DIVISION FOURTH.

PRACTICAL SHIPBUILDING.

CHAPTER I.

SPECIAL PROPERTIES OF MATERIALS.

SECTION I.—IRON AND STEEL.

ARTICLE 1. *Sources and Kinds of Iron.*—The following are the most common conditions in which iron is found in its ores :—

		By Chemical equivalents.*	By Weight.		Per centage of Iron.
I. *Native Iron*, being iron nearly pure, or combined with from one-fourth to one-hundredth part of its weight of nickel. This is found in detached masses, and is very rare,.................					80 to 100
II. Protoxide or Black Oxide of Iron,.....................	Iron,........	2	56	72	77·8
	Oxygen,...	1	16		
Protoxide of iron is found only in combination with other substances.					
III. Peroxide or Red Oxide of Iron,..	Iron,........	4	112	160	70
	Oxygen,...	3	48		
IV. Magnetic Oxide of Iron,...	Iron,........	3	84	116	72·4
	Oxygen,...	2	32		
V. Hydrate of Peroxide of Iron =					
Peroxide of Iron, 2 equivs.,	Iron,........	8	224	374	60
	Oxygen,...	6	144		
Water,..............3 equivs.,	Oxygen,...	3			
	Hydrogen,.	6	6		
VI. Carbonate of Iron =					
Protoxide of Iron, 1 equiv.,	Iron,........	2	56	116	48·3
	Oxygen,...	1	48		
Carbonic Acid,....1 equiv.,	Oxygen,...	2			
	Carbon,....	2	12		

Iron is found combined with sulphur, forming what is called *Iron Pyrites;* but that mineral is not available for the manufacture of iron; and it forms a pernicious ingredient in ores, or in the fuel used to smelt them, because of the weakening effect of sulphur upon iron. The same is the case with *Phosphate of Iron.*

The most abundant foreign ingredients found mixed with compounds of iron in its ores are siliceous sand, and silicate of alumina, or clay; next in abundance are the carbonates of lime and magnesia. Amongst other foreign ingredients, which, though not abundant, have an influence on the quality of the iron produced, are carbon, manganese, arsenic, &c. Of these manganese and carbon alone are beneficial: all the rest are hurtful.

The most common *Ores of Iron* are the following :—

I. MAGNETIC IRON ORE, consisting of magnetic oxide of iron, pure, or almost pure, and containing 72 per cent. of iron, is found chiefly in veins traversing the primary strata, and amongst plutonic rocks, and is the source of some of the finest qualities of iron, such as those of Sweden and the North-eastern United States.

II. RED IRON ORE is peroxide of iron, pure or mixed. When pure and crystalline, it is called *Specular Iron Ore*, or *Iron-glance:* when pure, or nearly so, and in kidney-shaped masses, showing a fibrous structure, it is called *Red Hæmatite;* when mixed with less or more clay and sand, it is called *Red Ironstone* and *Red Ochre.* It is found in various geological formations, and is purest in the oldest. The purer kinds, iron-glance and hæmatite, produce excellent iron; for example, that of Nova Scotia.

III. BROWN IRON ORE is hydrate of peroxide of iron, pure or mixed. When compact and nearly pure, it is called *Brown Hæmatite;* when earthy and mixed with much clay, *Yellow Ochre.* It is found amongst various strata, especially those of later formations.

IV. CARBONATE OF IRON, when pure and crystalline, is called *Sparry* or *Spathose Iron Ore;* when mixed with clay and sand, *Clay Ironstone;* when clay ironstone is coloured black by carbonaceous matter, it is called *Black-band Ironstone.* These ores are found amongst various primary and secondary stratified rocks, and especially amongst those of the coal formation. The proportion of earthy matter in the ordinary ores containing carbonate of iron ranges from 10 to 40 per cent.

The iron of Britain is manufactured partly from hæmatite, but chiefly from clay ironstone and black-band.

The metallic products of the iron manufacture are of three kinds; *malleable* or *wrought iron*, being pure or nearly pure iron; *cast iron* and *steel*, being certain compounds of iron with carbon.

2. *Impurities of Iron.*—The strength and other good qualities of those products depend mainly on the absence of impurities, and especially of certain substances which are known to cause brittleness and weakness, of which the most important are, sulphur, phosphorus, silicon, calcium, and magnesium.

Sulphur and calcium, and probably also magnesium, make iron "*red short*," that is, brittle at high temperatures; phosphorus and silicon make it "*cold short*," that is, brittle at low temperatures. These are both serious defects; but the latter is the worse.

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* The chemical equivalents adopted in the above Table, are as follows:—

Oxygen, ...	16
Carbon, ...	6
Hydrogen, ...	1
Iron, ...	28

Sulphur comes in general from coal or coke used as fuel. Its pernicious effects can be avoided altogether by using fuel which contains no sulphur; and hence the strongest and toughest of all iron is that which is smelted, reduced, and puddled either with charcoal, or with coal or coke that is free from sulphur.

Phosphorus comes in most cases from phosphate of iron in the ore, or from phosphate of lime in the ore, the fuel, or the flux. The ores which contain most phosphorus are those found in strata where animal remains abound, such as those of the oolitic formation.

Calcium and *Silicon* are derived respectively from the decomposition of lime and of silica by the chemical affinity of carbon for their oxygen. The only iron which is entirely free from these impurities is that which is made by the reduction of ores that contain neither silica, nor lime, such as pure magnetic iron ore, pure hæmatite, and pure sparry iron ore.

If either of those earths be present in the ore, the other must be added as a *flux*, to form a slag with it; and a small portion of each of them will be deoxidated, the bases uniting with the iron.

The statements made relative to calcium, are applicable also to magnesium.

The effect of aluminium upon iron is not known with certainty.

3. *Cast Iron* is the product of the process of *smelting* iron ores. In that process the ore in fragments, mixed with fuel and with flux, is subjected to an intense heat in a blast-furnace, and the products are *slag*, or glassy matter formed by the combination of the flux with the earthy ingredients of the ore, and *pig iron*, which is a compound of iron and carbon, either unmixed, or mixed with a small quantity of uncombined carbon in the state of plumbago.

The ore is often *roasted* or calcined before being smelted, in order to expel carbonic acid and water.

The proportions of ore, fuel, and flux are fixed by trial; and the success of the operation of smelting depends much on those proportions. The flux is generally limestone, from which the carbonic acid is expelled by the heat of the furnace; while the lime combines with the silica and alumina of the ore. If the ore contains carbonate of lime, less lime is required as a flux. If either lime or silica is present in excess, part of the earth which is in excess forms a glassy compound with oxide of iron, which runs off amongst the slag, so that part of the iron is wasted; and another part of that earth becomes reduced, its base combining with the iron and making it brittle, as has been stated in the preceding Article; so that in order to produce at once the greatest quantity and best quality of iron from the ore, the earthy ingredients of the entire charge of the furnace must be in certain definite proportions, which are discovered for each kind of ore by careful experiment.

The total quantity of carbon in pig iron ranges from 2 to 5 per cent. of its weight.

Different kinds of pig iron are produced from the same ore in the same furnace under different circumstances as to temperature and quantity of fuel. A high temperature and a large quantity of fuel produce *grey cast iron*, which is further distinguished into No. 1, No. 2, No. 3, and so on; No. 1 being that produced at the highest temperature. A low temperature and a deficiency of fuel produce *white cast iron*. Grey cast iron is of different shades of bluish-grey in colour, granular in texture, softer and more easily fusible than white cast iron. White cast iron is silvery white, either granular or crystalline, comparatively difficult to melt, brittle, and excessively hard.

It appears that the differences between those kinds of iron depend, not so much on the total quantities of carbon which they contain, as on the proportions of that carbon which are respectively in the conditions of mechanical mixture and of chemical combination with the iron. Thus, grey cast iron contains *one* per cent., and sometimes less, of carbon in chemical combination with the iron, and from *one* to *three* or *four* per cent. of carbon in the state of plumbago in mechanical mixture; while white cast iron is a homogeneous chemical compound of iron with from 2 to 4 per cent. of carbon. Of the different kinds of grey cast iron, No. 1 contains the greatest proportion of plumbago, No. 2 the next, and so on.

There are two kinds of white cast iron, the *granular* and the *crystalline*. The granular kind can be converted into grey cast iron by fusion and slow cooling; and grey cast iron can be converted into granular white cast iron by fusion and sudden cooling. This takes place most readily in the best iron. Crystalline white cast iron is harder and more brittle than granular, and is not capable of conversion into grey cast iron by fusion and slow cooling. It is said to contain more carbon than granular white cast iron; but the exact difference in their chemical composition is not yet known.

Grey cast iron, No. 1, is the most easily fusible, and produces the finest and most accurate castings; but it is deficient in hardness and strength; and, therefore, although it is the best for castings of moderate size, in which accuracy is of more importance than strength, it is inferior to the harder and stronger kinds, No. 2 and No. 3, for large structures.

The presence of plumbago renders iron comparatively weak and pliable, so that the order of strength and stiffness among different kinds of cast iron from the same ore and fuel is as follows:—

Granular white cast iron.
Grey cast iron, No. 3.
" " No. 2.
" " No. 1.

Crystalline white cast iron is not introduced into this classification, because its extreme brittleness makes it unfit for use in engineering structures or in machinery.

Granular white cast iron also, although stronger and harder than grey cast iron, is too brittle to be a safe material for the entire mass of any girder, or other large piece of a structure or machine; but it is used to form a hard and impenetrable *skin* to a piece of grey cast iron by the process called *chilling*. This consists in lining the portion of the mould where a hardened surface is required with suitably shaped pieces of iron. The melted metal, on being run in, is cooled and solidified suddenly where it touches the cold iron; and for a certain depth from the chilled surface, varying from about $\frac{1}{8}$th to $\frac{1}{2}$ inch in different kinds of iron, it takes the white granular condition, while the remainder of the casting takes the grey condition.

Even in castings which are not chilled by an iron lining to the mould, the outermost layer, being cooled more rapidly than the interior, approaches more nearly to the white condition, and forms a *skin* harder and stronger than the rest of the casting.

The best kinds of cast iron for large structures are No. 2 and No. 3; because, being stronger than No. 1, and softer and more flexible than white cast iron, they combine strength and pliability in the manner which is best suited for safely bearing loads that are in motion.

A strong kind of cast iron called *toughened cast iron*, is produced by the process invented by Mr. Morries Stirling, of adding to the cast iron, and melting amongst it, from one-fourth to one-seventh of its weight of wrought iron scrap.

Malleable Cast Iron is made by the following process:—The castings to be made malleable are imbedded in the powder of red hæmatite; they are then raised to a bright red heat (which occupies about 24 hours), maintained at that heat for a period varying from three to five days, according to the size of the casting, and allowed to cool (which occupies about 24 hours more). The oxygen of the hæmatite extracts part of the carbon from the cast iron, which is thus converted into a sort of soft steel; and its tenacity (according to experiments by Messrs. A. More & Son) becomes more than 48,000 lbs. per square inch.

The strength of cast iron to resist cross breaking was found by Mr. Fairbairn to be increased by *repeated meltings* up to the *twelfth*, when it was greater than at first in the ratio of 7 to 5 nearly. After the twelfth melting that sort of strength rapidly fell off.

The resistance to crushing went on increasing after each successive melting; and after the *eighteenth* melting it was double of its original amount, the iron becoming silvery white and intensely hard.

The transverse strength of No. 3 cast iron was found by Mr. Fairbairn not to be diminished by raising its temperature to 600° Fahr. (being about the temperature of melting lead). At a red heat its strength fell to two-thirds.

The strength of cast iron of every kind is marked by two properties; the smallness of the tenacity as compared with the resistance to crushing, and the different values of the modulus of rupture of the same kind of iron in bars torn directly asunder, and in beams of different forms when broken across.

For the results of experiments on the strength of various kinds of cast iron, see the Table at the end of Division III.

4. *Castings for Engineering Structures and Machinery.*—The best course for an engineer or shipbuilder to take, in order to obtain cast iron of a certain strength, is not to specify to the founder any particular kind or mixture of pig iron, but to specify a certain minimum strength which the iron should show when tested by experiment.

As to the appearance of good iron for engineering castings, it should show on the outer surface a smooth, clear, and continuous skin with regular faces and sharp angles. When broken, the surface of fracture should be of a light bluish-grey colour and close-grained texture, with considerable metallic lustre; both colour and texture should be uniform, except that near the skin the colour may be somewhat lighter and the grain closer; if the fractured surface is *mottled*, either with patches of darker or lighter iron, or with crystalline spots, the casting will be unsafe; and it will be still more unsafe if it contains air-bubbles. The iron should be soft enough to be slightly indented by a blow of a hammer on an edge of the casting.

Castings are tested for air-bubbles by ringing them with a hammer all over the surface.

Cast iron, like many other substances, when at or near the temperature of fusion, is a little more bulky for the same weight in the solid than in the liquid state, as is shown by the solid iron floating on the melted iron. This causes the iron as it solidifies to fill all parts of the mould completely, and to take a sharp and accurate figure.

The solid iron contracts in cooling from the melting point down to the temperature of the atmosphere, by $\frac{1}{96}$th part in each of its linear dimensions, or *one-eighth of an inch in a foot;* and therefore patterns for castings are made larger in that proportion than the intended pieces of cast iron which they represent.

In designing patterns for castings, care must be taken to avoid all abrupt variations in the thickness of metal, lest parts of the casting near each other should be caused to cool and contract with unequal rapidity, and so to split asunder or overstrain the iron.

Iron becomes more compact and sound by being cast under pressure; and hence cast iron cylinders, pipes, columns, and the like, are stronger when cast in a vertical than in a horizontal position, and stronger still when provided with a *head*, or additional column of iron, whose weight serves to compress the mass of iron in the mould below it. The air bubbles ascend and collect in the head, which is broken off when the casting is cool.

Care should be taken not to cut or remove the skin of a piece of cast iron at those points where the stress is intense.

Cast iron expands in linear dimensions by about $\frac{1}{900}$, or ·00111, in rising from the freezing to the boiling point of water; being at the rate of ·00000617 for each degree of Fahrenheit's scale, or about ·0004 for the range of temperature which is usual in the British climate. Every structure containing cast iron must be so designed that the greatest expansion and contraction of the castings by change of temperature shall not injure the structure.

5. *Wrought or Malleable Iron* in its perfect condition is simply pure iron. It falls short of that perfect condition to a greater or less extent owing to the presence of impurities, of which the most common and injurious have been mentioned, and their effects stated, in Article 2; and its strength is in general greater or less according to the greater or less purity of the ore and fuel employed in its manufacture.

Malleable iron may be made either by direct reduction of the ore, or by the abstraction of the carbon and various impurities from cast iron. The process of direct reduction is applicable to rich and pure ores only; and it leaves a slag or "cinder" which contains a large proportion of oxide of iron, and yields pig iron by smelting. The most economical and generally applicable process is that of removing the foreign constituents from pig iron; and for that purpose white pig iron (called "forge pig") is usually employed, partly because it retains less carbon on the whole than grey pig iron, and partly because it is unfit for making castings. The details of the process are very much varied; but the most important principle of its operation always is to bring the pig iron in a melted state into close contact with a quantity of air sufficient to oxidate all the carbon and silicon. The carbon escapes in carbonic oxide or carbonic acid gas; the silica produced by the oxidation of the silicon combines partly with protoxide of iron and partly with lime (which is sometimes introduced as a flux for it), and forms slag or "cinder." Chloride of sodium (common salt) is used to remove sulphur and phosphorus. In another form of the process this is performed by injecting jets of steam amongst the molten iron; the oxygen of the steam assists in oxidating the carbon and silicon, and the hydrogen combines with the sulphur and phosphorus. The surest method, however, of obtaining iron free from the weakening effects of sulphur and phosphorus is to employ ores and fuel that do not contain those constituents.

The most common form of the process of making malleable iron is *puddling*, in which the pig iron is melted in a reverberatory furnace, and is brought into close contact with the air by stirring it with a rake or "rabble." Some iron-makers precede the process of puddling by that of "refining," in which the pig iron, in a melted state, has a blast of air blown over its surface. This removes part of the carbon, and leaves a white crystalline compound of iron and carbon called "refiners' metal." Others omit the refining, and at once puddle the pig iron; this is called "*pig boiling.*" The removal of the carbon is indicated by the thickening of the mass of iron, malleable iron requiring a higher temperature for its fusion than cast iron. It is formed into a lump called a "loup" or "bloom," taken out of the furnace, and placed under a tilt hammer or in a suitable squeezing machine, to be "*shingled;*" that is, to have the cinder forced out, and the particles of iron welded together by blows or pressure.

The bloom is then passed between rollers, and rolled into a bar; the bar is cut into short lengths, which are fagotted together, reheated, and rolled again into one bar; and this process is repeated till the iron has become sufficiently compact, and has acquired a fibrous structure.

Bars are called No. 1, No. 2, No. 3 bars, &c., according to the number of times they have been rolled.

In Mr. Bessemer's process, the molten pig iron, having been run into a suitable vessel, has jets of air blown through it by a blowing machine. The oxygen of the air combines with the silicon and carbon of the pig iron, and in so doing produces enough of heat to keep the iron in a melted state till it is brought to the malleable condition; it is then run into large ingots, which are hammered and rolled in the usual way. The process has been most successful when applied to pig iron that is free from sulphur and phosphorus, such as that of Sweden and Nova Scotia.

Strength and toughness in bar iron are indicated by a fine, close, and uniform fibrous structure, free from all appearance of crystallization, with a clear bluish-grey colour and silky lustre on a torn surface where the fibres are shown.

Plate iron of the best kind consists of alternate layers of fibres crossing each other. It should have a hard smooth skin, somewhat glossy, and when broken, should show perfect uniformity of structure, and be free from all tendency to split into layers.

To examine the internal structure of iron, whether in bars or in plates, a short piece may be notched on one side near the middle and bent double. The fitness of bar iron for shipbuilding and smith-work is tested by bending and punching it cold, and by punching and forging it hot, so as to ascertain whether it shows any signs of brittleness either when cold or when hot, (called "cold-short" and "hot-short").

Malleable iron is distinguished by the property of *welding:* two pieces, if raised nearly to a white heat and pressed or hammered firmly together, adhering so as to form one piece. In all operations of which welding forms a part, such as rolling and forging, it is essential that the surfaces to be welded should be brought into close contact, and should be perfectly clean and free from oxide of iron, cinder, and all foreign matter.

In all cases in which several bars are to be fagotted or rolled into one, attention should be paid to the manner in which they are "*piled*" or built together, so that the pressure exerted by the hammer or the rollers may be transmitted through the whole mass. If this be neglected, the finished bar, plate, or other piece, may show flaws marking the divisions between the bars of the pile.

Wrought iron, although it is at first made more compact and strong by *reheating* and hammering, or otherwise working it, soon reaches a state of maximum strength, after which all reheating and working rapidly makes it weaker, as is shown in the Tables of Division III. Good bar iron has in general attained its maximum strength; and therefore, in all operations of forging it, whether on a great or small scale, by the steam-hammer or by that in the hand of the blacksmith, the desired size and figure ought to be given with the least possible amount of reheating and working.

