1840 the Cunard steamship *Britannia*, built of wood, propelled by paddle-wheels, maintained a sea-speed of about 8½ knots. Her steam pressure was 12 lbs. per square inch. She was 207 feet long, about 2000 tons in displacement, her engines developed about 750 horse-power, and her coal consumption was about 40 tons per day, nearly 5 lbs. of coal per indicated horse-power per hour. She had a full spread of sail.

In 1871 the White Star steamship *Oceanic* (first of that name) occupied a leading position. She was iron-built, propelled by a screw, and maintained a sea-speed of about 14½ knots. The steam pressure was 65 lbs. per square inch, and the engines were on the compound principle. She was 420 feet long, about 7200 tons in displacement, her engines developed 3000 horse-power, and she burnt about 65 tons of coal per day, or about 2 lbs. per indicated horse-power per hour. She carried a considerable spread of sail.

In 1889 the White Star steamer *Teutonic* appeared, propelled by twin screws and practically with no sail-power. She is steel-built, and maintains a sea-speed of about 20 knots. The steam pressure is 180 lbs. per square inch, and the engines are on the triple expansion principle. She is about 565 feet long, 16,000 tons displacement, 17,000 horse-power indicated, with a coal consumption of about 300 tons a day, or from 1·6 to 1·7 lbs. per indicated horse-power per hour.

In 1894 the Cunard steamship *Campania* began her service, with triple expansion engines, twin screws and no sail-power. She is about 600 feet long, 20,000 tons displacement, develops about 28,000 horse-power at full speed of 22 knots, and burns about 500 tons of coal per day.

The new *Oceanic*, of the White Star Line, is just beginning her work. She is of still larger dimensions, being 685 feet in length and over 25,000 tons displacement. From the authoritative statements made, it appears that she is not intended to exceed 22 knots in speed, and that the increase in size is to be largely utilised in additional carrying power.

The latest German steamers for the Transatlantic service are also notable. A speed of 22½ knots has been maintained by the *Kaiser Wilhelm der Grosse*, which is 25 feet longer than the *Campania*. Two still larger steamers are now building. The *Deutschland* is 660 feet long and 23,000 tons displacement; her engines are to be of 33,000 horse-power, and it is estimated she will average 23 knots. The other vessel is said to be 700 feet long, and her engines are to develop 36,000 horse-power, giving an estimated speed of 23½ knots. All these vessels have steel hulls and twin screws. It will be noted that to gain about three knots an hour nearly 50 per cent. will have been added to the displacement of the *Teutonic*, the engine-power and coal consumption will be doubled, and the cost increased proportionately.

Sixty years of continuous effort and strenuous competition on this great "ocean ferry" may be summarised in the following statement. Speed has been increased from 8½ to 22½ knots; the time on the voyage has been reduced to about 38 per cent.

of what it was in 1840. Ships have been more than trebled in length, about doubled in breadth, and increased tenfold in displacement. The number of passengers carried by a steamship has been increased from about 100 to nearly 2000. The engine-power has been made forty times as great. The ratio of horse-power to the weight driven has been increased fourfold. The rate of coal consumption (measured per horse-power per hour) is now only about one-third what it was in 1840. To drive 2000 tons weight across the Atlantic at a speed of 8½ knots, about 550 tons of coal were then burnt: now, to drive 20,000 tons across at 22 knots, about 3000 tons of coal are burnt. With the low pressure of steam and heavy slow-moving paddle-engines of 1840, each ton weight of machinery, boilers, &c., produced only about 2 horse-power for continuous working at sea. With modern twin-screw engines and high steam pressure, each ton weight of propelling apparatus produces from 6 to 7 horse-power. Had the old rate of coal consumption continued, instead of 3000 tons of coal, 9000 tons would have been required for a voyage at 22 knots. Had the engines been proportionately as heavy as those in use sixty years ago, they would have weighed about 14,000 tons. In other words, machinery, boilers, and coals would have exceeded in weight the total weight of the *Campania* as she floats to-day. There could not be a more striking illustration than this of the close relation between improvements in marine engineering and the development of steam navigation at high speeds.

Equally true is it that this development could not have been accomplished but for the use of improved materials and structural arrangements Wood, as the principal material for the hulls of high-powered swift steamers, imposed limits upon dimensions, proportions and powers which would have been a bar to progress. The use of iron, and later of steel, removed those limits. The percentage of the total displacement devoted to hull in a modern Atlantic liner of the largest size is not much greater than was the corresponding percentage in the wood-built *Britannia* of 1840, of one-third the length and one-tenth the total weight.

Nor must it be overlooked that with increase in dimensions have come considerable improvements in *form*, favouring economy in propulsion. This is distinct from the economy resulting from increase in *size*, which Brunel appreciated thoroughly half a century ago when he designed the *Great Britain* and the *Great Eastern*. The importance of a due relation between the lengths of the "entrance and run" of steamships and their intended maximum speeds, and the advantages of greater length and fineness of form as speeds are increased, were strongly insisted upon by Scott Russell and Froude. Naval architects, as a matter of course, now act upon the principle, so far as other conditions permit. For it must never be forgotten that economy of propulsion is only one of many desiderata which must be kept in view in steamship design. Structural weight and strength, seaworthiness and stability, all claim attention, and may necessitate modifications in dimensions and form which do not favour the maximum economy of propulsion.

Swift Passenger Steamers for Long Voyages.

Changes similar to those described for the Transatlantic service have been in progress on all the great lines of ocean traffic. In many instances increase in size has been due, not only to increase in speed, but to enlarged carrying power and the extension of the lengths of voyages. No distance is now found too great for the successful working of steamships, and the sailing fleet is rapidly diminishing in importance. So far as long-distance steaming is concerned, the most potent factor has undoubtedly been the marvellous economy of fuel that has resulted from higher steam pressures and greater expansion. In all cases, however, advances have been made possible, not merely by economy of fuel, but by improvements in form, structure and propelling apparatus, and by increased dimensions.

Did time permit, this might be illustrated by many interesting facts drawn from the records of the great steamship companies which perform the services to the Far East, Australia, South America, and the Pacific. As this is not possible, I must be content with a brief statement regarding the development of the fleet of the Peninsular and Oriental Company.

The paddle steamer *William Fawcett* of 1829 was about 75 feet long, 200 tons displacement, of 60 nominal horse-power (probably about 120 indicated horse-power), and in favourable weather steamed at a speed of 8 knots. Her hull was of wood, and, like all the steamers of that date, she had considerable sail-power.