It is of great importance to the strength of all pieces of forged iron that the *continuity of the fibres* near the surface should be as little interrupted as possible; in other words, that the fibres near the surface should lie in layers parallel to the surface.[*]

Another important principle in designing pieces of forged iron which are to sustain shocks and vibrations, is to avoid as much as possible abrupt variations of dimensions, and angular figures, especially those with re-entering angles; for at the points where such abrupt variations and angles occur fractures are apt to commence. If two parts of a shaft, for example, or of a beam exposed to shocks and vibrations, are to be of different thicknesses, they should be connected by means of curved surfaces, so that the change of thickness may take place gradually, and without re-entering angles.

6. *Steel and Steely Iron.*—Steel, the hardest of the metals and the strongest of known substances, is a compound of iron with from 0·5 to 1·5 per cent. of its weight of carbon. These, according to most authorities, are the only essential constituents of steel.

The term "steely iron," or "semi-steel," may be applied to compounds of iron with less than 0·5 per cent. of carbon. They are intermediate in hardness and other properties between steel and malleable iron.

In general, such compounds are the harder and the stronger, and also the more easily fusible, the more carbon they contain; those kinds which contain less carbon, though weaker, are more easily welded and forged, and from their greater pliability are the fitter for structures that are exposed to shocks.

Impurities of different kinds affect steel injuriously in the same way with iron.

There are certain foreign substances which have a beneficial effect on steel. One 2000th part of its weight of silicon causes steel to cool and solidify without bubbling or agitation; but a larger proportion is not to be used, as it would make the steel brittle. The presence of manganese in the iron, or its introduction into the crucible or vessel in which steel is made, improves the steel by increasing its toughness and making it easier to weld and forge.

Steel is distinguished by the property of *tempering:* that is to say, it can be hardened by sudden cooling from a high temperature, and softened by gradual cooling; and its degree of hardness or softness can be regulated with precision by suitably fixing that temperature. The ordinary practice is, to bring all articles of steel to a high degree of hardness by sudden cooling, and then to soften them more or less by raising them to a temperature which is the higher the softer the articles are to be made, and letting them cool very gradually. The elevation of temperature previous to the "annealing" or gradual cooling is produced by plunging the articles into a bath of a fusible metallic alloy. The temperature of the bath ranges from 430° to 560° Fahr.

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[*] On this subject see a paper by the Editor of this Treatise, in the Proceedings of the Institution of Civil Engineers for 1843.

According to the experiments of Mr. Kirkaldy, a great increase of strength is produced by hardening steel in oil.

Steel is made by various processes, which have of late become very numerous. They may all be classed under two heads, viz., adding carbon to malleable iron, and abstracting carbon from cast iron. The former class of processes, though the more complex, laborious, and expensive, is preferred for making steel for cutting tools and other fine purposes, because of its being easier to obtain malleable iron than cast iron in a high state of purity. The latter class of processes is the best adapted for making great masses of steel and steely iron rapidly and at moderate expense. The following are some of the processes employed in making different kinds of steel:—

Blister Steel is made by a process called "*cementation*," which consists in imbedding bars of the purest wrought iron (such as that manufactured by charcoal from magnetic iron ore) in a layer of charcoal, and subjecting them for several days to a high temperature. Each bar absorbs carbon, and its surface becomes converted into steel, while the interior is in a condition intermediate between steel and iron. Cementation may also be performed by exposing the surface of the iron to a current of carburetted hydrogen gas at a high temperature. Cementation is sometimes applied to the surfaces of articles of malleable iron in order to give them a skin or coating of steel, and is called "*case-hardening.*"

Shear Steel is made by breaking bars of blister steel into lengths, making them into bundles or fagots, and rolling them out at a welding heat, and repeating the process until a near approach to uniformity of composition and texture has been obtained. It is used for various tools and cutting implements.

Cast Steel is made by melting bars of blister steel in a crucible, along with a small additional quantity of carbon (usually in the form of coal tar) and some manganese. It is the purest, most uniform, and strongest steel, and is used for the finest cutting implements.

Another process for making cast steel, but one requiring a higher temperature than the preceding, is to melt bars of the purest malleable iron with manganese and with the whole quantity of carbon required in order to form steel. The quality of the steel as to hardness is regulated by the proportion of carbon. A sort of semi-steel, or steely iron, made by this process, and containing a small proportion of carbon only, is known as *homogeneous metal.*

Steel made by the air blast is produced from molten pig iron by Mr. Bessemer's process in two ways; either the blowing of jets of air through the iron is stopped at an instant determined by experience, when it is known that a quantity of carbon still remains in the iron sufficient to make steel of the kind required, or else the blast is continued until the carbon is all removed, so that the vessel is full of pure malleable iron in the melted state, and carbon is added in the proper proportion, along with manganese and silicon. The usual way of adding the carbon is by running into the vessel a sufficient quantity of highly carbonized cast iron. The steel thus produced is run into large ingots, which are hammered and rolled like blooms of wrought iron.

Puddled Steel is made by puddling pig iron, and stopping the process at the instant when the proper quantity of carbon remains. The bloom is shingled and rolled like bar iron.

Granulated Steel is made by running melted pig iron into a cistern of water, over a wheel, which dashes it about so that it is found at the bottom of the cistern in the form of grains or lumps of the size of a hazel nut, or thereabouts. These are imbedded in pulverized hæmatite, or in sparry iron ore, and exposed to a heat sufficient to cause part of the oxygen of the ore to combine with and extract the carbon from the superficial layer of each of the lumps of iron, each of which is reduced to the condition of malleable iron at the surface, while its heart continues in the state of cast iron. A small additional quantity of malleable iron is produced by the reduction of the ore. These ingredients, being melted together, produce steel.

There are other processes for making steel and steely iron, of which the details are not yet publicly known.

7. *Strength of Wrought Iron and Steel.*—Wrought iron, like fibrous substances in general, is more tenacious along than across the fibres; and its tenacity is greater than its resistance to crushing. The effect of the latter difference on the best forms of cross-section for beams has already been considered in the Third Division.

The ductility of wrought iron often causes it to yield by degrees to a load, so that it is difficult to determine its strength with precision.

Wrought iron has its longitudinal tenacity considerably increased by rolling and wire-drawing; so that the smaller sizes of bars are on the whole more tenacious than the larger; and iron wire is more tenacious still, as is shown in the Table of tenacity at the end of Division III.

Wrought iron is weakened by too frequent reheating and forging; so that even in the best of large forgings, the tenacity is only about *three-fourths* of that of the bars from which the forgings were made, and sometimes even less.

As to the *effect of heat on the strength of wrought iron*, it has been shown by Mr. Fairbairn ("Useful Information for Engineers," second series)—

I. That the tenacity of ordinary *boiler plate* is not appreciably diminished at a temperature of 395° Fahr., but that at a dull red heat it is diminished to about three-fourths.

II. That the tenacity of good *rivet iron* increases with elevation of temperature up to about 320° Fahr., at which point it is about one-third greater than at ordinary atmospheric temperatures; and that it then diminishes, and at a red heat is reduced to little more than one-half of its value at ordinary atmospheric temperatures.

Numerous experiments have been made on the tenacity of steel; but its other kinds of strength have been very little investigated. Its tenacity, like that of bar iron, is increased by rolling and wire-drawing.

Plate iron is somewhat less tenacious crosswise than lengthwise; but the difference ought not to exceed about one-tenth.

When the tenacity of iron intended for purposes of shipbuilding is tested by a machine, it is considered not to be fit for use if the specimen is broken by a less load than 20 tons on the square inch of the original sectional area, or 24 tons on the square inch of the area as diminished by drawing out at the place of fracture. As to the greater strength possessed by the better qualities of iron, see the Tables.

It is highly important also that the iron should possess *toughness;* and this may be tested by observing *in what proportion the length of the piece is increased at the instant before breaking.* The ultimate elongation of really good and tough specimens of iron and steel, as ascertained in Mr. Kirkaldy's experiments, was nearly as follows, in fractions of the original length :—

Bar iron, from	0·15	to 0·30
Plate iron, lengthwise, from	0·04	to 0·17
" crosswise, from	0·015	to 0·11
Steel bars, from	0·05	to 0·19
Steel plates, from	0·03	to 0·19

8. *Preservation of Iron in the Air.*—The present Article has reference only to the preservation of pieces of iron work exposed to the air. The subject of the preservation of ships' bottoms belongs to a later Chapter of the present Division; and that of the preservation of steam-boilers, to the Sixth Division.

The corrosion of iron is a sort of slow combustion, during which the iron combines with oxygen, and produces rust. The ordinary methods of preserving iron in the air consist principally in preventing the access of oxygen to the metal.

Cast iron will often last for a long time without rusting, if care be taken not to injure its skin, which is usually coated with a film of silicate of the protoxide of iron, produced by the action of the sand of the mould on the iron. Chilled surfaces of castings are without that protection, and therefore rust more rapidly.

The corrosion of iron is more rapid when partly wet and partly dry, than when wholly immersed in water or wholly exposed to the air. It is accelerated by impurities in water, and especially by the presence of decomposing organic matter, or of free acids. It is also accelerated by the contact of iron with any metal which is electro-negative relatively to the iron, or in other words, has less affinity for oxygen (such as copper), or with the rust of the iron itself. If two portions of a mass of iron are in different conditions, so that one has less affinity for oxygen than the other, the contact of the former makes the latter oxidate more rapidly. In general, hard and crystalline iron is less rapidly oxidable than ductile and fibrous iron. Cast iron and steel decompose rapidly in warm or impure sea-water.

Pieces of iron which are kept constantly in a state of vibration oxidate less rapidly than those which are at rest.

(See Mallet "On the Corrosion of Iron," in the "Reports of the British Association" for 1843 and 1849).

The following are amongst the ordinary methods of preserving iron which is not immersed in sea-water, hot or cold, nor exposed to hot steam :—

I. Boiling in coal-tar, especially if the pieces of iron have first been heated to the temperature of melting lead.

II. Heating the pieces of iron to the temperature of melting lead, and smearing their surfaces, while hot, with cold linseed oil, which dries and forms a sort of varnish.

III. Painting with oil-paint, which must be renewed from time to time. The linseed oil process is a good preparation for painting.

IV. Coating with zinc, commonly called galvanizing. This is efficient, provided it is not exposed to acids capable of dissolving the zinc; but it is destroyed by sulphuric acid in the atmosphere of places where much coal is burned.

9. *Expansion of Iron and Steel by Heat.*—The following are proportionate longitudinal expansions produced by heating from the temperature of melting ice (32° Fahr., or 0° Cent.) to that of water boiling under the average atmospheric pressure (212° Fahr., or 100° Cent.), being a rise of 180° Fahr. = 100° Cent.

Cast iron,	0·00111
Steel,	0·00120
Malleable iron,	0·00125

SECTION II.—COPPER AND OTHER METALS AND ALLOYS.

10. *Copper* (except when found in the native or metallic state) is extracted from ores which contain that metal in the state of oxide, of carbonate, or of sulphuret; and the sulphuret of copper is almost always in combination with sulphuret of iron, and often with sulphurets and selenurets of arsenic, antimony, lead, and other metals. Besides the copper-bearing minerals, most of the ores contain earthy matter, consisting chiefly of silica and alumina.

The richer ores containing oxides and carbonates are in the first place smelted along with a flux (usually lime) suitable for combining with the earthy constituents, which run off in the form of slag; the greater part of the oxygen is taken away by the carbon of the fuel; the substance remaining, called *black copper*, is an impure copper, containing small quantities of iron, oxide of iron, silica, sulphur, and other ingredients. The ores containing sulphurets are roasted, sometimes repeatedly, before being melted, to expel part of the sulphur; the principal product obtained after smelting is called *matt*, and is a compound of sulphuret of copper with sulphuret of iron.

The poorer ores containing oxides and carbonates are sometimes deoxidated by being smelted along with sulphuret of iron; the iron takes the oxygen, and the copper the sulphur, and the products are matt and black copper mixed.

The matt obtained by either of those processes is subjected to a series of smeltings along with a siliceous flux, which have the effect of gradually expelling the sulphur, and removing the iron in the form of a silicate of the protoxide of iron; so that the final product is black copper.

The black copper is purified by melting it in a suitable furnace, in which a stream of air is directed on its surface; the oxygen of the air combines with and carries off the iron, sulphur, and other impurities. The melted copper, when purified as completely as possible, retains a certain quantity of oxygen, which is removed as far as possible by sprinkling the surface of the melted metal with charcoal, and stirring it with a pole of green wood. Much skill is required to stop this process at the right moment; for whether it is stopped too soon, or carried on too long, the metal obtained is injured and weakened; in the former case by the presence of oxide of copper; and in the latter, by some weakening action of the carbon, the precise nature of which is not known with certainty.

The greater or less admixture of oxide of copper with the metal, is indicated by the greater or less redness of its colour.

The preceding is a very brief outline of the processes of smelting and refining copper ores; for the details of which, as well as for an account of various recent modifications and improvements, reference must be made to works on metallurgy, such as those of Mr. Phillips and Dr. Percy.

For marine purposes, copper is chiefly used in the form of sheets for sheathing ships, and bolts for fastening them, made by rolling and hammering; which operations considerably increase its tenacity (see the Table of the Strength of Metals).

The quality principally required in such copper is that of resisting the oxidating action of sea-water. At the same time, it must not be wholly protected against oxidation; but must be eaten away at the slowest rate that is sufficient to make a thin film of oxide scale off from time to time, carrying with it the shell-fish and weeds which would otherwise incrust the bottom of the ship and impede her motion.

The protection of ships' bottoms will be treated of fully in a later Chapter; the present Article is limited to the consideration of the qualities of copper suitable for sheathing. Our knowledge of that subject is still very imperfect. A summary of the facts hitherto ascertained regarding it is given in a paper read by Mr. W. J. Hay, Admiralty Chemist, to the Institution of Naval Architects in 1863 (see their Transactions for that year). From that paper it appears that the following conclusions may be regarded as established :—

I. Extreme purity of the copper, as regards freedom from other metals, is not essential to durability: on the contrary, the following proportions of alloy are favourable to durability :—

Silver, from	$\frac{1}{600}$	to	$\frac{1}{1000}$.
Iron, "	$\frac{1}{300}$	"	$\frac{1}{800}$.
Zinc, "	$\frac{1}{60}$	"	$\frac{1}{300}$.
Tin, "	$\frac{1}{100}$	"	$\frac{1}{300}$.

Potassium, in the proportion of $\frac{1}{300}$, softens copper.

II. Carbon, in the proportion of from $\frac{1}{200}$ to $\frac{1}{500}$, combined chemically with copper, renders it hard. A larger proportion of carbon does not combine chemically with the copper, but mixes with it mechanically, and is very injurious.

III. Oxygen and sulphur in the copper are very injurious.

IV. *Uniformity* of texture and composition is of the highest importance to durability; and nothing tends more to promote corrosion of the copper than the presence of patches of electro-negative metal or of oxide; because those patches, together with the other parts of the copper and the sea-water, form electric circuits.

As a means of increasing the compactness, and consequently the durability, of sheet copper for sheathing, *cold rolling* is recommended by Mr. Fincham.

11. *Alloys of Copper* with *Tin* and with *Zinc* are used, like copper itself, for sheathing and fastenings, and also for machinery. Various names, such as *brass, bronze, mixed metal,* &c., are applied to them indiscriminately; but strictly speaking, *Bronze* is the proper name of the alloys of copper and tin; *Brass,* that of the alloys of copper and zinc.

Both classes of alloys are less expensive than pure copper; and that is one reason for using them. Bronze, besides, is at least equal to copper in tenacity, and is considerably superior in hardness and resistance to crushing. Brass is inferior to copper in strength. Both bronze and brass make good castings, which quality is not possessed by copper.

As zinc is cheaper than tin, alloys of copper and zinc are preferable to those of copper and tin for sheathing: their inferiority of strength being of little consequence for that purpose.

The following general principle should be observed in the manufacture of all alloys whatsoever, as being essential to the soundness, strength, and durability of the compound metal—*The quantities of the constituents should bear definite atomic proportions to each other.*

For example, the chemical equivalents of Copper, Tin, and Zinc bear to each other the following proportions :—

Copper.		Tin.		Zinc.
31·5	....	59	....	32·5
or 63	....	118	....	65

and the proportions in which they are combined in any alloy should be expressed by multiples of those numbers.

When this rule is not observed, the metal produced is not a homogeneous compound, but a mixture of two or more different compounds in irregular masses, shown by a mottled appearance when broken; and those masses being different in expansibility and elasticity, tend to separate from each other; and being different in chemical composition, they produce electric circuits and promote corrosion.

The following is a list of some of the alloys of copper with tin and zinc, which are fit for use in machinery or in shipbuilding.

COMPOSITION.				ALLOYS OF COPPER AND TIN.
By Equivalents.		By Weight.		
Copper.	Tin.	Copper.	Tin.	
12	1	378	59	Very hard bronze.
14	1	441	59	Hard bronze, for machinery bearings.
16	1	504	59	Bronze, or gun-metal: contracts in cooling from its melting point, $\frac{1}{130}$.
18	1	567	59	Bronze, somewhat softer.
20	1	630	59	Soft bronze, for toothed wheels, &c.

COMPOSITION.				ALLOYS OF COPPER AND ZINC.
By Equivalents.		By Weight.		
Copper.	Zinc.	Copper.	Zinc.	
4	1	126	32·5	Malleable brass.
2	1	63	32·5	Ordinary brass: contracts in cooling from its melting point, $\frac{1}{60}$.
3	2	94·5	65	Yellow metal for sheathing and fastenings. This is cast in ingots, and rolled and worked at a red heat into sheets and bolts.

Various alloys of copper, tin, and zinc, are used in machinery, and may be regarded as modifications of true bronze, produced by substituting one or two equivalents of zinc for one or two equivalents of the copper. They are less expensive than true bronze, but not so tough.

12. *Other Alloys.*—The strongest of all alloys yet known is *Aluminium Bronze,* as a reference to the Table of the strength of metals will show. Different sorts contain from 5 to 10 per cent. of aluminium, and from 95 to 90 per cent. of copper; and if 31·5 be taken as the equivalent of copper, and 13·7 as that of aluminium, their atomic constitution is probably from 8 to 4 equivalents of copper to one equivalent of aluminium.

Alloys of copper and lead, called *pot-metal,* are sometimes used for cocks and valves where strength is unimportant; but they are weak and brittle; and in bronze, lead is a pernicious adulteration.

Soft metal, for the bearings of shafts, consists of 50 parts of tin, 1 of copper, and 5 of antimony; it is, in fact, a sort of metallic grease. Its use will be referred to in the Sixth Division.

SECTION III.—TIMBER.

13. *Structure of Timber.*—Timber is the material of trees belonging almost exclusively to that class of the vegetable kingdom in which the stem grows by the formation of successive layers of wood all over its external surface, and is therefore said by botanists to be *exogenous.*

The exceptions are, trees of the palm family, and tree-like grasses, such as the bamboo, which belong to the *endogenous* class; so called because, although the stem grows partly by the formation of layers of new wood on its outer surface, the fibres of that new wood do nevertheless cross and penetrate amongst those previously formed in such a manner as to be mixed with them in one part of their course, and internal to them at another.

The stems of endogenous trees, though light and tough, are too flexible and slender to furnish materials suitable for shipbuilding. They will therefore not be further mentioned in this Section, except to refer to the Tables in the Third Division for the tenacity and heaviness of bamboo.

The following is a condensed view of the classification of exogenous timber, as above described:—

- CLASS I.—Pine-wood. (Natural order *Coniferæ.*)—Examples: Pine, Fir, Larch, Cowrie, Yew, Cedar, Juniper, Cypress, &c.
- CLASS II.—Leaf-wood. (Non coniferous trees.)
  - Division I.—With distinct large medullary rays. (The trees in this division form part of the natural order *Amentaceæ.*)
    - *Subdivision* 1.—Annual rings distinct.—Example: Oak.
    - *Subdivision* 2.—Annual rings indistinct.—Examples: Beech, Plane, Sycamore, &c.
  - Division II.—No distinct large medullary rays.
    - *Subdivision* 1.—Annual rings distinct.—Examples: Chestnut, Ash, Elm, &c.
    - *Subdivision* 2.—Annual rings indistinct.—Examples: Mahogany, Walnut, Teak, Greenheart, Mora, Lignum-Vitæ, &c.

The chief practical bearings of the foregoing classification are as follows:—

Pine-wood, or coniferous timber, in most cases, contains turpentine. It is distinguished by straightness in the fibre and regularity in the figure of the trees; qualities favourable to its use for spars, beams, and planking. The lightness of pine-wood makes the stronger kinds specially suitable for spars. At the same time, the lateral adhesion of the fibres is small; so that it is much more easily shorn and split along the grain, or torn asunder across the grain, than leaf-wood; and is therefore less fitted to resist thrust or shearing stress, or any kind of stress that does not act along the fibres. Even the toughest kinds of pine-wood are easily wrought. A peculiar characteristic of pine-wood (but one which requires the microscope to make it visible) is that of having the vascular tissue "*punctated;*" that is to say, there are small lenticular hollows in the sides of the tubular fibres. This structure is probably connected with the smallness of the lateral adhesion of those fibres to each other. Pine-wood is, on the whole, inferior to leaf-wood for the frames and skins of ships; because the strong kinds (as pine and fir) are deficient in durability; and the durable kinds (as cedar and cypress) are deficient in strength.

In *Leaf-wood*, or non-coniferous timber, there is no turpentine. The degree of distinctness with which the structure is seen, whether as regards medullary rays or annual rings, depends on the degree of difference of texture of different parts of the wood. Such difference tends to produce unequal shrinking in drying; and consequently those kinds of timber in which the medullary rays, and the annual rings, are distinctly marked, are more liable to warp than those in which the texture is more uniform. At the same time, the former kinds of timber are, on the whole, the more flexible, and in many cases are very tough and strong, which qualities make them suitable for structures that have to bear shocks.

15. *Appearance of good Timber.*—There are certain appearances which are characteristic of strong and durable timber, to what class soever it belongs.

In the same species of timber, that specimen will in general be the strongest and the most durable which has grown the slowest, as shown by the narrowness of the annual rings.

The cellular tissue as seen in the medullary rays (when visible) should be hard and compact.

The vascular or fibrous tissue should adhere firmly together, and should show no woolliness at a freshly-cut surface, nor should it clog the teeth of the saw with loose fibres.

If the wood is coloured, darkness of colour is in general a sign of strength and durability.

The freshly-cut surface of the wood should be firm and shining, and should have somewhat of a translucent appearance. A dull, chalky appearance is a sign of bad timber.

In wood of a given species, the heavier specimens are in general the stronger and the more lasting.

Amongst resinous woods, those which have least resin in their pores, and, amongst non-resinous woods, those which have least sap or gum in them, are in general the strongest and most lasting.

Timber should be free from such blemishes as "clefts," or cracks radiating from the centre; "cup-shakes," or cracks which partially separate one annual layer from another; "upsets," where the fibres have been crippled by compression; "rind-galls," or wounds in a layer of the wood, which have been covered and concealed by the growth of subsequent layers over them; and hollows or spongy places, in the centre or elsewhere, indicating the commencement of decay.

16. *Examples of Pine-wood.*—The following are examples of timber of this class:—

I. Pine timber of the best sort is the produce of the Red Pine, or Scottish Fir (*Pinus sylvestris*), grown in Norway, Sweden, Russia, and Poland. The best is exported from Riga, the next from Memel and from Dantzic. The same species of tree grows also in Britain, but is inferior in strength. The annual rings, when this timber is of the best kind, consist of a hard part, of a clear dark-red colour, and a less hard part, of a lighter colour, but still clear and compact. The thickness of the rings should not exceed one-tenth of an inch. The most common size of the logs to be met with in the market, is about 13 inches square. This is the best of all timber for the spars of ships.

Pine timber is also obtained from various other species, chiefly North American, of which the best are the Yellow Pine (*Pinus variabilis*), and White Pine (*Pinus Strobus*). It is softer and less durable than the Red Pine of the North of Europe, but lighter, and can be had in larger logs.

II. White Fir, or Deal timber of the best kind, is the produce of the Spruce Fir (*Abies excelsa*), grown in Norway, Sweden, and Russia. The best is that known as Christiania Deal. Much of this timber is sawn up for sale into pieces of various thicknesses suited for planking, which,

When 7 inches broad are called "*battens.*"
When 9 " " "*deals.*"
When 11 " " "*planks.*"

They are to be had of various lengths; but the most usual length is about 12 feet.

This is an excellent kind of timber for boarding, light framing, and joiners' work, and for the lighter spars of ships.

Amongst other kinds of spruce fir, applied to the same purposes, are the North American White Spruce (*Abies alba*), and Black Spruce (*Abies nigra*).

III. The Larch (*Larix Europæa*), grown in various parts of Europe, furnishes timber of great strength, and remarkable for durability when exposed to the weather; but harder to work and more subject to warp than red pine. The best sort has the harder part of the rings of a dark-red, and the softer part of a honey-yellow; and its rings are somewhat thicker than those of red pine.

Two North American species, the Black Larch, or Hackmatack (*Larix pendula*), and the Red Larch (*Larix microcarpa*), produce timber similar to that of the European Larch.

IV. The Cowrie or Kawrie (*Dammara Australis*), a coniferous tree, grown in New Zealand, produces timber similar in its properties to the best kinds of pine, except that it is said to be more liable to warp, and more variable in quality. It is of a brownish-yellow colour, and more uniform in its texture than red pine and larch.

V. The term Cedar is applied, not only to the timber of the true Cedar (*Cedrus Libani*), but also to that of various large species of Juniper (such as *Juniperus Virginiana*) and of Cypress. Those kinds of wood are remarkable for durability, in which they excel all other timbers; but they are deficient in strength.

17. *Examples of Leaf-wood with large Medullary Rays.*—The kinds of timber mentioned in this Article belong to the first division of Tredgold's system. Of the examples cited, the Oak alone belongs to the first subdivision, in which the divisions between the annual rings are distinctly marked by circles of pores. The other examples belong to the second subdivision, in which the rings are less distinctly marked:—

I. Oak timber, the strongest, toughest, and most lasting of those grown in temperate climates, is the produce of various species or varieties of the botanical genus *Quercus*. In Europe there are two kinds of oak trees; and it is doubtful whether they are distinct species or varieties of one species. They are—

The old English Oak, or Stalk-fruited Oak (*Quercus Robur* or *Quercus pedunculata*), in which the acorns grow on stalks, and the leaves close to the twig, and

The Bay Oak, or Cluster-fruited Oak (*Quercus sessiliflora*), in which the acorns grow in close clusters, and the leaves have short stalks.

Both those kinds of oak come to their greatest perfection in Britain.

The wood of the stalk-fruited oak is lighter in colour, and has more numerous and distinct medullary rays than that of the cluster-fruited oak, in which they are sometimes so few and indistinct as to have caused it in old buildings to be mistaken for chestnut. The stalk-fruited oak is the stiffer and the straighter-grained of the two, the easier to work, and the less liable to warp; it is therefore preferable where stiffness and accuracy of form are desired; the cluster-fruited oak is the more flexible, which gives it an advantage where shocks have to be borne.

The best oak timber when new is of a pale brownish-yellow colour, with a perceptible shade of green, a firm and glossy surface, very small and regular annual rings, and hard and compact medullary rays. Thick rings, many large pores, a dull surface, and a reddish, or "foxy" hue (caused by a fungus called "drux"), are signs of weak and perishable wood.

It is considered that oak timber comes to maturity at the age of 100 years, at which period each tree produces on an average about 75 cubic feet of timber; and that it should not be felled before the 60th year of its age, nor later than the 200th.

The species of oak in North America are very numerous. The best of them are, the Red Oak (*Quercus rubra*), and White Oak (*Quercus alba*), which are little inferior to the best European kinds, and the Live Oak (*Quercus virens*), which is said to be superior in strength, toughness, and durability, to all other species, but is very scarce. Large quantities of oak timber, very hard and durable, and well suited on account of great curvature for the frame-timbers of ships, have been obtained for H.M. service from Italy; but as the timber on becoming seasoned is full of shakes, it is unsuitable for other purposes.

The wood of the oak contains gallic acid, which contributes to the durability of the timber, but corrodes iron fastenings. Metal fastenings for oak should therefore be of copper, or its alloys.

The following are examples of trees belonging to the second subdivision:—

II. Beech (*Fagus sylvatica*), common in Europe.

III. American Plane (*Platanus occidentalis*), common in North America.

IV. Sycamore (*Acer Pseudo-platanus*), also called Great Maple, and in Scotland and the North of England, Plane; common in western Europe.

All these afford compact timber of uniform texture. They are valuable for blocks of wood which have to resist a crushing force, as for wedges for purposes of shipbuilding. They last well when constantly wet (especially beech, which is considered suitable for keels and bottom planking), but when alternately wet and dry they decay rapidly.

18. *Leaf-wood without large medullary rays.*—The examples of timber in this Article belong to the first subdivision of the second division, according to Tredgold's system, having no large distinct medullary rays, and having the divisions between the annual rings distinctly marked by a more porous structure. They are in general strong, but flexible.

I. The Ash (*Fraxinus excelsior*) furnishes timber whose toughness and flexibility render it superior to that of all other European trees for making handles of tools, shafts of carriages, and the like; but which is not sufficiently stiff and durable to be used in great works of carpentry. The colour of the wood is like that of oak, but darker, and with more of a greenish hue; the annual rings are broader than those of oak, and the difference between their compact and porous parts more marked.

II. The common Elm (*Ulmus campestris*) and Smooth-leaved Elm (*Ulmus globra*) yield timber which is valued for its durability when constantly wet, and is specially suited for keels, garboard strakes, and bottom planking; but not for planking that is alternately wet and dry. Its strength across the grain, and its resistance to crushing, are comparatively great; and these properties render it useful for some parts of mechanism, such as shells of ships' blocks. There are other European species of elm, such as the Wych Elm (*Ulmus montana*), but their timber is inferior to that of the two species named.

A North American species, the Rock Elm, is said to be not only durable under water, but straight-grained and tough, so as to be well suited for long beams and stringers.

19. *Examples of Leaf-wood without large medullary rays continued.*—The kinds of timber mentioned in this Article are examples of the second subdivision of Tredgold's second division, having no large distinct medullary rays, and no distinct difference of compactness in the rings. This uniformity of structure is accompanied by comparative freedom from warping.

I. Mahogany (*Swietenia Mahagoni*) is produced in Central America and the West Indian Islands: that of the former region being commonly known as "Bay Mahogany;" that of the latter as "Spanish Mahogany." When of good quality, it is very straight-grained, very strong in all directions (though easily split along the grain), very durable, and preserves its shape under varying circumstances as to heat and moisture better than any

The stem of an exogenous tree is covered with bark, which grows by the formation of successive layers on its inner surface, at the same time that the wood grows by the formation of successive layers on its outer surface. This double operation takes place in the narrow space between the previously-formed wood and bark, during the circulation of the sap. The sap ascends from the roots to the leaves through vessels contained in the outer layers of the wood; at the surface of the leaves it acquires carbon from the atmosphere, and becomes denser, thicker, and more complex in its composition; it then descends from the leaves to the roots through vessels contained chiefly in the innermost layers of the bark. It is believed that the formation of new wood and bark takes place either wholly or principally from the descending sap.

The circulation of the sap is either wholly or partially suspended during a portion of each year (in tropical climates during the dry season, and in temperate and polar climates during the winter); and hence the wood and bark are usually formed in distinct layers, at the rate of one layer in each year; but this rule is not universal. Each such layer consists of parts differing in density and colour to an extent which varies in different kinds of trees.

The tissues of which both wood and bark consist are distinguished into two kinds—*cellular tissue*, consisting of clusters of minute cells; and *vascular tissue*, or *woody fibre*, consisting of bundles of slender tubes; the latter being distinguished from the former by its fibrous appearance. The difference, however, between those two kinds of tissue, although very distinct both to the eye and to the touch, is really one of degree rather than of kind; for the fibres or tubes of vascular tissue are simply very much elongated cells, tapering to points at the ends, and "breaking joint" with each other.

The tenacity of wood when strained "along the grain" depends on the tenacity of the walls of those tubes or fibres; the tenacity of wood when strained "across the grain" depends on the adhesion of the sides of the tubes and cells to each other. Examples of the difference of strength in those different directions are given in the Tables.

When a woody stem is cut across, the cellular and vascular tissue are seen to be arranged in the following manner:—

In the centre of the stem is the *pith*, composed of cellular tissue, inclosed in the medullary sheath, which consists of vascular tissue of a particular kind. From the pith there extend, radiating outwards to the bark, thin partitions of cellular tissue, called *medullary rays;* between these, additional medullary rays extend inwards from the bark to a greater or less distance, but without penetrating to the pith.

When the medullary rays are large and distinct, as in oak, they are called "*silver grain.*"

Between the medullary rays lie bundles of vascular tissue, forming the woody fibre, arranged in nearly concentric rings or layers round the pith. These rings are traversed radially by the medullary rays. The boundary between two successive rings is marked more or less distinctly by a greater degree of porosity, and by a difference of hardness and colour.

The annual rings are usually thicker at that side of the tree which has had most air and sunshine, so that the pith is not exactly in the centre.

The wood of the entire stem may be distinguished into two parts—the outer and younger portion, called "*sap-wood,*" being softer, weaker, and less compact, and sometimes lighter in colour, than the inner and older portion, called "*heart-wood.*" The heart-wood is alone to be employed in those works of carpentry in which strength and durability are required. The boundary between the sap-wood and the heart-wood is in general distinctly marked, as if the change from the former to the latter occurred in the course of a single year. The following examples of the proportion of sap-wood to the entire volume are given on the authority of Tredgold ("Principles of Carpentry," Section X.):—

Tree.	Age. Years.	Diameter. Inches.	Rings of Sap-wood.	Thickness of Sap-wood. Inches.	Proportion of Sap-wood to whole Trunk.
Chestnut,	58	$15\frac{1}{2}$	7	$\frac{3}{4}$	0·1
Oak,	65	17	17	$1\frac{1}{4}$	0·294
Scotch Fir,	?	24	?	$2\frac{1}{2}$	0·416

The following data are given on the authority of Mr. Andrew Murray, C.E. (Ency. Brit., articlo "Timber"):—

Tree.	Rings of Sap-wood.
English Oak (*Quercus pedunculata*),	12 to 15
Durmast Oak (*Quercus sessiliflora*),	20 to 30
Chestnut (*Castanea Vesca*),	5 or 6
Elm (*Ulmus campestris*),	about 10
Larch (*Larix Europæa*),	" 15
Scotch Fir (*Pinus sylvestris*),	" 30
Memel Fir (*Pinus sylvestris*),	" 44
Canadian Yellow Pine (*Pinus variabilis*),	" 42

The structure of a *branch* is similar to that of the trunk from which it springs, except as regards the difference in the number of annual rings, corresponding to the difference of age. A branch becomes partially imbedded in those layers of the trunk which are formed after the time of its first sprouting; it causes a perforation in those layers, accompanied by distortion of their fibres, and constitutes what is called a *knot.* (On various matters mentioned in this Article, see Balfour's "Manual of Botany," Part I., chaps. i. and ii.)

14. *Timber Trees Classed.*—For purposes of carpentry, trees may be classed according to the mechanical structure of the wood. It has already been stated that the botanical classes of Endogens and Exogens correspond to essential differences of mechanical structure.

In further dividing the class of exogenous trees, or timber-trees proper, according to the structure of the wood, a division into two classes at once suggests itself, which exactly corresponds with a botanical division, viz.:—

Pine-wood, comprising all timber-trees belonging to the coniferous order; and

Leaf-wood, comprising all other timber-trees.

Beyond this primary division, the place of a tree in the botanical system has little or no connection with the structure of its timber.

A classification of timber according to its mechanical structure was proposed by Tredgold, founded, in the first place, on the greater or less distinctness of the medullary rays; and secondly, on the greater or less distinctness of the annual rings. According to that classification, pine-wood, or coniferous timber, is placed in the same class with leaf-wood that has the medullary rays indistinct; and this is certainly a fault in the system. If, however, pine-wood be placed in a class apart, Tredgold's system may very well be applied to divide and subdivide the class of leaf-wood; but it is to be observed that the characters on which that system is founded, being mere differences in degree, and not in kind, are not of that definite sort which a thoroughly satisfactory system of classification requires; and if they are adopted, it is because no better set of distinguishing characters has yet been proposed.

other kind of timber which can be procured in equal abundance. Mahogany varies much in quality; bay mahogany being in general superior to Spanish mahogany in strength, stiffness, and durability, and in the size of the logs, which are from 24 to 48 inches square. Bay mahogany of good quality is an excellent timber for all purposes of shipbuilding. Spanish mahogany is the more highly valued for ornamental purposes.

Spanish mahogany is distinguished by having a white chalky substance in its pores, those of bay mahogany being empty.

II. TEAK (*Tectona grandis*), from its great strength, stiffness, toughness, and durability, is the most valuable of all woods for ship-building. It is produced in the mountainous districts of south-eastern Asia and the East India Islands. The best comes from Moulmein, Malabar, Ceylon, Johore, and Java. The best logs of teak range from 40 to 80 feet in length, and from 15 to 30 inches square; trees are to be found of much greater size, but they are liable to be unsound at the heart. This timber is frequently perforated with holes to a considerable depth by insects, which defect frequently causes great loss in converting logs into planks.