In 1853 the *Himalaya* iron-built screw steamer of this line was described as "of larger dimensions than any then afloat, and of extraordinary speed." She was about 340 feet long, over 4000 tons load displacement, 2000 indicated horse-power on trial, with an average sea-speed of about 12 knots. The steam pressure was 14 lbs. per square inch, and the daily coal consumption about 70 tons. This vessel was transferred to the Royal Navy and did good service as a troopship for forty years.

In 1893 another *Himalaya* was added to the company's fleet. She was steel-built, nearly 470 feet long and 12,000 tons load displacement, with over 8000 indicated horse-power and a capability to sustain 17 to 18 knots at sea, on a daily consumption of about 140 tons of coal. The steam pressure is 160 lbs. per square inch, and the engines are of the triple expansion type.

Comparing the two *Himayalas*, it will be seen that in forty years the length has been increased about 40 per cent., displacement trebled, horse-power quadrupled and speed increased about 50 per cent. The proportion of horse-power to displacement has only been increased as three to four, enlarged dimensions having secured relative economy in propulsion. The rate of coal consumption has been probably reduced to about one-third of that in the earlier ship

The latest steamers of the line are of still larger dimensions, being 500 feet long and of proportionately greater displacement. It is stated that the *Himalaya* of 1853 cost 132,000*l.* complete for sea; the corresponding outlay on her successors is not published, but it is probably twice as great.

On the service to the Cape similar developments have taken place. Forty years ago vessels less than 200 feet long and about 7 knots performed the service, whereas the latest additions to the fleets exceed 500 feet in length, and can, if required, be driven at 17 to 18 knots, ranking in size and power next to the great Transantlantic liners.

Commercial considerations necessarily regulate what is undertaken in the construction of merchant steamers, including the swift vessels employed in the conveyance of passengers and mails. The investment of 600,000*l.* to 700,000*l.* in a single vessel like a great Transatlantic liner is obviously a serious matter for private owners; and even the investment of half that amount in a steamer of less dimensions and speed is not to be lightly undertaken. It is a significant fact that, whereas fifteen years ago nearly all the largest and swiftest ocean steamers were British built and owned, at the present time there is serious competition in this class by German, American and French companies. It is alleged that this change has resulted from the relatively large subsidies paid by foreign Governments to the owners of swift steamers; and that British owners, being handicapped in this way, cannot continue the competition in size and speed on equal terms unless similarly assisted. This is not the place to enter into any discussion of such matters, but they obviously involve greater considerations than the profit of shipowners, and have a bearing on the naval defence of the Empire. In 1887 the Government recognised this fact, and made arrangements for the subvention and armament of a number of the best mercantile steamships for use as auxiliary cruisers. Since then other nations have adopted the policy, and given such encouragement to their shipowners that the numbers of swift steamers suitable for employment as cruisers have been largely increased. Not long since the First Lord of the Admiralty announced to Parliament that the whole subject was again under consideration.

Cargo and Passenger Steamers.

Cargo steamers, no less than passenger steamers, have been affected by the improvements mentioned. Remarkable developments have occurred recently, not merely in the purely cargo-carrier, but in the construction of vessels of large size and good speed carrying very great weights of cargo and considerable numbers of passengers. The much-decried "ocean-tramp" of the present day exceeds in speed the passenger and mail steamer of fifty years ago. Within ten years vessels in which cargo-carrying is the chief element of commercial success have been increased in length from 300 or 400 feet to 500 or 600 feet; in gross register tonnage from 5000 to over 13,000 tons; and in speed from 10 or 12 knots to 15 or 16 knots. Vessels are now building for the Atlantic service which can carry 12,000 to 13,000 tons deadweight, in addition to passengers, while possessing a sea-speed as high as that of the swiftest mail steamers afloat in 1880. Other vessels of large carrying power and good speed are running on much longer voyages, such as to the Cape and Australia. In order to work these ships successfully very complete organisation is necessary for the collection, embarkation and discharge of cargo. The enterprise and skill of shipowners have proved equal to this new departure, as they have in all other developments of steamships.

How much further progress will be made in the sizes and speeds of these mixed cargo and passenger steamers cannot be foreseen. The limits will be fixed by commercial considerations, and not by the capability of the shipbuilder.

In passing, it may be noted that while the lengths and breadths of steamships have been greatly increased, there has been but a moderate increase in draught. Draught of water is, of course, practically determined by the depths available in the ports and docks frequented, or in the Suez Canal for vessels trading to the East. From the naval architect's point of view, increase in draught is most desirable as favouring increase of carrying power and economy of propulsion. This fact has been strongly represented by shipowners and ship-designers, and not without result. The responsible authorities of many of the principal ports and of the Suez Canal have taken action towards giving greater depth.

Other changes have become necessary on the part of dock and port authorities in consequence of the progress made in shipbuilding. Docks and dock-entrances have had to be increased in size, more powerful lifting appliances provided and large expenditure incurred. There is no escape from these changes if the trade of a port is to be maintained. The chief lesson to be learnt from past experience is that when works of this character are planned it is wise to provide a large margin beyond the requirements of existing ships.

Cross-Channel Steamers.

The conditions to be fulfilled in vessels designed to steam at high speed for limited periods differ essentially from those holding good in ocean-going steamers. None the less interest attaches, however, to cross-Channel steamers, and in no class has more notable progress been made. It is much to be desired that at this meeting some competent authority should have presented to the Association an epitome of the history of the steam packet service between Dover and the continent. I cannot attempt it. So far as I am informed, the first steamer was placed on this route in 1821, was of 90 tons burden, 30 horse-power nominal, and maintained a speed of 7 to 8 knots. She was built by Denny of Dumbarton, engined by David Napier and named the *Rob Roy*. It is interesting to note that the lineal successors of the builder of this pioneer vessel have produced some of the most recent and swiftest additions to the cross-Channel service.

In 1861-2 a notable advance was made by the building of vessels which were then remarkable for structure and speed, although small and slow when compared with vessels now running. Their designers realised that lightness of hull was of supreme importance, and with great trouble and expense obtained steel of suitable quality. The machinery was of special design and relatively light for the power developed. A small weight of coal and cargo had to be carried, and the draught of water was kept to about 7 feet. Under then existing conditions it was a veritable triumph to attain speeds of 15 to 16 knots in vessels only 190 feet long, less than 25 feet broad, and under 350 tons in displacement. To raise the trial speed to 20 or 21 knots in later vessels performing the same service, whose design includes the improvements of a quarter of a century, it has been found necessary to adopt lengths exceeding 320 feet and breadths of about 35 feet, with engines developing 4500 to 6000 indicated horse-power, and with very great increase in coal consumption and cost. On other cross-Channel services between Dover and the continent still larger and more powerful paddle-steamers are employed.