Good teak resembles oak in colour and lustre, is very uniform and compact in texture, and has very narrow and regular annual rings. It contains a resinous, oily matter in its pores, in order to extract which the tree is sometimes tapped; but this injures the strength and durability of the timber, and ought to be avoided. Iron is not corroded by contact with teak, unless it has been grown in a marshy soil.

III. GREENHEART (*Nectandra Rodiæi*), a tree of British Guiana, yields a very strong and durable timber, considered of the first quality for shipbuilding and all kinds of carpentry, and also for piled foundations and other structures under water. The colour is olive green, verging on drab and on black in two varieties respectively. The black variety is considered the more durable, but is very scarce. The lighter-coloured variety is comparatively abundant, and may be had in logs from 12 to 24 inches square, and from 40 to 70 feet long. Greenheart is very straight-grained, and its fibrous structure very distinct. The texture of the wood closely resembles that of bay mahogany.

IV. MORA (*Mora excelsa*), also a tree of British Guiana, yields a first-class timber for shipbuilding. The trunk grows very long and straight, and furnishes logs about as large as those of greenheart. The branches grow crooked, and are serviceable for knees and curved timbers. It is strong in all directions, and difficult to split or splinter.

V. LIGNUM-VITÆ (*Guaiacum officinale*) is produced in the West India Islands. It is remarkable for heaviness, compactness, toughness, and hardness, and for the property of resisting a crushing force with nearly equal strength across and along the grain; a property which makes it specially useful for rollers, sheaves, and dead-eyes. In converting logs into sheaves, the direction of the fibre of the timber is parallel to the axis of the sheave. The heart-wood is yellowish-green, the sap-wood greenish-yellow; and it is considered advisable, in cutting it into pieces suitable for sheaves and dead-eyes, to leave a ring of sap-wood all round the heart-wood, which is thus protected against too rapid drying, and prevented from splitting.

VI. AFRICAN TEAK, or AFRICAN OAK, called also TURTOSA, grows in the western tropical parts of Africa. It somewhat resembles true Teak in appearance, but has more of a brownish or yellowish hue. It is strong, hard, and straight-grained, and is well suited for long and straight, or nearly straight, pieces, such as keelsons, stringers, shelf-pieces, waterways, and beams. It is often much damaged by shakes, and by the boring of insects.

VII. SABICU, a West Indian timber, is much esteemed for all parts of shipbuilding, being in general strong, durable, and sound. The best logs are straight-grained; others, through having grown spirally, have the fibres crooked and short, and are thereby unfitted to bear any great strain, except direct compression. Logs are sometimes found to be shaken and fractured at the heart, while the outside is sound: this is ascribed by Fincham to shocks received in felling or transportation.

20. *Leaf-wood continued—Australian Timber.*—Many species of the genus *Eucalyptus*, peculiar to Australia, yield timber of great size, strength, and durability; especially that of the IRON-BARK, BLUE-GUM, and JARRAH. The wood of iron-bark is white or yellowish; that of blue-gum, straw-coloured; that of jarrah resembles mahogany, and is sometimes called "Australian Mahogany." The *Eucalypti*, in common with some other Australian trees, are distinguished from the trees of other quarters of the globe by being more easily split in concentric layers, than in planes radiating from the pith; and the most frequent blemish in their timber is the occurrence of cracks of that kind, or "cup-shakes," filled with gum.

21. *Influence of Soil and Climate on Timber.*—Most timber trees are capable of flourishing in a great variety of soils. The best soil for all of them is one which, without being too dry and porous, allows water to escape freely, such as gravel mixed with sandy loam.

The most injurious soil to trees is that of swampy ground containing stagnant water: it never fails to make the timber weak and perishable.

As to the influence of climate, two general laws seem to prevail: that the strongest timber is yielded, amongst *different species* of trees, by those produced in tropical climates; and amongst trees of *the same species*, by those grown in cold climates. The first law is exemplified in such woods as teak, iron-wood, ebony, and lignum-vitæ, surpassing in strength all those of temperate climates: the second, in the red pine of Norway, as compared with that of Scotland, in the oak of Britain as compared with that of Italy, and even in the oak of Scotland and the North of England, as compared with that of the South of England.

22. *Age and Season for felling Timber.*—There is a certain age of maturity at which each tree attains its greatest strength and durability. If cut down before that age, the tree, besides being smaller, contains a greater proportion of sap-wood, and even the heart-wood is less strong and lasting; if allowed to grow much beyond that age, the centre of the tree begins either to become brittle, or to soften, and a decay commences by slow degrees, which finally renders the heart hollow. The age of maturity is therefore the best age for felling the tree to produce timber. The following data respecting it are given on the authority of Tredgold:—

	Age of Maturity. Years.
Oak,	60 to 200 average 100
Ash, Elm, Larch,	50 to 100
Fir,	70 to 100

The best season for felling timber is that during which the sap is not circulating—that is to say, in cold and temperate climates, the winter, and in tropical climates, the dry season; for the sap tends to decompose, and so to cause decay of the timber. The best authorities recommend, also, as a means of hardening the sap-wood, that the bark of trees which are to be felled should be stripped off in the preceding spring.

Immediately after timber has been felled, it should be *squared*, by sawing off four "slabs" from the log, in order to give the air access to the wood and hasten its drying. If the log is large enough, it may be sawn into halves or quarters.

23. *Seasoning, Natural and Artificial.*—Seasoning timber consists in expelling, as far as possible, the moisture which is contained in its pores.

Natural Seasoning is performed simply by exposing the timber freely to the air in a dry place, sheltered, if possible, from sunshine and high winds. The seasoning yard should be paved and well drained, and the timber supported on stone or cast-iron bearers, and piled so as to admit of the free circulation of air over all the surfaces of the pieces.

Natural seasoning to fit timber for carpenters' work usually occupies about two years; for joiners' work, about four years; but much longer periods are sometimes employed.

To steep timber in water for a fortnight after felling it extracts part of the sap, and makes the drying process more rapid.

The best method of *Artificial Seasoning* is that of which the principle was first proposed by Sir Samuel Bentham, and which consists in exposing the timber in a chamber or oven to a current of hot air. In Mr. Davison's modification of that method, the current of air is impelled by a fan at the rate of about 100 feet per second; and the fan, air-passages, and chamber are so proportioned, that one-third of the volume of air in the chamber is blown through it per minute. The best temperature for the hot air varies with the kind and dimensions of the timber; thus, for—

Oak, of any dimensions, the temperature should not exceed	105° Fahr.
Leaf-woods in general, in logs or large pieces,	90° to 100°
Pine-woods, in thick pieces,	120°
" in thin boards,	180° to 200°
Bay mahogany, in boards one inch thick,	280° to 300°

The time required for drying is stated to be as follows:—

Thickness in inches,	1,	2,	3,	4,	6,	8;
Time in weeks,	1,	2,	3,	4,	7,	10,

the current of hot air being kept up for *twelve hours per day* only.

The drying of timber by hot air from a furnace has also been practised successfully by Mr. James Robert Napier, in a brick chamber, through which a current is produced by the draught of a chimney. The equable distribution of the hot air amongst the pieces of timber is insured by introducing the hot air close to the roof of the chamber, and drawing it off through holes in the floor into an underground flue. The hot air on entering, being more rare than that already in the chamber, which is partially cooled, spreads into a thin stratum close under the roof, and gradually descends amongst the pieces of wood to the floor. The air is introduced at the temperature of 240° Fahr. The expenditure of fuel is at the rate of 1 lb. of coke for every 3 lbs. of moisture evaporated.

Many experiments have been made on the loss of weight and shrinkage of dimensions undergone by timber in seasoning; of which the details may be found in the works of Fincham on "Shipbuilding," Tredgold on "Carpentry," Mr. Murray on "Timber," &c. The results of those experiments vary so much that it is almost impossible to condense them into any general statement. The following shows the limits within which they generally lie:—

Timber.	Loss of Weight per Cent.	Transverse Shrinking per Cent.
Red Pine,	from 12 to 25	2½ to 3
American Yellow Pine,	" 18 to 27	2 to 3
Larch,	" 6 to 25	2 to 3
Oak (British),	" 16 to 30	about 8
Elm, "	" about 40	about 4
Mahogany,	" 16 to 25	

24. *Durability and Decay of Timber.*—All kinds of timber are most lasting when kept constantly dry, and at the same time freely ventilated.

Timber kept constantly wet is softened and weakened; but it does not necessarily decay. Various kinds of timber, some of which have been already mentioned, such as greenheart, elm, and beech, possess great durability in that condition.

The situation which is least favourable to the duration of timber is that of alternate wetness and dryness, or of a slight degree of moisture, especially if accompanied by heat and confined air. For pieces of carpentry, therefore, which are to be exposed to these causes of decay, such as the planking of a ship's side, the stem and sternpost, the timbers of the hold, &c., the most durable kinds of timber only are to be employed, and proper precautions are to be taken for their preservation.

Timber exposed to confined air alone, without the presence of any considerable quantity of moisture, decays by "*dry rot*," which is accompanied by the growth of a fungus, and finally converts the wood into a fine powder.

Table A, in the Appendix to the Third Division, shows the comparative durability of timber, for purposes of shipbuilding, as estimated by the committee of Lloyd's. Table H (also extracted from Lloyd's Register, by permission of the committee) gives the same information in a more detailed form, and arranged in a different way.

25. *Preservation of Timber.*—Amongst the most efficient means of preserving timber, are good seasoning and the free circulation of air.

Protection against moisture is afforded by oil-paint, provided that the timber is perfectly dry when first painted, and that the paint is renewed from time to time. A coating of pitch or tar may be used for the same purpose.

Protection against the dry rot may be obtained by saturating the timber with solutions of particular metallic salts. For this purpose Chapman employed copperas (*sulphate of iron*); Mr. Kyan, corrosive sublimate (*bichloride of mercury*); Sir William Burnett, *chloride of zinc*. All these salts preserve the timber so long as they remain in its pores; but it would seem that they are gradually removed by the long-continued action of water.

Dr. Boucherie employs a solution of *sulphate of copper* in about one hundred times its weight of water. The solution, being contained in a tank about 30 or 40 feet above the level of the log, descends through a flexible tube to a cap fixed on one end of the log, whence it is forced by the pressure of the column of fluid above it through the tubes of the vascular tissue, driving out the sap before it at the other end of the log, until the tubes are cleared of sap and filled with the solution instead.

Timber is protected against wet rot, dry rot, and white ants, by Mr. Bethell's process of saturation with the liquid called commercially "*creosote*," which is a kind of pitch oil. This is effected by first exhausting the air and moisture from the pores of the timber in an air-tight vessel, in which a partial vacuum is kept up for a few hours, and then forcing the creosote into those pores by a pressure of about 150 lbs. on the square inch, which is kept up for some days. The timber absorbs from a *ninth* to a *twelfth* of its weight of the oil.

26. *Strength of Timber.*—Amongst different specimens of timber of the same species, those which are most dense in the dry state are in general also the strongest.

Tables of the results of the most trustworthy experiments on the strength of different kinds of timber strained in various ways have been given at the end of the Third Division.

The following are some general remarks as to the different ways in which the strength of timber is exerted:—

The *Tenacity along the grain*, depending, as it does, on the tenacity of the fibres of the vascular tissue, is on the whole greatest in those kinds and pieces of wood in which those fibres are straightest and most distinctly marked. It is not materially affected by temporary wetness of the timber, but is diminished by long-continued saturation with water, and by steaming and boiling.

The *tenacity across the grain*, depending chiefly on the lateral adhesion of the fibres, is always considerably less than the tenacity along the grain, and is diminished by wetness and increased by dryness. Very few exact experiments have been made upon it. Its smallness in pine-wood as compared with leaf-wood forms a marked distinction between those two classes of timber, the proportion which it bears to the tenacity along the grain having been found to be, by some experiments,

In pine-wood, from 1-20th to 1-10th.
In leaf-wood, from 1-6th to 1-4th, and upwards.

II. The *Resistance to Shearing*, by sliding of the fibres on each other, is the same, or nearly the same, with the tenacity across the grain.

III. The *Resistance to Crushing* along the grain, depending, as it does, on the resistance of the fibres to being crippled or "upset," and split asunder, is greatest when their lateral adhesion is greatest, and was found by Mr. Hodgkinson to be nearly twice as great for dry timber as for the same timber in the green state. In most kinds of timber, when dry, it ranges from one-half to two-thirds of the tenacity.

Experiments have been made on the crushing of timber across the grain, which takes place by a sort of shearing; but they have not led to any precise result, except that timber in general is both more compressible and weaker against a transverse than against a longitudinal pressure; and consequently, that intense transverse compression of pieces of timber ought to be avoided. Certain special kinds of timber are valued for the property of resisting compression across the grain well. Of these the most generally used is Lignum Vitæ, already mentioned in Article 19; to which may be added boxwood, iron-wood, and ebony.

IV. The *Modulus of Rupture* of timber, which expresses its resistance to cross-breaking, is usually somewhat less than its tenacity, but seldom much less.

CHAPTER II.

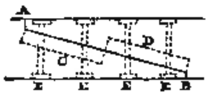
DESCRIPTION OF THE PARTS OF A SHIP.

27. *Object of this Chapter.*—In Article 74 of the Third Division, the principal parts of a ship have been classed according to the manner in which they contribute to her strength. The object of the present Chapter is to describe those parts, together with the parts subordinate to them, more in detail, and with reference to the manner in which they are connected with each other. The processes by which those parts are made and put together will be described in the Third and Fourth Chapters of the present Division.

28. *Keel and its appendages.*—The *keel*, in *iron ships*, has various forms, which have been illustrated in Plate $\frac{H}{I}$. When it is a plain bar, the lengths of which it consists are either welded or scarfed together, the plane of each scarf being vertical. When it is built of various pieces, such as plates and angle-irons, they are made to break joint, as specified in the rules quoted in the Appendix to the Third Division. Some iron ships are built without a keel.

In *wooden* and *composite ships* the keel is a rectangular piece of timber, and usually of equal, or nearly equal, siding and moulding. In large vessels the siding of the keel for about a sixth or an eighth of its length at each end is often tapered at the rate of $\frac{1}{8}$ inch, or thereabouts, at each side, in the foot of length. The lengths of timber of which the keel consists are scarfed together either with horizontal or with "up and down," or vertical *scarfs*, such as that represented in Fig. 1. The vertical scarf is the stronger. The length of the scarf is at least three times the "moulding" or depth of the keel. A and B are the *lips* of the scarf. C and D are *raised coaks*, *tablings*, or tenons, upon the thin ends of the two pieces, each fitting into a *sunk coak*, or mortise, in the opposite piece. The length of each coak is half the length of the scarf; the breadth, one-third of the moulding of the keel. E, E, E, E, are bolts to hold the scarf together.

Fig. 1.



Wooden ships are sometimes built upon a *temporary keel* of inferior timber, to save the permanent keel from the risk of decay. The temporary keel is removed piece by piece, and the permanent keel fitted in its place, after the framework has been built, and before the planking next the keel is permanently fastened.

A wooden keel has in each side a triangular *rabbet*, or groove, to receive the edge of the planking. This has already been frequently referred to in the Second Division.

To give a wooden keel a better hold of the water, its depth is increased by adding a *false keel* below it, of the same siding with the main keel. This should be so fastened that it may be knocked ship's bottom free from barnacles and weeds; but it is not advisable to protect the sheathing completely against corrosion (as was done by Sir Humphry Davy's protectors, consisting of bands of an electro-positive metal, such as iron or zinc); for then the bottom rapidly becomes foul, to the injury of the vessel's speed.[*]

The sides above the sheathing, and the other woodwork of a ship, usually receive three or four coats of paint. All wood should be thoroughly dry when painted.

67. *Protection of Iron Ships.*—The process of galvanizing, or coating with zinc, forms a very efficient protection for iron against oxidation in sea-water, as well as in air. The processes I., II., and III., mentioned in Article 8 of this Division, by which iron plates are coated with pitch, drying oil, and paint, have also a considerable effect in protecting the plating of an iron ship against oxidation, especially if the iron is coated with oil while hot, and afterwards painted. The paint used should be such as will not of itself tend to oxidate the iron; red lead paint is therefore objectionable, for it contains a large proportion of oxygen combined with lead; and as lead is electro-positive to iron, the oxygen tends to quit the lead and combine with the iron. Zinc paint has no such effect; for zinc is electro-negative to iron. The ironwork of ships usually receives three coats of paint outside, and two inside.[†]

Care should be taken to avoid the use of paint thickened with the white powder of sulphate of barytes (heavy spar) as a cheap imitation of oxide of zinc: that substance is without chemical action on the iron; but it injures the tenacity and compactness of the paint, and makes it pervious to water and air, and liable to crumble off after drying.

Mere protection against oxidation has no effect in preventing iron ships from growing foul, by the adhesion of shells, and afterwards of sea-weed; for that purpose a coating is required which shall peel off by slow degrees, carrying the barnacles away with it, and shall neither be too durable, which would enable the barnacles to adhere, nor too perishable, which would cause it to be too soon worn out, and lead to too great expense for its renewal. Copper and yellow metal have exactly those properties; but they cannot be directly applied to an iron ship, because of their being electro-positive to iron, and causing it to corrode rapidly. Various compositions have been used with more or less success, such as lime soap, amalgam of mercury and zinc, paint containing metallic copper in powder, or red oxide of copper, insulated from the iron by the oily matter of the paint, &c.

To enable iron ships to be sheathed with copper or yellow metal, it is necessary that the sheathing should be insulated from the iron. This has been effected by Mr. Grantham in the following manner: outside the iron skin are rivetted angle-iron ribs, whose projecting flanges are of a dovetail shape in section. An equal weight of iron is saved in the inside framing. The iron skin is then coated with pitch, and the spaces between the dovetail flanges are filled by packing and wedging into them short pieces of plank. The outside ribs with their wooden filling rise to a short distance above the water-line, and the upper edge of the filling is guarded by a longitudinal angle-iron. The outer surface of the fillings having been payed with pitch, a complete wooden sheathing, about 1½ inch thick, is put on, and fastened to the filling pieces with mixed metal nails, which should not pass through those pieces. The wooden sheathing is then pitched, and is sheathed with copper or mixed metal in the usual way; care being taken to keep the metal sheathing two or three inches from any exposed piece of iron.

Mr. Daft's method of sheathing iron ships with copper, mixed metal, or zinc, is as follows:—The inner layer of the iron skin consists of narrow strips of plate, merely wide enough to make lap joints with the outer layer, and to leave a groove between the edges of each pair of outer plates, about as wide as the plates are thick. Into that groove is inserted a filling of teak or of ebonite (a hard compound of caoutchouc and sulphur). Outside the plating is a layer of tarred felt, about ¼ inch thick, upon which the sheathing is laid, and fastened with sheathing nails of the same metal, driven through the felt into the teak or ebonite fillings. Intermediate fastenings are obtained, if required, by inserting ebonite plugs into holes drilled in the iron plates, and driving sheathing nails into them through the felt.