Another interesting contrast is to be found in the comparison of the steamers running between Holyhead and Kingstown in 1860 and at the present time. The *Leinster* of 1860 was 328 feet long, 35 feet broad and rather less than 13 feet draught. Her trial displacement was under 2000 tons and with 4750 horse-power she made 17¾ knots. She had a steam pressure of 25 lbs. per square inch and was propelled by paddle-wheels driven by slow-moving engines of long stroke. Her successor of 1896 is about 30 feet greater length, 6½ feet greater breadth and about 10 per cent. greater displacement. The steam pressure is 170 lbs. per square inch. Forced draught is used in the stokeholds. Twin screws are adopted, driven by quick-running vertical engines of the triple expansion type. Very great economy of coal consumption is thus secured as compared with the earlier vessel, and much lighter propelling apparatus in proportion to the power, which is from 8000 to 9000 horse-power at the full speed of 23 knots. The hull is built of steel, and is proportionately lighter.

This is a typical case, and illustrates the effect of improvements in shipbuilding and engineering in thirty-five years. The later ship probably requires to carry no greater load of coal than, if so great as, her predecessor, although her engine-power is nearly double. The weight devoted to propelling machinery and boilers is probably not so great. Thanks to the use of steel instead of iron, and to improved structural arrangements, the weight of hull is reduced in comparison with dimensions, and a longer ship is produced better adapted to the higher speed. Messrs. Laird of Birkenhead, who built three of the *Leinster* class forty years ago, and have built all the new vessels, are to be congratulated on their complete success.

Between such vessels designed for short runs at high speed and requiring therefore to carry little coal, while the load carried exclusive of coal is trifling, and an ocean-going steamer of the same average speed designed to make passages of 3000 miles, there can obviously be little in common. But equal technical skill is required to secure the efficient performance of both services. In the cross-Channel vessel, running from port to port, and under constant observation, conditions of working in engine and boiler rooms, as well as relative lightness in scantlings of hull, can be accepted which would be impossible of application in a sea-going ship. These circumstances in association with the small load carried explain the apparent gain in speed of the smaller vessel in relation to her dimensions.

Increase in Size and Speed of Warships.

Turning from sea-going ships of the mercantile marine to warships, one finds equally notable facts in regard to increase in speed, associated with enlargement in dimensions and advance in propelling apparatus, materials of construction, structural arrangements and form.

Up to 1860 a measured-mile speed of 12 to 13 knots was considered sufficient for battleships and the largest classes of cruisers. All these vessels possessed good sail-power and used it freely as an auxiliary to steam, or as an alternative when cruising or making passages.

When armoured battleships were built (1859) the speeds on measured-mile trials were raised to 14 or 14½ knots, and so remained for about twenty years. Since 1880 the speeds of battleships have been gradually increased, and in the latest types the measured-mile speed required is 19 knots.

Up to 1870 the corresponding speeds in cruisers ranged from 15 to 16 knots. Ten years later the maximum speeds were 18 to 18½ knots in a few vessels. Since then trial speeds of 20 to 23 knots have been attained or are contemplated.

There is, of course, a radical distinction between these measured-mile performances of warships and the average sea-speeds of merchant steamers above described. But for purposes of comparison between warships of different dates, measured mile trials may fairly be taken as the standard. For long-distance steaming the power developed would necessarily be much below that obtained for short periods and with everything at its best. This is frankly recognised by all who are conversant with the warship design, and fully allowed for in estimates of sea-speeds. On the other hand, it is possible to point to sea trials made with recent types where relatively high speeds have been maintained for long periods. For example, the battleship *Royal Sovereign* has maintained an average speed of 15 knots from Plymouth to Gibraltar, and the *Renown* has maintained an equal speed from Bermuda to Spithead. As instances of good steaming by cruisers, reference may be made to 60-hour trials with the *Terrible* when she averaged over 20 knots, and to the run home from Gibraltar to the Nore by the *Diadem* when she exceeded 19 knots. Vessels of the *Pelorus* class of only 2100 tons displacement have made long runs at sea averaging over 17 knots. Results such as these represent a substantial advance in speed of Her Majesty's ships in recent years.

Similar progress has been made in foreign warships built abroad as well as in this country. It is not proposed to give any facts for these vessels, or to compare them with results obtained by similar classes of ships in the Royal Navy. Apart from full knowledge of the conditions under which speed trials are made, a mere statement of speeds attained is of no service. One requires to be informed accurately respecting the duration of the trial, the manner in which engines and boilers are worked, the extent to which boilers are "forced," or the proportion of heating surface to power indicated, the care taken to eliminate the influence of tide or current, the mode in which the observations of speed are made, and other details, before any fair or exact comparison is possible between ships. For present purposes, therefore, it is preferable to confine the illustrations of increase in speed in warships to results obtained under Admiralty conditions, and which are fairly comparable.

A great increase in size has accompanied this increase in speed, but it has resulted from other changes in modern types, as well as from the rise in speed. Modern battleships are of 13,000 to 15,000 tons, and modern cruisers of 10,000 to 14,000 tons, not merely because they are faster than their predecessors, but because they have greater powers of offence and defence and possess greater coal endurance. Only a detailed analysis, which cannot now be attempted, could show what is the actual influence of these several changes upon size and cost, and how greatly the improvements made in marine engineering and ship-building have tended to keep down the growth in dimensions consequent on increase in load carried, speed attained, and distance traversed.

It will be noted also that, large as are the dimensions of many classes of modern warships, they are all smaller in length and displacement than the largest mercantile steamers above described. There is no doubt a popular belief that the contrary is true, and that warships exceed merchant ships in tonnage. This arises from the fact that merchant ships are ordinarily described, not by their displacement tonnage, but by their "registered tonnage," which is far less than their displacement. As a matter of fact, the largest battleships are only of about two-thirds the displacement of the largest passenger steamers, and from 200 to 300 feet shorter. The largest cruisers are from 100 to 200 feet shorter than the largest passenger steamers, and about 60 per cent. of their displacement. In breadth the warships exceed the largest merchant steamers by 5 to 10 feet. This difference in form and proportions is the result of radical differences in the vertical distribution of weights carried, and is essential to the proper stability of the warships. Here we find an illustration of the general principle underlying all ship-designing. In selecting the forms and proportions of a new ship, considerations of economical propulsion cannot stand alone. They must be associated with other considerations, such as stability, protection and manœuvring power, and in the final result economy of propulsion may have to be sacrificed, to some extent, in order to secure other essential qualities.

Advantages of Increased Dimensions.

Before passing on, it may be interesting to illustrate the gain in economy of propulsion resulting from increase in dimensions by means of the following table, which gives particulars of a number of typical cruisers, all of comparatively recent design :—

—	No. 1	No. 2	No. 3	No. 4	No. 5
Length (feet)	280	300	360	435	500
Breadth (feet)	35	43	60	69	71
Mean draught (feet) ...	13	16½	23¾	24½	26¼
Displacement (tons) ...	1800	3400	7,400	11,000	14,200
Indicated horse-power for 20 knots...	6000	9000	11,000	14,000	15,500
Indicated horse-power per ton of displacement ...	3·33	2·65	1·48	1·27	1·09

The figures given are the results of actual trials, and embody therefore the efficiencies of propelling machinery, propellers and forms of the individual ships. Even so they are instructive. Comparing the first and last, for example, it will be seen that, while the displacement is increased nearly *eightfold*, the power for 20 knots is only increased about 2·6 times. If the same types of engines and boilers had been adopted in these two vessels—which was not the case, of course—the weights of propelling apparatus and coal for a given distance would have been proportional to the respective powers; that is to say, the larger vessel would have been equipped with only 2·6 times the weight carried by the smaller. On the other hand, roughly speaking, the *disposable weights*, after providing for hulls and fittings in these two vessels, might be considered to be proportional to their displacements. As a matter of fact, this assumption is distinctly in favour of the smaller ship. Adopting it, the larger vessel would have about *eight* times the disposable weight of the smaller; while the demand for propelling apparatus and fuel would be only *2·6 times* that of the smaller vessel. There would therefore be an enormous margin of carrying power in comparison with displacement in the larger vessel. This might be devoted, and in fact was devoted, partly to the attainment of a speed considerably exceeding 20 knots (which was a maximum for the smaller vessel), partly to increased coal endurance and partly to protection and armament.

Another interesting comparison may be made between vessels Nos. 4 and 5 in the preceding table, by tracing the growth in power necessary to drive the vessels at speeds ranging from 10 knots up to 22 knots.

	No. 4	No. 5
10 knots ...	1,500-horse-power	1,800-horse-power
12 " ...	2,500 " "	3,100 " "
14 " ...	4,000 " "	5,000 " "
16 " ...	6,000 " "	7,500 " "
18 " ...	9,000 " "	11,000 " "
20 " ...	14,000 " "	15,500 " "
22 " ...	23,000 " "	23,000 " "

It will be noted that up to the speed of 18 knots there is a fairly constant ratio between the powers required to drive the two ships. As the speeds are increased the larger ship gains, and at 22 knots the same power is required in both ships. The smaller vessel, as a matter of fact, was designed for a maximum speed of 20½ knots, and the larger for 22 knots. Unless other qualities had been sacrificed, neither space nor weight could have been found in the smaller vessel for machinery and coals corresponding to 22 knots. The figures are interesting, however, as illustrations of the principle that economy of propulsion is favoured by increase in dimensions as speeds are raised.

Going a step further, it may be assumed that in unsheathed cruisers of this class about 40 per cent. of the displacement will be required for the hull and fittings, so that the balance or "disposable weight" would be about 60 per cent.; say 6600 tons for the smaller vessel, and 8500 tons for the larger, a gain of nearly 2000 tons for the latter. If the speed of 22 knots were secured in both ships, with machinery and boilers of the same type, the larger ship would therefore have about 2000 tons greater weight available for coals, armament, armour and equipment.

These illustrations of well-known principles have been given simply for the assistance of those not familiar with the subject, and they need not be carried further. More general treatment of the subject, based on experimental and theoretical investigation, will be found in text-books of naval architecture, but would be out of place in this Address.

Swift Torpedo Vessels.

Torpedo flotillas are comparatively recent additions to war fleets. The first torpedo boat was built by Mr. Thornycroft for the Norwegian Navy in 1873, and the same gentleman built the first torpedo boat for the Royal Navy in 1877. The construction of the larger class, known as "torpedo-boat destroyers," dates from 1893. These various classes furnish some of the most notable examples extant of the attainment of extraordinarily high speeds, for short periods and in smooth water, by vessels of small dimensions. Their qualities and performances, therefore, merit examination.

Mr. Thornycroft may justly be considered the pioneer in this class of work. Greatly impressed by the combination of lightness and power embodied in railway locomotives, Mr. Thornycroft applied similar principles to the propulsion of small boats, and obtained remarkably high speeds. His work became more widely known when the results were published of a series of trials conducted in 1872 by Sir Frederick Bramwell on a small vessel named the *Miranda*. She was only 45 feet long and weighed 4 tons, yet she exceeded 16 knots on trial. The Norwegian torpedo boat built in 1873 was 57 feet long, 7½ tons, and of 15 knots; the first English torpedo boat of 1877 was 81 feet long, 29 tons and attained 18½ knots.

Mr. Yarrow also undertook the construction of small swift vessels at a very early date, and has greatly distinguished himself throughout the development of the torpedo flotilla. Messrs. White, of Cowes, previously well known as builders of steam-boats for use on board ships, extended their operations to the construction of torpedo boats. These three firms for a considerable time practically monopolised this special class of work in this country. Abroad they had able competitors in Normand in France, Schichau in Germany, and Herreshoff in the United States. Keen competition led to successive improvements and rapid rise in speed. During the last six years the demand for a fleet of about 100 destroyers, to be built in the shortest possible time, involved the necessity for increasing the sources of supply. At the invitation of the Admiralty, a considerable number of the leading shipbuilding and engineering firms have undertaken and successfully carried through the construction of destroyers varying from 26 to 33 knots in speed, although the work was necessarily of a novel character, involving many difficulties.

As the speeds of torpedo vessels have risen, so have their dimensions increased. Within the class the law shown to hold good in larger vessels applies equally. In 1877 a first-class torpedo boat was 81 feet long, under 30 tons weight, developed 400-horse-power, and steamed 18½ knots. Ten years later the corresponding class of boat was 135 feet long, 125 tons weight, developed 1500 horse-power and steamed 23 knots. In 1897 it had grown to 150 feet in length, 140 to 150 tons, 2000 horse-power and 26 knots.

Destroyers are not yet of seven years' standing, but they come under the rule. The first examples (1893) were 180 feet long, 240 tons, 4000 horse-power and 26 to 27 knots. They were followed by 30-knot vessels, 200 to 210 feet long, 280 to 300 tons, 5500 to 6000 horse-power. Vessels now in construction are to attain 32 to 33 knots, their lengths being about 230 feet, displacements 360 to 380 tons and engine-power 8000 to 10,000 horse-power.

Cost has gone up with size and power, and the limit of progress in this direction will probably be fixed by financial considerations, rather than by constructive difficulties, great as these become as speeds rise.

It may be interesting to summarise the distinctive features of torpedo-vessel design.