The tarred felt serves to insulate the copper or mixed metal from the iron. It may be used with zinc sheathing also, but is not then absolutely necessary; for zinc, being electro-positive to iron, protects the iron against oxidation.

During some experiments made in 1864 at Shoeburyness, it was found that *zinc sheathing upon iron* lost about ·002 inch of its thickness by six months' exposure to sea-water, and remained free from shell-fish and sea-weed, like copper or yellow metal.

68. *Boat-building.*—Boats are almost always built of wood. The best kinds of timber for them are the same with those which are suited for the parts of ships that are alternately wet and dry. According to the manner of building them, they are distinguished into *Carvel-built*, *Clinker-built*, and *Diagonal-built* boats.

In all three of those styles of boat-building, there are a keel, stem, and stern-post, rabbeted to receive the planking, as in a ship; the stem is scarfed, and the stern-post tenoned, to the keel.

I. *Carvel-built* boats are built like ships in miniature. They have frames, each generally consisting of a floor and two futtocks; the floors are scored down over the keel, and fastened to it with bolts in the larger and nails in the smaller boats. The frames are

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[*] Experiments have been made by Major-General Sir Arthur T. Cotton on the comparative resistance of paint and of metal sheathing on the bottoms of vessels. In the course of those experiments it was found, that sheathing the bow of a vessel with copper produced a diminution of the friction to little more than one-half of that on a painted surface, while sheathing the run with copper produced no sensible diminution whatsoever.

This appears to prove, that the run of a vessel has a skin or shell of water adhering to it and following it; so that while at the entrance, the friction to be overcome is that of water gliding over a surface of paint or of metal, as the case may be, the friction to be overcome at the run is that of one layer of water gliding past another.

Hence the "coefficients of propulsion" deduced from experiment in the First Division of this Treatise, Articles 164 to 167, such as 20,000 for clean painted iron ships, and 21,800 for a coppered wooden ship, probably correspond to coefficients of friction intermediate, in the one case, between the friction of water on water, and that of water on paint; and in the other, between the friction of water on water, and that of water on copper.

[†] Dr. Crace Calvert and Mr. R. Johnson have made experiments on the loss of weight undergone by plates of various metals and alloys when exposed for *one month* to the action of sea-water. The details will be found in the "Transactions of the Literary and Philosophical Society of Manchester for 1865." The following Table gives an abridgment of the general results, reduced to fractions of a pound (avoirdupois) per square foot of immersed surface per month:—

	In a vessel of Sea-water.		In the Sea.
Steel,	·0060	....	·0216
Iron,	·0056	....	·0204
Copper (best selected),	·0027	....	·0061
Do. (rough cake),	·0028	....	
Zinc,	·0012	....	·0070
Galvanised Iron,	·00023	....	·0030
Tin,	·0008	....	
Lead,	trace	....	·0053
Brass (Copper 50, Zinc 50),	·0024	....	
Do. (Copper 50, Zinc 48, Tin 2),	·0022	....	
Do (Copper 66, Zinc 32·5, Iron and lead 1·5),	·00155	....	
Muntz's Metal—Sheet (Copper 70, Zinc 29·2, Iron and Lead 0·8),	·0015	....	
Muntz's Metal—Bars (Copper 62, Zinc 37, Lead and Iron 1),	·0014	....	

The loss of weight of lead exposed to the sea is ascribed chiefly to mechanical wearing. In brass, the presence of tin appeared to protect the zinc and increase the corrosion of the copper; the presence of iron seemed to protect both copper and zinc.

sided, moulded, and trimmed to their proper bevellings, like those of a ship, and are kept temporarily in their shapes and places by cross-spalls, ribands, harpins, and shores. The planking consists of strakes laid fore and aft with flush seams, like those of a ship; they are usually fastened with two nails in each timber of the frame. The strakes first put on are the lowest, or *garboard strake*, and the uppermost but two, called the *binding strake*. Above the binding strake is the *landing strake;* the *gunwale* rests on the timber heads, and covers the upper edge of the landing strake; and the uppermost, or *sheer-strake*, has its upper edge flush with the top of the gunwale, and its lower edge overlapping the landing strake. The stern is usually strengthened by a *transom*, and the bow by two *hooks*. Moveable strakes above the gunwale are called *wash-strakes*.

The *thwarts* are the transverse planks which keep the sides asunder, like the beams of a ship, and serve as seats for the rowers; some are fixed, and others loose; the fixed thwarts are secured to the sides with knees. The thwarts are spaced about 2 feet 10 inches, from centre to centre, in single-banked boats, and 3 feet in double-banked boats.

Some boats have a fixed inside planking, or *footwaling*, in the bottom; others have moveable *bottom boards;* others, *gratings*.

II. *Clinker-built* boats are the lightest class for their strength and size; they are distinguished by the lower edge of each strake of plank overlapping the upper edge of the next strake below. They are not built upon frames, but upon temporary transverse sectional moulds, two, three, or four in number, which are fixed at their proper stations on the keel; the strakes are then put on, beginning with the garboard strake, and bent to the figure given by the moulds: each strake is fastened to the next below it by nails driven from the outside through the *lands* or overlaps. When two or more lengths of plank occur in a strake, they are scarfed to each other, the outside lip of each scarf pointing aft. The scarfs have a layer of tarred paper between, and are fastened with nails driven from the thin end of each piece. Towards the hooding-ends, the strakes are *chased* into each other; that is to say, a gradually deepening rabbet is taken out of each edge at the lands, so that the projection of each strake beyond the next below it gradually diminishes, and they all fit flush with each other into the rabbets of the stem and stern-post. Floors, futtocks, and hooks, are afterwards put in, and fastened to the planking by nails driven from the outside, and clenched inside.

III. In *Diagonal-built* boats the skin consists of two layers of planking, with flush seams, making angles of about 45° with the keel, in opposite directions. They are built, like clinker-built boats, upon temporary transverse moulds. After setting up and fixing the moulds upon the keel, the gunwale, a shelf-piece, and a series of ribands are temporarily fixed on the moulds. The two layers of planking are then put on, bent to fit the moulds and ribands, and fastened to each other and to the keel, stem, stern-post, shelf, and gunwale with nails, driven from the outside, and clenched inside upon small rings. The gunwale is then shored to keep it in shape; the moulds and ribands are taken out, and floors, hooks, thwarts, &c., are put in, as in a clinker-built boat.

As boats precisely similar in all their parts[*] are made in large numbers, machinery has been applied to their manufacture.

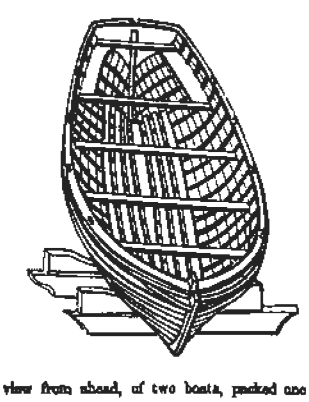
CHAPTER V.

VARIOUS EQUIPMENTS OF SHIPS.

69. *Rudder.*—The form and dimensions of the rudder, as affecting its action on the water, have already been considered in the First Division, Articles 187, 188; its strength has been treated of in the Third Division, Article 86; and the rules commonly followed as to the scantlings of its principal parts, have been given in the Appendix to that Division. The pieces of which the rudder consists, and the way in which they are put together, remain to be described.

An *iron* or *steel* rudder usually consists of a frame, covered on both sides with flush-jointed plating; the two layers of plating being rivetted through the frame to each other with rivets countersunk at both ends, and also rivetted at their seams to covering straps inside. For illustrations of the framing in an iron ship see Plate $\frac{A}{V}$; and in a steel ship, Plate $\frac{F}{I}$. The foremost piece of the framing is the *rudder-stock;* its upper end, called the *rudder-head*, is cylindrical, and rises through the cylindrical *rudder-port*, and through a vertical tube or rudder case, having a stuffing box at the top, into the stern of the vessel; its lower end, or *heel*, usually forms a pivot turning in a hole in the *skeg*, or projecting after-end of the keel; its intermediate part is square, and (except in the balanced rudder) is hinged by pins, called *pintles*, fitting into eyes, called *braces*, to the stern-post, or to the rudder-post. The aftermost piece of the framing is curved to the shape of the after-edge of the rudder, and is usually welded at its upper and lower end to the rudder-stock. The cross-pieces are in general opposite the pintles, and are welded to the rudder-stock and the after-piece of the framing. In fitting iron rudders it is usual for one or two of the eyes or braces to have the holes for the pintles drilled only partially through them. Into each hole is fitted a steel pin, with the upper surface spherical. The corresponding pintle is fitted with a steel pin having its lower surface spherical. When

Fig. 2 A.



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[*] According to a method of constructing boats introduced by Mr. George Fawcus, the outer and inner surfaces of each boat are so shaped, that any number of boats of similar figure and equal size can be packed one inside another in any order, the projecting lower edge or land of the sheer-strake of one boat resting on the gunwale of the boat next below. The thwarts are all moveable, and when in their places in a boat, are fastened by means of oval pins to fixed iron knees. When a set of boats are packed together, the rudders of all the boats, and the thwarts of all except the uppermost, are unshipped, and laid in the uppermost boat. Fig. 2 A gives a bird's-eye view from ahead, of two boats, packed one inside the other.

the rudder is shipped, its weight is borne at the points of contact of these spherical surfaces, so that the friction is very small.

For an illustration of the manner in which a *wooden rudder* is hinged with pintles and braces of mixed metal to the stern-post, see Plate $\frac{C}{5}$. The rudder consists of an assemblage of pieces of timber, coaked and bolted together like those of the framing of the stem and stern-post. Fig. 1 shows the usual arrangement of those pieces. The dotted line, X X, represents the axis of motion of the rudder, being the common axis of all the pintles and braces, and of the rudder-head. M M is the *main-piece*, usually of oak or other timber of equal quality. Its upper end is cylindrical, and is the *rudder-head*. The shoulder, C, where it is in contact with the head of the stern-post, is conical; and at the small end of the cone is the uppermost of the pintles, which are all marked P. The other pintles are fitted into scores in the foremost piece of the rudder, F, which is usually of elm. The form of the after-part of the rudder is made up with the pieces A, A, usually of fir. At the bottom of the rudder is the *sole-piece*, S, usually of elm, lightly fastened on, so that, like the false keel, it may be knocked off without further injury to the rudder.

Fig. 1.

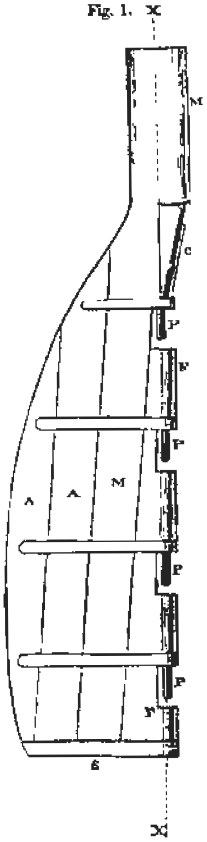
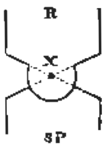


Fig. 2 is a horizontal section of the foremost edge of the rudder, R, and the aftermost edge of the stern-post, S P, showing how they are bevelled or *bearded*, so as to admit of the helm being put over either way to the usual greatest angle of 42°; and how the shoulders of the pintles, and the wood above and below them, having cylindrical surfaces described about the axis of motion, X, fit into a cylindrical hollow in the stern-post.

Fig. 2.



Wooden rudders are *sheathed*, like the ship's bottom, with copper or yellow metal.

Before the rudder is hung, the braces on the stern-post are adjusted to their correct positions by passing through them a perfectly straight cylindrical wooden rod, of the same diameter with the pintles.

The rudder when hung is guarded against being *unshipped* (or thrown upwards out of its place), by a moveable piece called a *wood-lock*, which is screwed upon the stern-post or rudder, and fits into a score a little below the uppermost pintle.

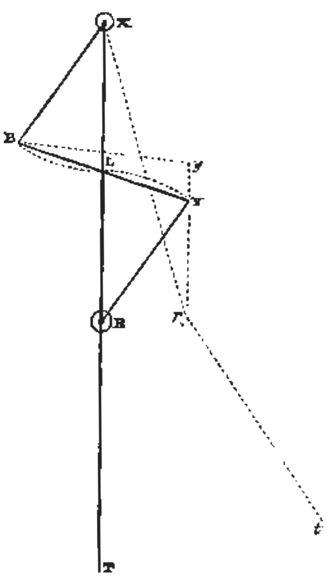
In the First Division, Article 188, a general description has been given of Mr. Lumley's rudder, consisting of a *body* hung to the stern-post in the usual way, and a *tail* hung in the same manner to the body, and moved in such a way, that when the body is put over to a given angle, the tail is at the same time put over to about double that angle.

There are different ways of effecting this by mechanism; the simplest is that illustrated by the skeleton plan, Fig. 3, in which X is the axis of motion; X R the body, and R T the tail. To the tail is fixed a *yoke* or arm, R Y, connected by a link, Y B, with a fixed projecting bracket, which is fastened to the stern of the vessel; the effect when the helm is put over is shown by the dotted lines.

The breadth of the body is from one-half to three-fourths, and the breadth of the tail from one-half to one-fourth, of the whole breadth of the rudder.

The following is the construction for adjusting this apparatus so as to work in the most correct manner. X R T being the midship position of the rudder and tail, bisect X R in L. Lay off the equal angles L X B = L R Y = one-half of the greatest angle to which the *tail* is to be put over; make X B = R Y = X L; and draw the straight line B L Y. Then R Y will represent the yoke; Y B the link; and B the position of the point where the link is to be jointed to the bracket.

Fig 3.



The link may pass either over the top of the body of the rudder, or through a hole in it.

This rudder may be converted, when required, into a common rudder, by unshipping the link, and dropping over the tail a strap or bridle, which fixes it to the body.

The rudder-head in every case turns in a collar in the uppermost of the decks which it traverses. In small vessels this is often the weather-deck; in large ships, and especially in ships of war, it is usually the gun-deck, or lowest deck, that is permanently above water.

Rudder-chains, and *rudder-pendants*, are chains or ropes which are shackled to a bolt at the after edge of the rudder, immediately above water, and fastened to bolts at the ship's quarter. They hang slack enough to permit the free motion of the rudder. Their use is to prevent the rudder from being lost, in the event of its being unshipped; and sometimes also they are led inboard, and used for steering, in the event of the tiller or rudder-head giving way.

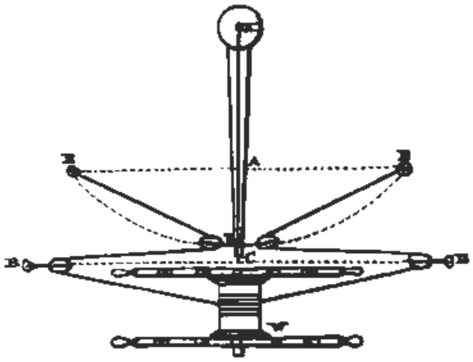
70. The *Helm* comprises the whole steering apparatus. Besides the rudder, it most frequently consists of a *tiller* or a *yoke* (as the case may be), a *steering-wheel*, and ropes or chains (or, in some cases, screws and nuts) to transmit motion from the wheel to the tiller or the yoke. Small vessels and boats only are steered by the tiller alone, or by a yoke with ropes held in the hand.

Wheel-ropes are often made from strips of untanned hide, kept dry and well greased; such being stronger than hempen ropes.

The tiller is a lever fixed to the rudder-head, and pointing in most cases forward, and in some cases aft. (For examples of tillers pointing aft, see Plates $\frac{A}{9}$, $\frac{D}{1}$, and $\frac{D}{8}$). The yoke consists of a pair of arms pointing sideways in opposite directions. The principles upon which the strength of the tiller or of the yoke depends, have been stated in the Third Division, Article 86.

When rope or chain tackles are used for putting over the tiller, their ordinary arrangement is that shown in Fig. 4; in which X is the rudder-head, and X T the tiller, having a pair of single blocks fixed to its forward end, T. E, E are a pair of eye-bolts in the deck, to which are made fast the ends or *standing parts* of the steering-chains or wheel-ropes. Those chains or ropes are led through the blocks of the tiller, already mentioned; then through a pair of fixed blocks, B, B, attached to the deck; then through another pair of fixed blocks beneath, or nearly beneath, the barrel of the steering-wheel, W, and hidden by it in the figure; then through holes or tubes in the deck or decks that lie between the tiller and the wheel; and then round the barrel, to which they are made fast at the middle of its upper side. The total number of turns of the steering-chains round the barrel is usually *five*, *seven*, or *nine*, so that from *two and a half* to *four and a half* turns of the steering-wheel are required to put the helm hard over to starboard or to port. The length of chain wound on the barrel on turning it either way with the single purchase, is about double the length of the arc through which the end of the tiller is put over; and the effective diameter of the barrel (being = its actual diameter + the diameter of the chain) is adjusted accordingly. Sometimes there is but one steering-wheel, and sometimes there are two, at opposite ends of the barrel. Steering-wheels range from 3 to 6 feet in diameter, and are made of mahogany, or timber of similar quality, strongly framed together, and bound with brass.

Fig. 4.



In every case the rudder is to be so connected with the steering-wheel, that in putting the helm over, the *lower* rim of the wheel shall be moved in the opposite direction to the rudder: that is, in the same direction with a tiller pointing forward.

Hence, when the tiller points *forward*, the steering-chains pass *over* the barrel first; and when it points *aft*, *under* the barrel. The arrangement of tackles, when the tiller points aft, is illustrated in the upper figure of Plate $\frac{D}{9}$.

When it is desired to have a steering-wheel on the bridge-deck, or any other part of the ship that is distant from the rudder, the steering-chains may be led from the blocks, B, B, to the barrel of that wheel through tubes and round sheaves arranged in any way which may be convenient; but to provide for the chance of such apparatus getting out of order, it is always advisable to have also a steering-wheel in the usual position, near the rudder.

Fig. 4 of the present Chapter shows the geometrical construction (as described by Mr. Peake, in his "Treatise on Ship-building,") for finding the positions where the eye-bolts, E, E, and blocks, B, B, are to be fixed, in order that the slackening of the chains when the helm is put over may be the least possible. About X, the axis of the rudder, with the radius, $\overline{XT}$, the effective length of the tiller, describe a circular arc. Take $\overline{TA} = \frac{1}{8}\,\overline{XT}$, and at A draw a straight line perpendicular to X T, cutting the circular arc in E, E; these points will be the stations for the eye-bolts. Then produce X T to C, making $\overline{TC} = \frac{1}{13}\,\overline{XT}$; and through C draw B C B perpendicular to X C, making $\overline{CB} = 1\frac{1}{4} \times \overline{AE}$. Then B, B will be the points to which the blocks are to be made fast.

The method usually adopted in H.M. service for getting rid of slack rope, is to make the diameter of the barrel smaller at the middle than at the ends, so that in moving the rudder from amidships to the extreme position, the excess of rope wound on the barrel over that unwound is equal to the rope which would have been slack had the form of the barrel been cylindrical.