(1) The propelling apparatus is excessively light in proportion to the maximum power developed. Water-tube boilers are now universally adopted, and on speed trials they are "forced" to a considerable extent. High steam pressures are used. The engines are run at a high rate of revolution—often at 400 revolutions per minute. Great care is taken in every detail to economise weight. Speed trials at maximum power only extend over three hours. On such trials in a destroyer each ton weight of propelling apparatus produces about 45 indicated horse-power. Some idea of the relative lightness of the destroyer's machinery and boilers will be obtained when it is stated that in a large modern cruiser with water-tube boilers, high steam pressure, and quick-running engines, the maximum power obtained on an eight hours' trial corresponds to about 12 indicated horse-power per ton of engines, boilers, &c. That is to say, the proportion of power to weight of propelling apparatus is from three and a half to four times as great in the destroyer as it is in the cruiser.

(2) A very large percentage of the total weight (or displacement) of a torpedo vessel is assigned to propelling apparatus. In a destroyer of 30 knots trial-speed, nearly one-half the total weight is devoted to machinery, boilers, &c. In the swiftest cruisers of large size the corresponding allocation of weight is less than 20 per cent. of the displacement, and in the largest and fastest mail steamers it is about 20 to 25 per cent.

(3) The torpedo vessel carries a relatively small load of fuel, equipment, &c. Taking a 30-knot destroyer, for example, the speed trials are made with a load not exceeding 12 to 14 per cent. of the displacement. In a swift cruiser the corresponding load would be from 40 to 45 per cent., or proportionately more than three times as great. What this difference means may be illustrated by two statements. If the load in a destroyer were trebled and the vessel correspondingly increased in draught and weight, the speed attained with the same maximum power would be about three knots less. If, on the other hand, the vessel were designed to attain 30 knots on trial with the heavier load, her displacement would probably be increased about 70 to 80 per cent.

(4) The hull and fittings of the torpedo vessel are exceedingly light in relation to the dimensions and engine-power. For many parts of the structure steel of high tensile strength is used. Throughout, the utmost care is taken to economise weight. In small vessels, for special service, many conditions can be accepted which would be inadmissible in larger sea-going vessels. The result of all this care is the production of hull-structures having ample *general* strength for their special service. Lightness of scantling, of course, involves small *local* strength against collision, grounding and other accident. Experience proves, however, that this involves no serious risk or difficulty.

These conditions are essential to the attainment of very high speeds for short periods. They resemble the conditions ruling the design of cross-Channel steamers, so far as relative lightness of propelling apparatus, small load and light scantlings are concerned. The essential differences lie in the requirements for passenger accommodation as compared with the requirements for armament of the torpedo vessel. No one has yet proposed to extend the torpedo-vessel system to sea-going ships of large dimensions. Very similar conditions for the propelling apparatus have been accepted in a few cruisers of considerable dimensions, wherein high speeds for short periods were required. It is, however, unquestionable that in many ways, and particularly in regard to machinery design, the construction of torpedo vessels has greatly influenced that of larger ships.

One important consideration must not be overlooked. For short-distance steaming at high speeds economy in coal consumption is of little practical importance, and it is all-important to secure lightness of propelling apparatus in relation to power. For long-distance steaming, on the contrary, economy in coal consumption is of primary importance; and savings in weight of propelling apparatus, even of considerable amount, may be undesirable if they involve increased coal consumption. Differences of opinion prevail as to the real economy of fuel obtainable with boilers and engines such as are fitted in torpedo vessels. Claims are made for some vessels which represent remarkable economy. Only enlarged experience can settle these questions.

Endurance is also an important quality in sea-going ships of large size, not merely in structures, but in propelling apparatus. The extreme lightness essential in torpedo vessels obviously does not favour endurance if high powers are frequently or continuously required. Still, it cannot be denied that the results obtained in torpedo vessels show such a wide departure from those usual in sea-going ships as to suggest the possibility of some intermediate type of propelling apparatus applicable to large sea-going ships and securing sufficient durability and economy of fuel in association with further savings of weight.

The Parsons Turbo-Motor.

The steam turbo-motor introduced by Mr. Charles Parsons is to be described by the inventor during these meetings; but it is impossible for me to pass it over in this review without a brief notice. This rotary engine, with its very high rate of revolution, reduces the weights of machinery, shafting and propellers greatly below the weight required in the quickest-running engines of the reciprocating type. This reduction in the proportion of weight to power carries with it, of course, the possibility of higher speed in a vessel of given dimensions; and when large powers are employed the absolute gain is very great. An illustration of this has been given by Mr. Parsons in the *Turbinia*. That remarkable vessel is 100 feet long and of 44½ tons displacement, but she has attained 33 to 34 knots in short runs. There are three shafts, each carrying three screw propellers, each shaft driven by a steam turbine making over 2000 revolutions at full speed, when more than 2000-horse-power is developed. A water-tube boiler of special design supplies steam of 175 lbs. pressure, and is exceptionally light for the steam produced, being highly forced. The whole weight of machinery and boilers is 22 tons; in other words, about 100 horse-power (indicated) is produced for each ton weight of propelling apparatus. This is rather more than twice the proportion of power to weight as compared with the lightest machinery and boilers fitted in torpedo boats and destroyers. It will be noted that in the *Turbinia*, as in the destroyers, about half the total weight is devoted to propelling apparatus; and in both instances the load carried is relatively small. The secret of the extraordinary speed is to be found in the extreme lightness of propelling apparatus and small load.

No doubt in the *Turbinia* lightness has been pushed further than it would be in vessels of larger size and greater power. In such vessels a lower rate of revolution would probably be accepted, additional motors would be fitted for manœuvring and going astern, boilers of relatively greater weight would be adopted and other changes made. But, after making ample allowance for all such increases in weight, it is unquestionable that considerable economies must be possible with rotary engines. Two other vessels of the destroyer type with turbo-motors (one for the Royal Navy) are now approaching completion. Their trials will be of great interest, as they will furnish a direct comparison with vessels of similar size and form, fitted with similar boilers and driven by reciprocating engines.

On the side of coal consumption, Mr. Parsons claims at least equality with the best triple expansion engines. Into the other advantages attending the use of rotary engines it is not necessary now to enter.

Reference must be made, however, to one matter in which Mr. Parsons has done valuable and original work. In torpedo vessels of high speed the choice of the most efficient propellers has always been a matter of difficulty, and the solution of the problem has in many instances involved extensive experimental trials. By means of alterations in propellers alone, very large increases in speed have been effected; and even now there are difficulties to be faced. When Mr. Parsons adopted the extraordinary speed of revolution just named for the *Turbinia*, he went far beyond all experience and precedent and had to face unknown conditions. He has found the solution, after much patient and original investigation, in the use of multiple screws of small diameter. His results in this direction are of general interest to all who have to deal with screw propulsion.