The arms of a yoke are usually connected by rope or chain tackles with a pair of ring-bolts at the stern, so that by hauling on one of those tackles, the corresponding arm of the yoke is pulled aft; from the fixed blocks of those tackles the ropes or chains are usually led straight ahead; then under a pair of sheaves in blocks fixed to the deck; then up through vertical tubes to the barrel, *over* which they first pass, for the reason formerly stated as to the direction of motion of the wheel. The use of a yoke becomes necessary in vessels which have a screw capable of being unshipped and lifted into a vertical trunk in the stern; because that trunk occupies the place where the tiller would move.

In merchant ships the steering-wheel, instead of a barrel, has sometimes on its axis a right and left handed screw, with two nuts, which are acted upon by the right and left handed threads respectively, and are connected by means of suitable links with the two arms of a yoke—the left-handed nut with the starboard arm, and the right-handed nut with the port arm. When the lower rim of the wheel is turned to starboard, the left-handed nut, with the starboard arm of the yoke, is driven aft, and the right-handed nut, with the port arm of the yoke, pulled forward. When the lower rim of the wheel is turned to port, the right-handed nut, with the port arm of the yoke, is driven aft; and the left-handed nut, with the starboard arm of the yoke, pulled forward. The links for connecting the two arms of the yoke with the nuts should be of exactly equal length, and if oblique, of exactly equal obliquity; otherwise the apparatus will work incorrectly, and be liable to jam.

An apparatus for *steering by steam-power*, invented by Mr. Sickels, has been in use since 1860, it is said, with good results. The steering-wheel, and the barrel for the steering-chains, are upon separate shafts, in a line with each other. On the shaft of the steering-barrel is a toothed wheel, gearing with a pinion upon a crank-shaft, which is driven by a small steam-engine having two cylinders working at right angles to each other. The eccentrics which work the slide-valves of that engine are upon a separate shaft, having a pinion similar to the former pinion, driven by a toothed wheel similar to the former wheel, which latter toothed wheel is fixed to, and moved by, the steering-wheel. Thus, when the steering-wheel is turned, it causes the eccentric shaft to turn, and every revolution of the eccentric shaft causes the engine to make one revolution; and thus the motions of the barrel are made to correspond exactly with those of the steering-wheel. Another steering-wheel is made fast to the barrel, to be used in the common way, in the event of the engine getting out of order; in which case the wheels and pinions are thrown out of gearing.

71. *Anchors.*—The subject of the strength of anchors has been considered in the Third Division, Article 87; and their weights and proof-loads for ships of different sizes, according to the ordinary rules, have been given in a table in the Appendix

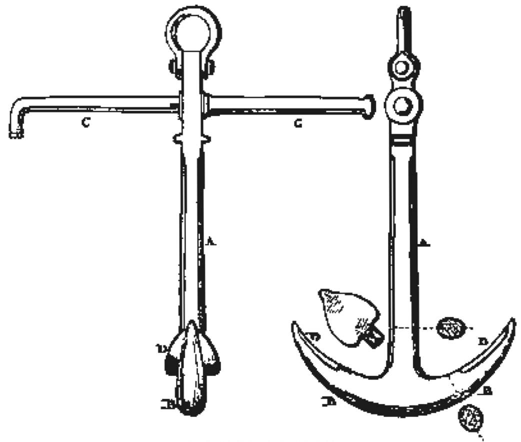
to that Division. The full complement of anchors for a large ship consists of six, and sometimes seven: two, called the *bower anchors*, for ordinary use in a roadstead; two, called the *sheet anchors*, of the same size with the bower anchors, kept in reserve in case the bower anchors should be lost; one smaller anchor, called the *stream anchor*, for riding in sheltered places; one smaller still, called the *kedge anchor*, or *kedge*, used for warping the ship along a river channel; and sometimes a second and smaller kedge anchor.

The usual shape and arrangement of anchors are illustrated in the upper-deck plan, $\frac{D}{5}$, and longitudinal section, $\frac{B}{7}$, of H.M.S. *Warrior;* and in the longitudinal section, $\frac{C}{7}$, of H.M.S. *Victoria and Albert.*

Figs. 5 and 5 A show the principal parts of which an ordinary anchor consists.

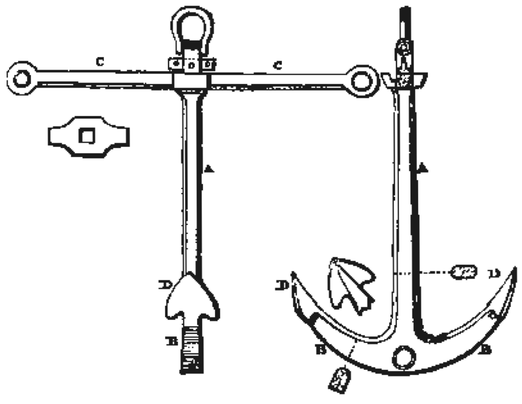
A is the *shank*, having at the smaller end the *ring* or *shackle*, which is fastened to the shank with a bolt passing through a round eye, and secured by a forelock. The length over all, including the shackle, ranges from about 8 feet to 18 feet; and the weight of the anchor, in cwts., (exclusive of the stock) may be roughly estimated at about *one-fiftieth part of the cube of the length in feet.* To deduce the length from the weight in cwts., *multiply by* 50 *and extract the cube root of the quotient.*

Fig. 5.



ADMIRALTY ANCHOR.

Fig. 5 A.



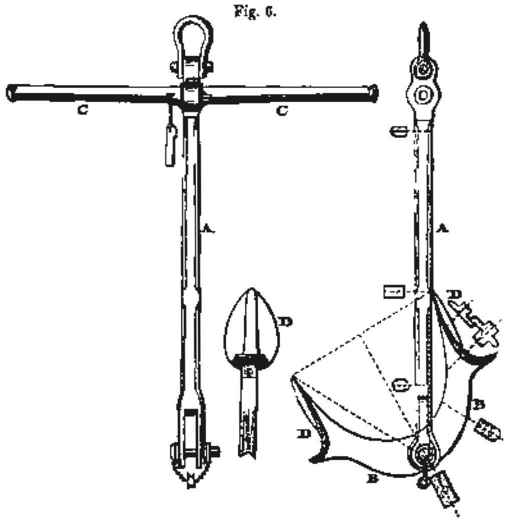
RODGER'S ANCHOR.

B, B are the *arms* for taking hold of the ground, forged in one piece with the shank, and terminating in the *flukes* or *palms*, D, D. The inner surface of each of the arms is shaped nearly like a circular arc of from 50° to 70°, with a radius equal to about half the length of the shank, or rather less.

Fig. 6 represents a kind of anchor called a *hinged anchor*, in which the piece forming the two arms is separate from the shank, to which it is bolted through a round hole, and each of the flukes has a horn or projection at the back to make it take hold of the ground the more surely.

The *crown* is the place where the two arms unite; the *throat* is the adjoining part of the shank; the *trend* is that part of the shank which extends from the throat to a distance equal to the length of the arm; the *nut* is a shoulder near the small end of the shank, to prevent a wooden stock from slipping; the *pee*, or *bill*, is the point of an arm.

Fig. 6.



TROTMAN'S ANCHOR.

C is the *stock*, which stands at right angles to the shank and to the plane of the arms, and can be removed when required. Its usual length is equal to that of the shank added to half the diameter of the ring. When made of iron (as in Figs. 5 and 6), it is a round rod, and passes through a hole in the shank, near the eye for the bolt of the shackle. When made of wood (as in Plate $\frac{B}{5}$), it is divided lengthwise into two pieces, which are placed one at each side of the square part at the small end of the shank, and fastened together with four bolts near the shank, six or eight treenails, and four or six hoops, two of which are at the ends. This stock is square in section; its dimensions for the middle sixth of its length are equal to one-twelfth part of its length, and it tapers each way to one-half of those dimensions at the ends. The use of the stock is to make the anchor *cant*, or turn over, on reaching the ground, so that one or other of the flukes shall be sure to take hold.

According to the report of a committee which made an experimental comparison of several different anchors in 1852, the following are the qualities which a good anchor ought to have, with numbers affixed indicating their relative importance:—

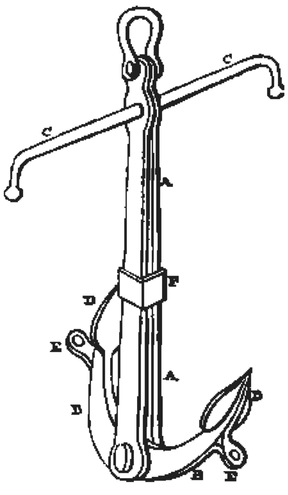
Canting quickly,	15
Holding on well,	80
Strength of form and material,	15
Exemption from fouling,	10
Quick tripping,	5
Ease of fishing in a heavy sea-way,	10
Facility of stowing,	10
Facility of sweeping,	5
Ease of transport in boats,	5
Sum,	155

It is difficult, however, to see why the qualities of holding on and of strength should have been estimated at values so different as 80 and 15; for neither of those two qualities is of any use without the other.

Figs. 5 A and 6 represent the two anchors which, according to the report of the committee, stood highest as to general merit, viz., first, Trotman's Anchor, Fig. 6; second, Rodger's Anchor, Fig. 5 A.

The advantages of the hinged anchor are, that it avoids the difficulty which is found in obtaining a sound forging at the crown of the common anchor; and that it is less liable to be *fouled* by the cable than the common anchor—that is to say, less liable to catch or entangle the cable with its upper arm; because when the lower arm has taken hold of the ground, the bill of the upper arm lies close to the shank.

Fig. 6 A.

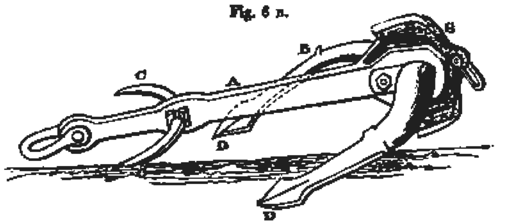


BETTELY AND MILLER'S ANCHOR.

Fig. 6 A represents a form of hinged anchor differing in some details from Fig. 6. The shank, A A, is divided longitudinally into two pieces, which are bound together by the square hoop, F, and against that hoop the bill of the upper arm presses. The spurs or horns, E, of the arms are made with eyes in them, to one or other of which the fish-tackle is hooked when the anchor is to be fished.

Fig. 6 B is a form of anchor, said by seamen to be very efficient, in which both flukes take hold of the ground at the same time. The palms and arms are in one plane, and they turn through an angle of about 40° either way, in a hole in the shank. The cross-piece or sector marked S, forged upon the arms at the crown, serves at once to limit the angle they make with the shank, and to cause them to take hold of the ground quickly.

Fig. 6 B.



MARTIN'S ANCHOR.

On the subject of anchors, besides the report of the committee already referred to, reference may be made to "A Treatise on Ships' Anchors," by Mr. George Cotsell, N.A.

72. *Cables.*—The strength of cables, whether iron or hempen, has been considered in the Third Division, Article 87; and their usual lengths and number have been stated in the Appendix to that Division.

Iron chain-cables are commonly made in lengths of from 12½ to 25 fathoms (but the term *cable's length*, when used as a measure of distance, means 100 fathoms of 6·08 feet each, being one-tenth of a nautical mile). According to the rules formerly observed in the British navy, each length of 12½ fathoms had a *swivel* in it, to prevent twisting; but, by a recent Admiralty order, all ships having Brown & Harfield's capstans have two swivels only on each cable, one at either end: the swivels having been found to work unsatisfactorily round those capstans.

The several lengths of chain are joined together by means of *shackles*, sometimes called *joining shackles*, in order to distinguish them from the *anchor-shackle*, which fastens the cable to the anchor. A joining shackle is U-shaped, with the curved end pointing outboard; it is fastened with a bolt; and the bolt does not project beyond the eyes of the shackle, but is secured with a small pin passing through both the bolt and the eye. The pin is fixed in its hole with a pellet of lead.

Chain-cables, when long and heavy, are stowed in compartments of the hold called *chain-lockers*. The nearer these are to the middle of the ship's length, the better is their position as regards liveliness in pitching, to which heavy weights near the ends of the vessel are unfavourable. Accordingly, in sailing ships of the Royal Navy, the chain-lockers are near the main-mast; and in steamers, immediately before the engine and boiler compartment: but in merchant vessels they are often placed further forward with a view to convenience (as in Plate $\frac{F}{I}$). In river steamers and other small vessels, the chain-lockers are often boxes on deck, running on four small wheels.

The space required for the stowage of 100 fathoms of chain-cable may be computed approximately by the following rule—*Multiply the square of the diameter of the cable iron in inches, by* 35; *the product will be the space required in cubic feet, nearly.*

To find the riding-scope, *or length of chain-cable, that should be payed out in order that it may lie horizontally where it is shackled to the anchor.* Reduce the greatest working pull on the anchor to an equivalent length of chain-cable, weighed in water: call this length the *modulus.* To the modulus add the depth of water; from the square of their sum subtract the square of the modulus; the square root of the remainder will be the scope required.

From the data given in Article 87 of the Third Division, it appears that the weight *in air* of 100 fathoms of chain cable is ·135 of the test-load of the cable, or ·54 of the greatest working pull on the anchor. Deducting $\frac{2}{15}$ for loss of weight in water, the weight of 100 fathoms of chain-cable *in water* is found to be ·468 of the working pull on the anchor; hence the *modulus* to be used in the preceding calculation is,

$$\frac{100}{\cdot 468} = 214 \text{ fathoms, nearly.}$$

For example, let the depth of water be 40 fathoms; then—

	Fathoms.
To the modulus,..	214
Add the depth,..	40
Sum,..........................	254
Square of the sum,..	64,516
Subtract square of the modulus,........................	45,796
Remainder,....................	18,720
Square root of the remainder, nearly..................	137

In moderate depths, the scope of cable required varies nearly as the square root of the depth. The following are some examples of the results of the rule, calculated to the nearest whole fathom:—

FATHOMS.

Depth,........	5	10	15	20	25	30	35	40	45	50
Scope,.........	47	67	82	95	107	118	128	137	146	155

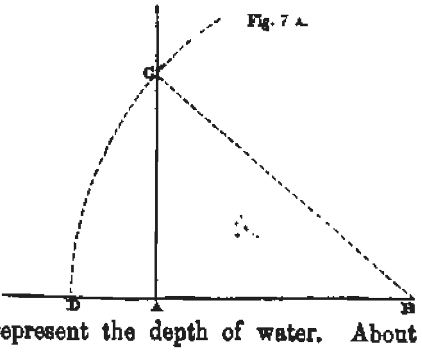


Fig. 7 A.

To solve the same question graphically, draw (in Fig. 7 A) a straight line, D A B, and another straight line, A C, meeting the first straight line at right angles in the point, A. Then from A set off $\overline{AB}$ to represent the modulus, and $\overline{AD}$, in the opposite direction, to represent the depth of water. About

B, with the radius, $\overline{BD}$, describe a circular arc, cutting A C in C; A C will represent the required scope of cable.[*]

The scope in practice is seldom so great as that given by the preceding rule.

Hempen cables are large ropes, of the kind called *cable-laid;* that is to say, the several parts of which the thickness of the rope consists are spun, or *laid up*, at four successive stages, in contrary directions alternately, as in the following example:—

> Hemp is laid up *right-handed* into *yarns;*
> Yarns are laid up *left-handed* into *strands;*
> Three strands laid up *right-handed* make a *hawser;*
> Three hawsers laid up *left-handed* make a *cable.*

Hempen cables are stowed by being coiled in the *cable-tiers,* which are placed on the orlop-deck.

73. *Manger.*—The hawse-holes, with their hawse-pipes, bolsters, and plugs, have already been mentioned in Article 44 of this Division. In ships of war and large merchant ships they are usually four in number; the foremost pair being for the bower cables, and the aftermost pair for the sheet cables: small merchant ships have usually two only.

A short way abaft the hawse-holes, on the working deck, is a low upright partition, composed of planks lying athwartships, called the *manger-boards,* to prevent the water that comes in at the hawse-holes from flooding the rest of the deck. The triangular space before the manger-boards is called the *manger;* and a pair of scupper-holes for discharging the water at its after corners, the *manger-scuppers.* The ends of the manger-boards fit into rabbets in upright pieces called the *manger-stanchions,* of which there are either two or four, according as the manger-boards are in one or in three lengths. The manger-boards can be removed when the flat of the deck requires to be caulked or repaired. They are now little used in merchant vessels; and in many ships they are rendered unnecessary by the hawse-pipes being made to slope upwards from the hawse-holes, and so to conduct the cables to the deck next above the hawse-holes, instead of that next below.

74. *Controllers—Bitts—Stoppers—Compressors.*—For the purpose of regulating and checking the motion of the cable as it runs towards the hawse-holes while the anchor is dropping, and also of holding on by the cable after the anchor has taken hold, four kinds of apparatus are used, together or separately—controllers, bitts, stoppers, and compressors.

A *controller* is a cast-iron block, having a hollow in its upper side of the shape of a link of the chain-cable. Controllers are bolted to the deck at various points in the lines along which the cables lie on their way from the chain-lockers to the hawse-holes. A cable while lying on a controller tends of itself to drop into the hollow; and while there, it is held by one of its links, which lies flat in the hollow; but at the bottom of a hollow is the short arm of a lever, which can be raised by hauling up the long arm, so as to lift the cable out of the hollow when required, and allow it to run.

The *riding-bitts,* whose strength has been already considered in Article 87 of the Third Division, bear in ordinary the principal part of the tension of the cables. Their usual station is between the foremast and mainmast; and there are two pairs —the foremost pair for ordinary use, and the aftermost to be used in case the foremost pair should give way. Riding-bitts are shown in some of the longitudinal sections and lower-deck plans given in the Plates. The two annexed figures show the arrangement and use of their principal parts—Fig. 7 being a side elevation, and Fig. 8 a plan. D B, D B, D B, are lower-deck beams; O B, an orlop beam, under the aftermost of them. B, B are a pair of bitts; being strong upright posts bolted against the after-sides of the two last-mentioned beams, and connected together by means of the *cross-piece,* C P. S T, S T are two *standards,* or horizontal struts, abutting against the front of the two bitts, and lying upon and fastened to three successive lower-deck beams, for the purpose of resisting the forward pull of the cables. H I is part of a bitted cable—H being towards the hawse-holes, and I towards the chain-locker. The bitts may be made wholly of iron; but when of wood, the head of each bitt (which is square) is guarded with a strong thick cylindrical casing of cast-iron; and the back part of the cross-piece is similarly protected. Sometimes a pin is fixed in the upper side of the end of the cross-piece, to prevent the cable from slipping off. Some riding-bitts have no cross-piece, but a large transverse pin instead of it. Other bitts, of smaller size, are used in various parts of the vessel for securing different ropes: their general construction is the same as that of riding-bitts, but on a smaller scale.

Fig. 7.