Such radical changes in propelling machinery as are involved in the adoption of turbo-motors must necessarily be subjected to thorough test before they will be widely adopted. The experiment which the Admiralty are making is not on a small scale as regards power. Although it is made in a destroyer, about 10,000 horse-power will probably be developed and a correspondingly high speed attained. It may well happen that from this experiment very far-reaching effects may follow. Mr. Parsons himself has prepared many designs illustrating various applications of the system to sea-going, cross-Channel and special service vessels. Where shallowmess of draught is unavoidable, the small diameter of the screws possible with the quick-running turbines is clearly an important matter.

Comparisons between Large and Small Vessels.

It has been shown that the attainment of very high speeds by vessels of small size involves many conditions not applicable to large sea-going steamships. But it is equally true that in many ways the trials of small swift vessels constitute model experiments from which interesting information may be obtained as to what would be involved in driving ships of large size at speeds much exceeding any of which we have experience. When the progressive steam-trials of such small vessels can be studied side by side with experiments made on models to determine their resistance at various speeds, then the fullest information is obtained and the best guide to progress secured. This advantage, as has been said, we owe to William Froude.

His contributions to the Reports of the British Association are classics in the literature of the resistance and propulsion of ships. In 1874 he practically exhausted the subject of frictional resistance so far as it is known; and his Presidential Address to this Section in 1875 dealt fully and lucidly with the modern or stream-line theory of resistance. No doubt there would be advantage in extending Froude's experiments on frictional resistance to greater lengths and to ship-shaped forms. It is probable also that dynamometric determinations of the resistance experienced by ships of modern forms and considerable size when towed at various speeds would be of value if they could be conducted. These extensions of what Froude accomplished are not easily carried out; and in this country the pressure of work on shipbuilding for the Royal Navy has, for many years past, taxed to the utmost limits the capacity of the Admiralty experimental establishment so ably superintended by Mr. R. E. Froude, allowing little scope for purely scientific investigations, and making it difficult to deal with the numerous experiments incidental to the designs of actual ships. Now that Holland, Russia, Italy and the United States have equipped experimental establishments, while Germany and France are taking steps in that direction, we may hope for extensions of purely scientific work and additions to our knowledge. In this direction, however, I am bound to say that much might be done if experimental establishments capable of dealing with questions of a general nature relating to resistance and propulsion were added to the equipment of some of our universities and colleges. Engineering laboratories have been multiplied, but there is as yet no example of a model experimental tank devoted to instruction and research.

It is impossible, and possibly is unnecessary, to attempt in this Address any account of Froude's "scale of comparison" between ships and models at "corresponding speeds." But it may be of interest to give a few illustrations of the working of this method, in the form of a contrast between a destroyer of 300 tons, 212 feet long, capable of steaming 30 knots an hour, and a vessel of similar form enlarged to 765 feet in length and 14,100 tons. The ratio of dimensions is here about 3·61 : 1; the ratio of displacements is 47 : 1; and the ratio of corresponding speeds is 1·9 : 1.

To 12 knots in the small vessel would correspond 22·8 knots in the large vessel; and the resistance experienced by the large vessel at 22·8 knots (neglecting a correction for friction) should be forty-seven times that of the small vessel at 12 knots. By experiment, this resistance for the small vessel was found to be 1·8 tons. Hence, for the large vessel at 22·8 knots the resistance should be 84·6 tons. This would correspond to an "effective horse-power" of over 13,000, or to about 26,000 indicated horse-power. The frictional correction would reduce this to about 25,000 horse-power, or about 1·8 horse-power per ton. Now turning to the destroyer, it is found experimentally that at 22·8 knots she experiences a resistance of about 11 tons, corresponding to an effective horse-power of over 1700, and an indicated horse-power of about 3000: say 10 horse-power per ton, or nearly five and a half times the power per ton required in the larger vessel. This illustrates the economy of propulsion arising from increased dimensions.

Applying the same process to a speed of 30 knots in the large ship, the corresponding speed in the small ship is 15 8 knots. Her resistance at that speed is experimentally determined to be 3·5 tons, and the resistance of the large ship at 30 knots (neglecting frictional correction) is about 165 tons. The effective horse-power of the large ship at 30 knots is, therefore, about 34,000, corresponding to 68,000 horse-power indicated. Allowing for the frictional correction, this would drop to about 62,000 horse-power, or 4·4 horse-power per ton. For the destroyer at 30 knots the resistance is about 17½ tons; the effective horse-power is 3600, and the indicated horse-power about 6000, or 20 horse-power per ton, nearly five times as great as the corresponding power for the large ship. But while the destroyer under her trial conditions actually reaches 30 knots, it is certain that in the large ship neither weight nor space could be found for machinery and boilers of the power required for 30 knots, and of the types usually adopted in large cruisers, in association with an adequate supply of fuel. The explanation of the methods by which the high speed is reached in the destroyer has already been given. Her propelling apparatus is about one-fourth as heavy in relation to its maximum power, and her load is only about one-third as great in relation to the displacement, when compared with the corresponding features in a swift modern cruiser.

It will, of course, be understood that in practice, under existing conditions, a cruiser of 14,000 tons would not be made 765 feet long, but probably about 500 feet. The hypothetical cruiser has been introduced simply for purposes of comparison with the destroyer.

The earlier theories of resistance assumed that the resistance experienced by ships varied as the square of the speed. We now know that the frictional resistances of clean-painted surfaces of considerable length vary as the 1·83 power of the speed. This seems a small difference, but it is sensible in its effects, causing a reduction of 32 per cent. at 10 knots, nearly 40 per cent. at 20 knots, and 42 per cent. at 25 knots. On the other hand, it is now known that the laws of variation of the residual or wave-making resistance may depart very widely from the law of the square of the speed, and it may be interesting to trace for the typical destroyer how the resistance actually varies.

Take first the *total resistance*. Up to 11 knots it varies nearly as the square of the speed; at 16 knots it has reached the cube; from 18 to 20 knots it varies as the 3·3 power. Then the index begins to diminish: at 22 knots it is 2·7; at 25 knots it has fallen to the square, and from thence to 30 knots it varies, practically, as does the frictional resistance.

The residual resistance varies as the square of the speed up to 11 knots, as the cube at 12½ to 13 knots, as the fourth power about 14½ knots, and at a higher rate than the fifth power at 18 knots. Then the index begins to fall, reaching the square at 24 knots, and falling still lower at higher speeds.

It will be seen, therefore, that when this small vessel has been driven up to 24 or 25 knots by a large relative expenditure of power, further increments of speed are obtained with less proportionate additions to the power.