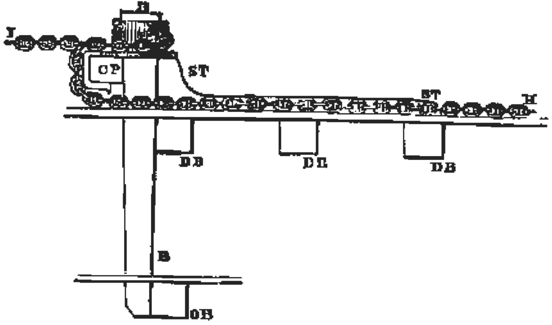
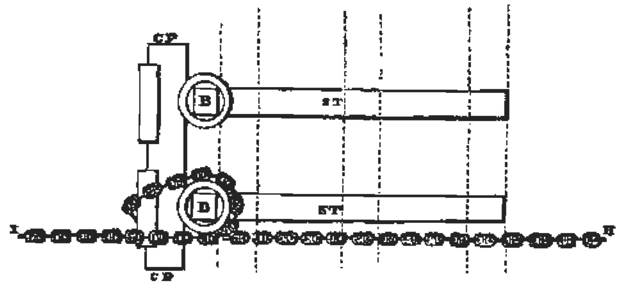


Fig. 8.



Deck-stoppers are short ropes or chains, shackled to bolts in the deck at one end, and secured at the other end to the cable by a fastening which can be *slipped,* or instantly let go, when required. The fastening commonly used for this purpose is called a *slip-hook.*

The *compressor* is usually a bent lever, shown in plan in

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[*] When a ship, being in a confined anchorage, is compelled to ride at short scope, the cable might still be made to lie flat on the bottom at the anchor-shackle by loading it with additional weight (for example, by hooking pieces of chain to it), according to the following rules:—

I. *From the square of the scope subtract the square of the depth of water: divide the remainder by twice that depth: the quotient will be the required modulus;* that is, the length of cable, which, with its load, when weighed in water, should be equivalent to the horizontal pull on the anchor.

II. *Divide the ordinary value of the modulus (say 214 fathoms) by the required value; the quotient will be the ratio which the gross weight of the loaded cable should bear to the weight of the cable alone.*

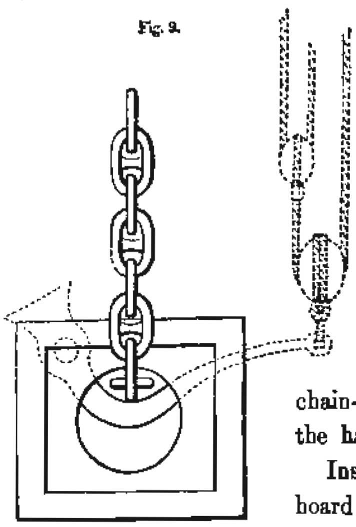
EXAMPLE.—Suppose the depth to be 20 fathoms, and the scope 80 fathoms. Then—

$$\frac{80^2 - 20^2}{2 \times 20} = 150 \text{ fathoms, the required modulus; and}$$

$$\frac{214}{150} = 1{\cdot}43 \text{ nearly, the ratio in which the gross weight of the cable should be increased by loading it.}$$

Fig. 9, which moves horizontally close to the lower end of the *chain-pipe*, through which the cable comes up from the chain-locker to the lower deck. By hauling on the tackle at its end, it is made to press the cable firmly against the inside of the pipe, so as to moderate the speed of its running out. Another kind of compressor consists of a pair of jaws, with a screw like that of a vice for drawing them together, and holding the cable between them.

Fig. 9.



The usual diameter of the chain-pipes is two-thirds of that of the hawse-pipes.

Inside the chain-locker, the inboard end of the cable is secured by a *slip-hook*, so that it can be instantly let go when required.

75. *Cat-heads—Fish-davits—Bill-boards—Tumblers—Anchor-struts.*—When a *bower anchor* is weighed, and has been hove up clear of the water, it is hauled up to the ship's bow by means of a tackle called the *cat-fall*, which hangs from the *cat-head*, and is hooked for the time to the ring of the anchor; and the arms are afterwards hauled up till the shank lies nearly level, with the crown pointing aft, by means of another tackle called the *fish-fall*, which hangs from the *fish-davit*. The cat-head serves also to hang the ring of the anchor from, ready for letting go, by means of a rope called the *cat-head stopper;* while at the same time the other end, or throat, of the shank is hung at the same level, or nearly so, by a rope or chain called the *shank-painter*, and partly supported by the inner fluke resting on an iron plate or iron-covered board, called the *bill-board*, which projects from the side with a slight outward slope. The cat-head stopper and shank-painter are secured in-board by means of moveable pins called *tumblers*, which are acted upon by a lever that casts them both loose at one instant when the anchor is to be let go.

Examples of *cat-heads* are shown in several of the Plates, especially the sheer-plans and longitudinal sections of vessels, such as, $\frac{C}{I}$, $\frac{B}{I}$, &c. They are usually a pair of square wooden beams, one projecting from each bow, with a moderate *flight* or upward slope; and of a length sufficient to insure that the anchors shall hang from them clear of the ship's side. They are placed as far forward as may be convenient, and nearly on a level with the gunwale, or sometimes with the planksheer. The projecting part of each cat-head is supported by a knee called the *cat-head supporter* (of which examples are shown in the Plates), bolted to the cat-head and to the ship's side. The inner end of each cat-head (sometimes called the *cat's-tail*) is made fast either by returning down inside the ship's side, through which it is bolted to the supporter, or by lapping under a beam of the weather-deck or forecastle, or by lying upon that deck and being bolted down to it; the last method being now the most frequent. The outer end of the cat-head is hooped, and has usually three mortises in it for the sheaves of the cat-fall. Cat-heads are sometimes of solid forged iron, and sometimes built of angle-irons and plates.

The *fish-davits* are a pair of davits, or small iron cranes, at such a distance abaft the cat-heads as the length of the anchors may require.

The *sheet-anchors* are usually stowed immediately abaft the fore-channels (or projecting ledges for securing the rigging of the foremast, to be more fully described in the Fifth Division). The rings of the sheet-anchors point ahead, and rest on the after-ends of the fore-channels; the stock of each of them is upright; the shank lies horizontal; the inner arm rests on a projecting ledge called the *anchor-chock;* the anchor is secured by chain-stoppers round the stock and shank, which can be let go at once when required. Two sloping shores or *anchor-struts*, hinged to the ship's side below the anchor, abut against its shank; and when it is let go, they cause it to fall clear of the ship.[*]

76. *Capstans and Windlasses* are machines for winding up ropes and chains, and raising weights, as when an anchor is weighed. A capstan has its axis vertical, and is specially suited for being driven by hand-power, the men walking or running round it, and pushing before them the capstan-bars which radiate from its head. It is well calculated for making available the strength of a numerous crew. A windlass has its axis horizontal. When driven by hand, it is usually less powerful than a capstan, being worked by fewer hands; so that if it is to be made to lift the same load with a few men driving it that a capstan does with many, that can be effected only by means of mechanism, which diminishes the speed with which the load is lifted in the same proportion with the number of men. In order that a windlass may be equal or superior to a capstan, taking speed as well as load into account, it must in general be driven by steam-power; and this is much practised in merchant vessels.

A windlass for lifting goods is sometimes called a *crab*, or *winch*.

A large ship has usually two capstans, called the *fore* and *after* capstan respectively—the fore capstan standing midway, or nearly so, between the foremast and mainmast; the after capstan at about the same distance abaft the mainmast.

Capstans are distinguished into *single* and *double*, according as they have one or two barrels upon the same spindle, or vertical axis. The barrel of a single capstan, or the lower barrel of a double capstan, is on the deck on which the cables are worked, and is used for heaving in the cables; the upper barrel of a double capstan is on the deck above. In either case, the spindle has the framing of two decks to keep it steady; it turns in a bush or collar in the upper of those decks, and has the pivot at its lower end supported by a step fixed to the lower of them.

Fig. 10 is an elevation of a double capstan; and Fig. 11 a plan of its lower barrel.

U C P are the upper, and L C P the lower *capstan-partners*, being strong platforms supported by the two decks, and composed, when made of wood, of pieces 6 or 7 inches deep, laid like carlings. U D B are upper, and L D B lower, deck beams.

S P is the *spindle*, of strong and tough wrought-iron. Its greatest diameter is about the middle, and ranges from 5 to 8 inches. It tapers towards the ends, where its diameter is about $\frac{2}{3}$ of the greatest diameter. When made of steel, its diameter may be reduced so as to preserve the same strength.

U B is the upper barrel, which is fast on the spindle, and

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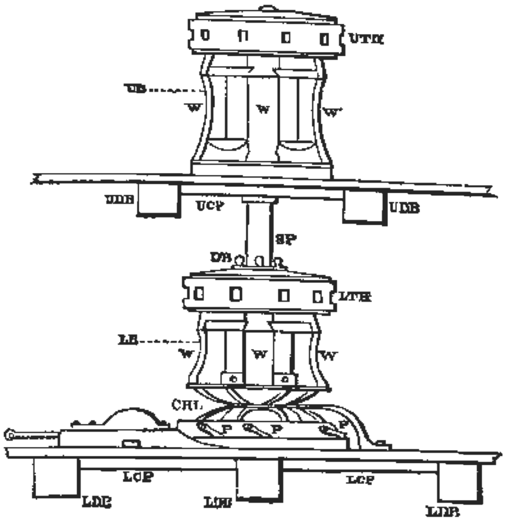
[*] For details as to the working of anchors and cables, and the construction of various fittings connected with them, reference may be made to the work of Lieutenant Nares, R.N., on "Seamanship."

turns with it; and L B the lower barrel, which is loose on the spindle, but can be made fast to it when required, so as to turn along with the upper barrel, in the following manner:—On the top of the head of the lower barrel is a circular plate; and just above it, fixed to the spindle, a similar circular plate—these are called the *connecting-plates:* they have corresponding holes in them; and by putting bolts, called *drop-bolts* (marked D B in Fig. 10), into those holes, the lower barrel is connected with the spindle, and made to turn with it.

Fig. 10.



The barrel of a capstan ranges from 16 to 28 inches in diameter, and is usually polygonal, with ten or twelve equal sides. From the alternate sides ribs project, called *whelps* (W), which are consequently five or six in number; and they are of such a breadth that the mean diameter, measured over the whelps, is about double the diameter of the barrel. They are kept apart at their upper and lower ends by *chocks.* They taper towards the upper end; so that the diameter over the whelps is 4 or 5 inches less near the upper end than at the lower end: this is called the *surging power;* and its object is to make a rope, when wound round the capstan, gradually *surge,* or slip from the larger end, where it is led on, to the smaller end, where it is led off, in order that the successive turns of the rope may not override each other at the larger end.

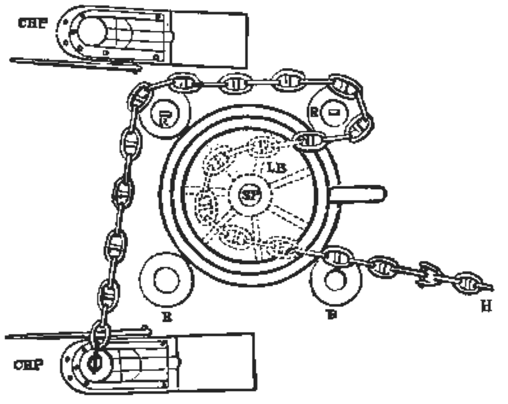
U T H is the *trundle-head* or *drum* of the upper capstan, and L T H that of the lower capstan. The trundle-head of a capstan ranges from 3 to 5 feet in diameter, being a little greater in diameter than the greatest diameter over the whelps. It has square holes all round its outer rim for inserting the *capstan-bars,* at the rate of about one to every foot of its circumference, or nearly so; these *bar-holes* are from 3 to 5 inches square, tapering inwards, and from 10 to 12 inches deep. The length of the capstan-bars is about three times the diameter of the trundle-head, or from 8 to 14 feet long. They are fastened in the bar-holes by means of small pins dropped in from above, and are connected together all round by a rope through their outer ends, called a *swifter.*

P are the *pauls,* or catches, for preventing the capstan from running back. They are carried by a round part of the capstan called the *paul-head;* and they drop between and take hold of the teeth of the *paul-rim* or *ratchet,* a strong toothed ring which is let down into and bolted to the lower partners. When required, the pauls can be supported clear of the ratchet by means of small pins.

C H L is the *chain-lifter* or *cable-holder,* made of cast-iron, for acting directly on a chain-cable. Its rim is of the form of a deep groove, with projecting ribs on its upper and lower surfaces; so that the alternate links of a chain may fit into the spaces between the ribs.

R, R, R, R, in Fig. 11, are upright rollers, for guiding a chain-cable, so as to make the chain-lifter lay hold of it.

Fig. 11.



C H P, C H P, in Fig. 11, are a pair of *chain-pipes* or *deck-pipes,* with controllers or deck-stoppers just ahead of them. A cable is represented coming from the bows (which are in the direction marked H), guided round the capstan by the rollers, and dropping into the starboard chain-pipe.

This mode of fitting a capstan, so as to enable it to act directly on a chain-cable, is known as *Brown's fittings.* In the absence of such fittings, or when a hempen cable is to be hove in, an endless chain or rope, called the *messenger,* is used, passing round the capstan, and round two pulleys near the hawse-holes. If a chain, the messenger is acted on by a *sprocket-wheel,* having teeth suited to the size and figure of the links: if a rope, it is put three times round the capstan-barrel. The messenger lies alongside the cable, to which it is fastened by iron or rope fastenings called *nippers;* these are successively taken off the part of the cable that is approaching the capstan, and put upon the part that has just come in through the hawse-hole.

The average total power of a man working at a capstan-bar is estimated at about 50 foot-pounds per second, or 3000 foot-pounds per minute; being $\frac{1}{11}$ of a horse-power.

A *windlass* of the old form, employed in small vessels, consists mainly of a barrel with a horizontal spindle, turning in bearings supported by upright posts called the *carrick-bitts;* provided with whelps, and also with a ratchet-wheel and pauls to prevent its running back; and driven by means of *hand-spikes* inserted into holes in the barrel. Improved windlasses have chain-lifters for heaving in chain-cables, and gearing of a great variety of kinds, more or less like the wheel-work of a crane, for enabling a small force with a great speed to overcome a great resistance slowly. Sometimes also the windlass is provided with a friction-brake, to be used in lowering weights; and then if the brake is powerful enough, the anchor may be lowered by means of it, without the aid of bitts or compressors. A windlass may be driven either by a small steam-engine forming part of its own mechanism, or by a messenger or endless chain, from an engine used for various purposes and placed in any convenient part of the vessel.

The shape and position of the windlass render it a convenient machine both for heaving-up chain-cables, and for paying them out by the aid of a friction-strap. On the other hand, the shape and position of the capstan are peculiarly well suited for employing the strength of a large number of men. Those advantages may be combined by having a capstan on an upper-deck, driving a windlass on the deck next below by means of a bevel pinion on the spindle of the capstan, gearing with a bevel wheel on the windlass. This is done in Emerson and Walker's windlass, as to which, see Nares on "Seamanship;" and by means of two sets of pauls, the capstan is so connected with two bevel pinions driving bevel wheels of different sizes, that by turning the capstan in one direction or in the opposite direction, two different speeds can be given to the windlass.

77. *Ships' Boats.*—As to the styles in which boats are built, see Article 68 of this Division. The sizes and usual mode of stowage of the boats of a large ship of war are illustrated in the Upper-deck Plan, $\frac{B}{5}$. The names, styles of build, and usual lengths and proportions of length to breadth of the principal classes of ships' boats, are shown in the following table:—

SHIPS' BOATS.

CARVEL-BUILT OR DIAGONALLY-BUILT.

Name.	Length. Feet.	Length ÷ Breadth.	Remarks.
Launch,	from 34 to 42	from 3½ to 4.	Strong heavy flat-floored boat, 10 to 12 oars; sometimes carries a gun.
Long-boat,	do.	do.	Like a launch, but sharper in the floor.
Barge,	from 30 to 32	do.	10 or 12 oars; boat of state for flag-officers and captains.
Pinnace,	from 28 to 32	do.	6 or 8 oars; boat for captains, commanders, and lieutenants.
Yawl,	from 23 to 28	do.	Boat for ordinary use.
CLINKER-BUILT.			
Galley,	from 28 to 36	from 4½ to 5.	10 or 12 oars; light sharp boat, for speedy rowing on expeditions.
Gig,	from 22 to 28	do.	4, 6, or 8 oars; similar to a galley, but smaller.
Cutter,	from 22 to 30	from 3½ to 4.	For general use; like pinnace and yawl, but lighter as being clinker-built.
Jolly-boat,	from 16 to 20	from 3 to 3½.	Like a small cutter: for general use.
Dingy,*	from 12 to 14	about 3.	For general use.

In addition to the boats referred to in the table, may be mentioned *troop-boats* for embarking and disembarking troops, and *paddle-box boats*, which are very broad and flat, and are made to fit bottom upwards on the tops of the paddle-boxes of a paddle steamer: these also are well adapted for landing troops.

The boats commonly used in merchant ships are long-boats, yawls, cutters, jolly-boats, and dingies; and *life-boats* are also often used, which are like cutters or jolly-boats, according to their size, but shaped alike at both ends, and with the addition of air-cases or cork floats running round both sides under the ends of the thwarts. For example, in the upper division of the upper figure of Plate $\frac{A}{5}$, there are seen two yawls slung at one of the vessel's quarters, and two life-boats at the wings of one of her paddle-boxes. In the lower figure of Plate $\frac{D}{5}$, a jolly-boat is slung at one quarter and a life-boat at the other.

Boats not likely to be immediately wanted are usually stowed above the upper-deck in the waist of the ship, sometimes bottom up, on beams, as illustrated in Plate $\frac{F}{1}$, and sometimes upright, on crutches, as shown in Plate $\frac{B}{5}$. Boats for immediate use are slung each by means of a pair of *boat-tackles*, from a pair of *davits* or small cranes, usually shaped like that shown in Division Third, Article 54, Fig. 17. The boat has a pair of *slings*, being short ropes made fast to ring-bolts in the keelson, near the head and stern; from near the upper ends of the slings *steadying lines* pass to the sides of the boat to prevent it from canting or turning over; and at the upper ends of the slings are two hooks, hooking into *thimbles* or rings at the lower ends of the tackles. The hooks are on the slings, and not on the tackles, lest in letting go the tackles a man should be hooked out of the boat. The davits for pinnaces, yawls, cutters, galleys, &c., are usually at or near the ship's quarters, and the boats slung from them are called *quarter-boats;* the quarter-davits can be turned about so as to make the boat hang either outboard or inboard; from a pair of davits projecting over the stern is hung the *stern-boat*, which is usually a jolly-boat, gig, or dingy. The last-mentioned pair of davits are often simply a pair of straight projecting arms, like the cat-heads. Boats hanging from davits are shown in Plates $\frac{A}{5}$, $\frac{B}{5}$, and various other Plates. To keep a boat in such a position from swinging about, it is secured to the lower part of the davits by the *gripes*, which are a pair of bands passing round the boat near the head and stern. Each of the gripes (according to the best construction) has a ring or *thimble* at each end, which in securing the boat is slipped upwards on to a pin or *prong* pointing downwards, so that when the boat is lowered the thimbles slip down off the prongs of themselves, and cast the gripes loose. Each of the gripes can be set taut by means of a lanyard.