Passing from the destroyer to the cruiser of similar form but of 14,100 tons, and once more applying the "scale of comparison," it will be seen that to 25 knots in the destroyer corresponds a speed of 47½ knots in the large vessel. In other words, the cruiser would not reach the condition where further increments of speed are obtained with comparatively moderate additions of power until she exceeded 47 knots, which is an impossible speed for such a vessel under existing conditions. The highest speeds that could be reached by the cruiser with propelling apparatus of the lightest type yet fitted in large sea-going ships would correspond to speeds in the destroyer, for which the resistance is varying as the highest power of the speed. These are suggestive facts.

Frictional resistance, as is well known, is a most important matter in all classes of ships and at all speeds. Even in the typical destroyer this is so. At 12 knots the friction with clean-painted bottom represents 80 per cent. of the total resistance; at 16 knots 70 per cent; at 20 knots a little less than 50 per cent.; and at 30 knots 45 per cent. If the coefficient of friction were doubled and the maximum power developed with equal efficiency, a loss of speed of fully 4 knots would result.

In the cruiser of similar form the friction represents 90 per cent. at 12 knots, 85 per cent. at 16 knots, nearly 80 per cent. at 20 knots, and over 70 per cent. at 23 knots. If the coefficient of friction were doubled at 23 knots and the corresponding power developed with equal efficiency, the loss of speed would approximate to 4 knots.

These illustrations only confirm general experience that clean bottoms are essential to economical propulsion and the maintenance of speed, and that frequent docking is necessary in vessels with bare iron or steel skins, which foul in a comparatively short time.

Possibilities of further Increase in Speed.

From the facts above mentioned it is obvious that the increase in speed which has been effected is the result of many improvements, and has been accompanied by large additions to size, engine-power and cost. These facts do not discourage the "inventor," who finds a favourite field of operation in schemes for attaining speeds of 50 to 60 knots at sea in vessels of moderate size. Sometimes the key to this remarkable advance is found in devices for reducing surface-friction by the use of wonderful lubricants to be applied to the wetted surfaces of ships, or by interposing a layer of air between the skins of ships and the surrounding water, or other departures from ordinary practice. If these gentlemen would "condescend to figures," their estimates, or guesses, would be less sanguine. In many cases the proposals made would fail to produce any sensible reduction in resistance; in others they would increase resistance.

Other proposals rest upon the idea that resistance may be largely reduced by adopting novel forms, departing widely from ordinary ship shapes. Very often small-scale experiments, made in an unscientific and inaccurate manner, are adduced as proofs of the advantages claimed. In other instances mere assertion is thought sufficient. Ordinarily no regard is had to other considerations, such as internal capacity, structural weight and strength, stability and seaworthiness. Most of these proposals do not merit serious consideration. Any which seem worth investigation can be dealt with simply and effectively by the method of model experiments. A striking example of this method will be found in the unusual form of a Parliamentary Paper (No. 313, of 1873), containing a report made by Mr. William Froude to the Admiralty. Those interested in the subject will find therein much matter of special interest in connection with the conditions attending abnormally high speeds. It must suffice now to say that ship-shaped forms are not likely to be superseded at present.

The most prolific "inventions" are those connected with supposed improvements in propellers. One constantly meets with schemes guaranteed by the proposers to give largely increased efficiency and corresponding additions to speed. Variations in the numbers and forms of screws or paddles, the use of jets of water or air expelled by special apparatus through suitable openings, the employment of explosives, imitations of the fins of fishes and numberless other departures from established practice are constantly being proposed. As a rule the "inventors" have no intimate knowledge of the subject they treat, which is confessedly one of great difficulty. When experiments are adduced in support of proposals they are almost always found to be inconclusive and inaccurate. More or less mathematical demonstrations find favour with other inventors, but they are not more satisfactory than the experiments. An air of great precision commonly pervades the statements made as to possible increase in efficiency or speed. I have known cases where probable speeds with novel propellers have been estimated (or guessed) to the third place of decimals. In one such instance a trial was made with the new propeller, with the result that instead of a gain in efficiency there was a serious loss of speed. Very few of the proposals made have merit enough to be subjected to trial. None of them can possibly give the benefits claimed.

It need hardly be added that in speaking thus of so-called "inventors" there is no suggestion that improvement has reached its limit, or that further discovery is not to be made. On the contrary, in regard to the forms of ships and propellers, continuous investigation is proceeding and successive advances are being made. From the nature of the case, however, the difficulties to be surmounted increase as speeds rise; and a thorough mastery of the past history and present condition of the problems of steamship design and propulsion is required as a preparation for fruitful work in the nature of further advance.

It would be idle to attempt any prediction as to the characteristic features of ocean navigation sixty years hence. Radical changes may well be made within that period. Confining attention to the immediate future, it seems probable that the lines of advance which I have endeavoured to indicate will remain in use. Further reductions may be anticipated in the weight of propelling apparatus and fuel in proportion to the power developed; further savings in the weight of the hulls, arising from the use of stronger materials and improved structural arrangements; improvements in form; and enlargement in dimensions. If greater draughts of water can be made possible, so much the better for carrying power and speed. For merchant vessels commercial considerations must govern the final decision; for warships the needs of naval warfare will prevail. It is certain that scientific methods of procedure and the use of model experiments on ships and propellers will become of increased importance.

Already avenues for further progress are being opened. For example, the use of water-tube boilers in recent cruisers and battleships of the Royal Navy has resulted in saving *one-third* of the weight necessary with cylindrical boilers of the ordinary type to obtain the same power, with natural draught in the stokeholds. Differences of opinion prevail, no doubt, as to the policy of adopting particular types of water-tube boilers; but the weight of opinion is distinctly in favour of some type of water-tube boiler in association with the high steam pressures now in use. Greater safety, quicker steam-raising and other advantages, as well as economy of weight, can thus be secured. Some types of water-tube boilers would give greater saving in weight than the particular type used in the foregoing comparison with cylindrical boilers.

Differences of opinion prevail also as to the upper limit of steam pressure which can with advantage be used, taking into account all the conditions in both engines and boilers. From the nature of the case, increases in pressure beyond the 160 to 180 lbs. per square inch commonly reached with cylindrical boilers cannot have anything like the same effect upon economy of fuel as the corresponding increases have had, starting from a lower pressure. Some authorities do not favour any excess above 250 lbs. per square inch on the boilers; others would go as high as 300 lbs., and some still higher.

Passing to the engine-rooms, the use of higher steam-pressures and greater rates of revolution may, and probably will, produce reductions in weight compared with power. The use of stronger materials, improved designs, better balance of the moving parts, and close attention to details have tended in the same direction without sacrifice of strength. Necessarily there must be a sufficient margin to secure both strength and endurance in the motive power of steamships. Existing arrangements are the outgrowth of large experience, and new departures must be carefully scrutinised.

The use of rotary engines, of which Mr. Parsons' turbo-motor is the leading example at present, gives the prospect of further economies of weight. Mr. Parsons is disposed to think that he could about halve the weights now required for the engines, shafting, and propellers of an Atlantic liner while securing proper strength and durability. If this could be done in association with the use of water-tube boilers it would effect a revolution in the design of this class of vessel, permitting higher speeds to be reached without exceeding the dimensions of existing ships.

It does not appear probable that, with coal as the fuel, water-tube boilers will surpass in economy the cylindrical boilers now in use; and skilled stoking seems essential if water-tube boilers are to be equal to the other type in rate of coal consumption. The general principle holds good that as more perfect mechanical appliances are introduced, so more skilled and disciplined management is required in order that the full benefits may be obtained. In all steamship performance the "human factor" is of great importance, but its importance increases as the appliances become more complex. In engine-rooms the fact has been recognised and the want met. There is no reason why it should not be similarly dealt with in the boiler-rooms.

Liquid fuel is already substituted for coal in many steamships. When sufficient quantities can be obtained it has many obvious advantages over coal, reducing greatly manual labour in embarking supplies, conveying it to the boilers and using it as fuel. Possibly its advocates have claimed for it greater economical advantages over coal than can be supported by the results of extended experiment. Even if the saving in weight for equal evaporation is put as low as 30 per cent. of the corresponding weight of coal, it would amount to 1000 tons on a first-class Atlantic liner. This saving might be utilised in greater power and higher speed, or in increased load. There would be a substantial saving on the stokehold staff. At present it does not appear that adequate supplies of liquid fuel are available. Competent authorities here and abroad are giving attention to this question, and to the development of supplies. If the want can be met at prices justifying the use of liquid fuel, there will undoubtedly be a movement in that direction.

Stronger materials for the construction of hulls are already available. They are, however, as yet but little used, except for special classes of vessels. Mild steel has taken the place of iron, and effected considerable savings of weight. Alloys of steel with nickel and other metals are now made which give strength and rigidity much superior to mild steel, in association with ample ductility. For destroyers and torpedo boats this stronger material is now largely used. It has also been adopted for certain important parts of the structures of recent ships in the Royal Navy. Of course the stronger material is more costly, but its use enables sensible economies of weight to be made. It has been estimated, for example, that in an Atlantic liner of 20 knots average speed about 1000 tons could be saved by using nickel steel instead of mild steel. This saving would suffice to raise the average speed more than a knot, without varying the dimensions of the ship.

Alloys of aluminium have also been used for the hulls or portions of the hulls of yachts, torpedo-boats, and small vessels. Considerable savings in weight have thus been effected. On the other hand, these alloys have been seriously corroded when exposed to the action of sea-water, and on that account are not likely to be extensively used. Other alloys will probably be found which will be free from this defect, and yet unite lightness with strength to a remarkable degree.

Other examples might be given of the fact that the metallurgist has by no means exhausted his resources, and that the shipbuilder may look to him for continued help in the struggle to reduce the weights of floating structures.

It is unnecessary to amplify what has already been said as to possible increase in the efficiency and types of propellers. With limited draught, as speeds increase and greater powers have to be utilised, multiple propellers will probably come into use. Mr. Parsons has shown how such problems may be dealt with; and other investigators have done valuable work in the same direction.

In view of what has happened and is still happening, it is practically certain that the dimensions of steamships have not yet attained a maximum.

Thanks to mechanical appliances, the largest ships built or to be built can be readily steered and worked. In this particular difficulties have diminished in recent years, notwithstanding the great growth in dimensions.

Increase in length and weight favour the better maintenance of speed at sea. The tendency, therefore, will be to even greater regularity of service than at present. Quicker passages will to some extent diminish risks, and the chance of breakdown will be lessened if multiple propellers are used. Even now, with twin screws, the risk of total breakdown is extremely small.

Whatever may be the size and power of steamships, there must come times at sea when they must slow down and wait for better weather. But the larger and longer the vessel, the fewer will be the occasions when this precaution need be exercised.

It must never be forgotten that as ships grow in size, speed, and cost, so the responsibilities of those in charge increase. The captain of a modern steamship needs remarkable qualities to perform his multifarious duties efficiently. The chief engineer must have great powers of organisation, as well as good technical knowledge, to control and utilise most advantageously the men and machinery in his charge. Apart from the ceaseless care, watchfulness and skill of officers and men, the finest ships and most perfect machinery are of little avail. The "human factor" is often forgotten, but is all-important. Let us hope that in the future, as in the past, as responsibilities increase so will the men be found to bear them.

NOTES.

A STATUE, erected in memory of the late M. F. Tisserand, will be unveiled at Nuits-Saint-Georges on October 15.

MAJOR RONALD ROSS has sent Mr. A. L. Jones a letter from Sierra Leone on his investigations into the cause of malaria. In the course of the communication he says:—We have now practically finished our work here. We have found—(*a*) that local species of Anopheles (mosquitoes) carry malaria; (*b*) that these species breed in a few stagnant puddles. For many scientific reasons we have come to the conclusion that the truly malarial fever is caused here solely by the mosquito—probably entirely by the Anopheles species. We estimate then that most of the malarial fever here can be got rid of at almost no cost except of a little energy on the part of the local authorities.

A SUCCESSION of earthquake shocks occurred on Monday night, September 25, in the district of Darjeeling, involving great loss of life and damage to property. No details as to the exact times of the shocks have been received. The earthquake was accompanied by a remarkable rainfall, and was followed by extensive landslips. It is reported that in twenty-four hours over 20 inches of rain fell, and in all 28 inches fell in thirty-eight hours.

THE associate editorship of the *American Journal of Science*, vacant by the death of Prof. Marsh, has been taken up by Prof. L. V. Pirsson, of Yale College.

IN a report just issued on metalliferous mines in the North Wales district, Dr. C. Le Neve Foster refers to the fact that several foreign companies have lately purchased mines in that district with the object of reworking them. He remarks:—"Though I welcome the advent into Wales of the famous Vieille Montagne Company, for I have hopes that its methods of mining and dressing will form useful object-lessons to us, I am not blind to the slur which is cast upon us as a mining nation. If such a capable body of commercial men as the directors of the Vieille Montagne Company propose to resuscitate some of our abandoned mines, it may be taken for granted that they consider the enterprise as likely to be profitable. Is our mining talent so far behind the times that foreigners can make a profit out of mines which we have abandoned as worthless? If so, the