In order that a boat may be capable of being lowered according to *Clifford's method*, it must be provided with a horizontal thwartship roller or barrel amidships. Two ropes called *lowering pendants* hang from the davits, and are led below sheaves fixed to the floor of the boat, near its head and stern respectively, and thence to the barrel, upon which they are wound in the same direction, their ends passing loosely through holes in the barrel. A third rope called the *lowering-line* is made fast to the barrel, and is wound round it in the contrary direction,* so that being passed twice round a cleat on the boat's midship thwart, it enables one man who holds it, standing in the boat, to control the motion of the barrel, and let the boat descend gently and steadily into the water. To increase the friction which controls the descent, and also to keep the boat from canting over, the upright parts of the lowering pendants pass through two three-sheave blocks, at the upper ends of the slings of the boat, which are unhooked from the tackles before lowering.—(See Nares on "Seamanship.")

For the regulations in force in Britain as to the number and size of the boats with which passenger ships are to be supplied, see the Merchant Shipping Act.

78. *Life-boats.*—The ordinary ships' life-boats referred to in the preceding Article are imperfect; because although the air-cases, or the floats which run round their sides, may enable

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* The "*g*" in "*Dingy*" is pronounced hard.

* In many of the published figures of Clifford's method of lowering boats, the lowering line is shown as wound upon the barrel the wrong way.

them to float when full of water, they want the power of *self-righting*, which is essential to a complete life-boat.

In an ordinary boat, the inverted position is a position of stability, as well as the upright position; and should the boat upset, it continues to float bottom upwards. In order to make a boat *self-righting*, the inverted position must be rendered unstable; and that is done by giving the boat a great sheer upwards at the bow and stern, and filling the ends which are thus raised with large buoyant air-cases. In some life-boats the side air-cases are carried up to the gunwale for the same purpose.

Figs. 12, 13, 14, and 15 show the general construction and arrangement of one of the life-boats of the Royal National Life-boat Institution, on a scale of $\frac{1}{30}$ of the real dimensions. Fig. 12 is the sheer-plan, Fig. 13 the deck-plan, Fig. 14 the body plan, and Fig. 15 the midship section. The length of the boat represented is about 30 feet; the breadth 7½ feet, being one-fourth of the length; the depth amidships is about 3 feet; and at each end there is an upward sheer of about 2½ feet. The lower gunwale has a regular upward curvature; and above it is an upper gunwale or plank-sheer, rising rapidly with a reverse curve, as Figs. 12 and 14 show. The midship section is nearly rectangular, and flat-bottomed; towards the ends, the cross-sections become U-shaped, as shown in Fig. 14, with a slight flare out. There is a heavy iron keel, which acts as ballast.

Fig. 12.

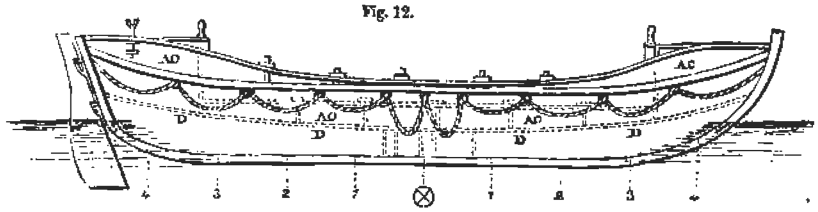


Fig. 13.

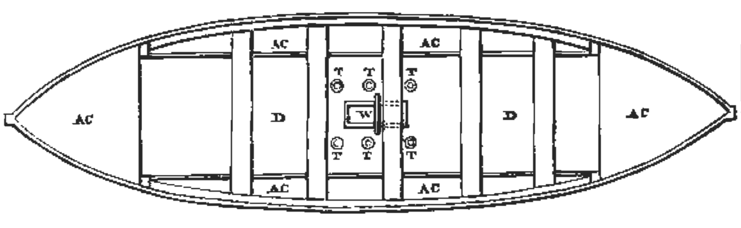


Fig. 14.

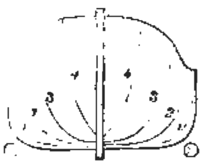
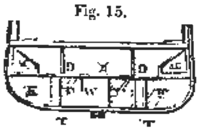


Fig. 15.



In Figs. 12, 13, and 15, D is the deck, having a moderate upward sheer: the space below it, for a length of rather more than one-fifth of the boat's length amidships, is filled up solid with light wood, marked F in Fig. 15. Amidships is a small well, W, with a pump for removing water which may leak into the space below the deck.

T, T, T, T, T, T, are six *relieving tubes*, 6 inches in diameter, with valves opening downwards, for discharging any water which may lodge on the deck.

A C are the air-cases of the sides and ends. The side air-cases are below the ends of the thwarts; the end air-cases rise to the level of the heads of the stem and stern-post respectively.

In Fig. 12 are shown the *life-lines*, hanging in festoons or bights round the sides of the boats, for persons in the water to hold on by. The two midship bights at each side hang lower than the rest, so as to form stirrups to assist men in clambering on board.

Life-belts or jackets made of cork should be provided for the whole crew of the life-boat.

79. *Life-buoys.*—The life-buoy for hanging over the stern, with which ships of war, and sometimes also merchant ships are fitted, is usually made of copper or yellow metal, and consists of an upright shank with a pair of horizontal arms, forming a cross, and having at the ends of the arms two thin hollow globes, to give buoyancy. At the lower end of the shank is a flat step or stirrup, for the foot of a man to rest upon while he holds by the arms, or by the lower part of the shank. Should he take hold of the upper part of the shank, the buoy capsizes. On the top of the shank is a port-fire, to show the position of the buoy at night: it is lighted by a trigger, which is pulled before the buoy is let go.

Circular life-buoys are large rings, filled with cork and covered with painted canvas, and having ropes round them to take hold by. They are distributed about the weather-decks.

80. *Pumps*, for discharging water from the ship's hold, usually stand in compartments called *pump-wells*, which extend from the ship's bottom to the lower-deck, and sometimes to the upper-deck. (See, for example, Plate $\frac{F}{I}$, where a pair of pumps are shown, immediately abaft the mainmast.) In iron ships, divided into compartments by water-tight bulkheads, there is usually a pump, from 6 to 8 inches in diameter, to each such compartment. Pumps draw the water from the *limbers*, or water-channels (already mentioned in this Division, Article 38), and discharge it into the sea through a channel or spout called the *pump-dale*. Pumps were once made of wood, but are now generally of mixed metal, or of iron. They are of an endless variety of kinds, both as to their own construction and that of the mechanism by means of which they are worked; but for the most part they belong to one or other of the three following classes:—

I. *Piston-pumps* are the most frequently used; and are those in which a piston either moves up and down or to and fro in a cylinder or barrel, or revolves in a circular casing—the former being by far the more usual form. Every pump with a reciprocating piston requires at least two clacks, or self-acting valves opening upwards, for the supply and discharge of the water respectively; the casings or chambers which contain those valves are called respectively the *lower* and the *upper pump-box*. When the lower pump-box is fixed, and the upper pump-box is also the piston, the pump is called a *sucking-pump;* and this is the oldest construction: when the lower pump-box is the piston, and the upper is fixed, the pump is called a *lifting-pump;* this construction is not usual on board ship: when both pump-boxes are fixed, and the piston is solid, the pump is called a *forcing-pump;* and this is the most efficient construction. A long solid piston, without packing, is called a *plunger*. The piston-rod is called by seamen the *pump-spear*. In a *double-acting forcing-pump*, there are two sets of pump-boxes, connected with the two ends of the cylinder or barrel, so that the piston may force up water during the return-stroke as well as during the forward-stroke; in this case the piston-rod must pass through a stuffing-box.

Reciprocating pumps may be worked either by means of levers (called by seamen *pump-brakes*), or by means of cranks on a revolving shaft.

II. The *Chain-pump* consists of a tube with its lower end dipping into the limber, and of an endless chain passing up the tube, over a sprocket-wheel, and down another tube called the *back-casing*, and carrying a series of circular discs which nearly fit the tube, but not so closely as to rub against it. The sprocket-wheel is turned by means of cranks or winches on its axle, and the discs are thus made to drive the water before them up the tube. At the upper end of the tube is a cistern, whence the water flows away by the pump-dale.

III. The *Centrifugal pump* consists of a fan-wheel rotating within a circular casing, at a speed sufficient to produce in the mass of water within the casing an outward pressure intense enough to raise it from the level of the limbers to that of the pump-dale, and discharge it overboard. The water is drawn into the casing at the centre, through holes at both sides, and discharged at the circumference, either through one pipe or through variously formed passages. In the most efficient centrifugal pumps, the vanes of the fan are curved backwards, in order that their leading edges may cleave the water without striking it; and outside the circumference of the fan, there is sufficient space to allow the rapid motion at first impressed on the particles of water by the vanes to subside, and to be replaced by pressure.

In all sorts of pumps it is essential to economy of power that the passages traversed by the water should be as roomy, as short, and as direct as the circumstances of the case will admit of, and should be free from sudden contractions, sudden enlargements, and sharp turns; and this requires special attention where there are valves.

The *efficiency* of good pumps, or proportion of useful work to total work, may be estimated as ranging from $\frac{2}{3}$ to $\frac{4}{5}$.

The *work of a man* in pumping, when the exertion is kept up for *eight hours per day*, may be estimated as equivalent nearly to an effort of 17½ lbs., exerted through 2½ feet in each second, or 150 feet per minute, or 9000 feet per hour; being 157,500 foot-lbs., or 70 foot-tons per hour; or 560 foot-tons per day of eight hours. But a much greater exertion than this can be kept up for a few minutes at a time.

Experience in the working of *fire-engines* has shown, that the most favourable length of stroke of pump-handles to be worked by hand-power is from 30 to 35 inches. A stroke of 42 inches can be worked by men specially trained to it, but is too long for other men in general. The number of men required to work a hand fire-engine of the best kind, is about *one man for every 22 cubic inches of pump-barrel* (or in other words, *one man for every 28 cylindrical inches*): the contents of a pump-barrel being found by multiplying the area of the piston by the length of its stroke. If the piston is double-acting, this is to be doubled. When the preceding conditions are observed, strong active men, if frequently relieved, can work fire-engines at the rate of nearly 60 effective strokes per minute.

A portable fire-engine usually has a pair of single-acting forcing pumps of about 8 inches length of stroke, acting alternately, and forcing water into an air-vessel, whence it comes out in a continuous stream. The area of piston is adapted to the number of men available to work the engines. The ordinary diameter of the hose, or flexible pipes for taking in and discharging water, are, for suction-hose, 3 inches or thereabouts; for delivery-hose, from 2 to 3 inches: the diameter of the nozzle ranges from 0·6 to 0·8 inch.[*]

Pumps may be driven by steam-power, supplied either by small engines for the purpose, or by the engines that propel the vessel. It is usual to fit every steam-boat engine with one or two *bilge-pumps*, for discharging water from the hold. When a steam-vessel leaks very rapidly, the water may be discharged by opening a valve from the hold into the condenser: the air-pump of the engine then becomes available as a bilge-pump; but this expedient is not to be used except in cases of emergency, as the foul water from the hold is injurious to the engine.

In some cases pumps have been worked by means of the pitching of the vessel and the heaving of the waves, by setting a loaded cask to float astern, and leading a rope from it by means of pulleys to the pump-spear.

81. *Tanks*, for holding a store of fresh water, are built of iron plates (which ought to be galvanized), and are usually rectangular in plan, and 4 feet square, or thereabouts. They are from 4 to 6 feet deep. They hold from 400 to 600 gallons. A *gallon* is ·1604 of a cubic foot, and, when the water is pure, weighs 10 lbs. Tanks are flat-topped, and most of them are also flat-bottomed; but some have one of the lower edges of the base tapered off, that they may fit into the bilge of the ship: these are called *bilge-tanks*. Each tank has a man-hole at one corner of the top, with a cover to fit it; and they are stowed so as to bring four man-holes together. They are stowed at the bottom of the hold, on a skeleton-floor, and arranged so as to bring their tops as nearly as possible to one level, the tallest tanks being placed amidships. (See Nares on "Seamanship.") In almost all the hold plans and longitudinal sections of ships given in the Plates of this Treatise, the water-tanks are shown.

It is advisable, on account of risk of fire, that the *spirit-room* should be a tight iron tank, entered only through a hatch in the top: care being taken to ventilate it properly, lest those who enter it should be stupefied or suffocated by the fumes from the casks and bottles.

82. *Ventilators.*—Ships are usually ventilated by guiding or forcing fresh air down into the places where it is required. The oldest contrivance for that purpose is the *wind-sail*, being a large tube of canvas, kept open by hoops inside, and slung by ropes in a vertical position down a hatchway. The top of a wind-sail forms a hood with a large vertical opening, which is directed to windward. Fixed wind-sails, or ventilating tubes of sheet copper, brass, or iron, are also used, passing vertically downwards through the decks to the space to be ventilated, and having bell-mouthed hoods at top, which are turned to windward. In almost all the vertical sections of ships given in the Plates, several such ventilators are shown. They are especially required in the engine-room and stoke-hole of a steamer.

To promote the circulation of air in the cabins and sleeping-berths of a ship, it is useful to make the bulkheads or partitions which inclose them pervious to air, though not to light. One way of doing this is to make each panel of a bulkhead consist of two layers, being a pair of wooden gratings with their bars

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[*] See Report of the Special Jury on Fire-Engines, in the Reports of the Juries upon the International Exhibition of 1862. As to pumps in general, see Mr. D. K. Clark's work on the Exhibited Machinery of 1862.

water from the jackets is distributed by pipes to the state-rooms, for purposes of washing.

85. The *Galley*, *Caboose*, or *Cook-room*, is a room, usually in a house on the upper-deck, containing the cooking apparatus. Various examples of its position are shown in the Plates. It is built either of iron or of wood. If of wood, the wood-work is usually lined with lead, having a layer of felt between the lead and the wood. The floor is often paved with fire-clay tiles. Care should be taken to ventilate the cook-room well.

85A. *Water-closets*, in ships of war, are often placed out-board, those for the seamen being on a grated platform at each side of the knee of the head, screened from view by the *berthing-boards*, or planking of the head-rails, and having vertical metal soil-pipes of uniform diameter descending through the cheeks of the head; while those for the officers are in the quarter-galleries. Fnr an example of the former position, see the upper-deck plan of H.M.S. *Warrior*, Plate $\frac{B}{3}$. Another very common out-board position in paddle-steamers, is on the *wings*, or grated projecting platforms, before and abaft the paddle-boxes. Various positions in-board for water-closets are illustrated in the Plates of deck-plans and longitudinal sections. The soil-pipes of in-board water-closets are usually about 2½ inches in diameter, and have outlets into the sea so placed as to be covered with water when the ship is pitching and rolling in a seaway. They are often made with slide-valves; because the action of a common valve is liable to be deranged by the pitching of the vessel. It is advisable that every in-board water-closet should be ventilated through independent passages or openings, having no connection with the adjoining cabins or other rooms. Water-closets below the water-line have the soil removed and discharged by means of a pump.

86. *Lightning-conductors* are used to protect ships against the destructive effects of electric discharges between the sea and the clouds. The electric discharge takes place between two bodies in opposite electrical states, along the line of least resistance; and its destructive effect is greater, the greater the resistance with which it meets. The objects of a conductor are, to establish a definite line of least resistance, along which every discharge within a given space is certain to take place; and to insure that the resistance of that line shall be so small that no destructive effects shall arise from any discharge along it. Lightning-conductors are required on each mast of a ship with wooden masts, and on the jib-boom and bowsprit.

It is essential that every lightning-conductor should have a sufficient sectional area, otherwise it may be melted by a flash; that it should form an unbroken metallic communication from the mast-head to the sea, for at every break in a conductor, an explosion may take place; and that its course should be as nearly as possible straight, because if its course is indirect, it may cease to be the line of least resistance.

The metal which has the greatest conducting power for electricity, or in other words, offers the least resistance to it, is copper; and to make an efficient lightning-rod, the sectional area of copper should be not less than from ⅕ to ¼ of a square inch. To give an iron rod equal conducting power, its sectional area should be about three times as great; and the iron should be pure and soft, and may be protected by galvanizing it.

According to the system introduced by Sir William Snow Harris into the Royal Navy, a conductor is made in the form of a double strip of copper, sunk into a groove in the after side of each mast, and the lower side of the jib-boom and bowsprit. The two strips break joint with each other. As each mast consists of pieces, of which the lowest, or lower mast, is alone fixed, while the upper, or top-mast and top-gallant-mast, are capable of being raised and lowered by sliding through pieces called caps, those caps are provided with tumblers, by means of which the connection between the divisions of the conductor is kept unbroken. The same arrangement is made to connect together the divisions of the conductor on the jib-boom and bowsprit. In wooden ships the lower end of the conductor of the bowsprit runs down the stem, and is connected with the copper sheathing; and the lower ends of the conductors of the masts are also connected with the sheathing by means of bolts passing through the ship's bottom. In iron ships it is sufficient to connect the conductors with the iron hull of the ship. When the conductors are of copper, care should be taken to connect them with the iron of the ship at points as little as possible exposed to wet, and at the same time easily accessible for the purpose of seeing whether the iron is corroded through galvanic action. A piece of zinc in close contact with the iron where the copper conductor joins it, tends to prevent that corrosion.

Iron or steel masts are themselves conductors, and render copper conductors unnecessary. If used in wooden or composite ships, care should be taken that they have an unbroken metallic communication with the water by means of galvanized iron bolts.

Wire-rope standing rigging answers for a conductor when it is straight and taut, and has metallic communication with the sea; but when a shroud or a backstay hangs in a bight, it may cease to form a line of least resistance, and so may cause an explosion.

Instead of conductors made of rods, ships are sometimes protected by means of copper wire ropes, one hanging from each mast-head. The lower ends of those ropes are in ordinary kept coiled up on the weather-deck; and when a thunderstorm is expected, they are cast loose and dropped over the side, so as to dip into the water.

A lightning conductor protects but a small space around it; according to Sir William Snow Harris, that space may be considered as bounded by a cone having its apex at the top of the conductor, and its base of a radius equal to twice the height of the conductor; and hence the necessity for having a conductor on each mast; because a conductor on one of the masts does not protect the others.

87. *Lights.*—According to regulations enforced by the British and French governments, every vessel under way after sunset and before sunrise is to carry lights, as follows:—

A green lamp on the starboard side, and a red lamp on the port side, each visible for a distance of at least two miles on a dark night and in a clear atmosphere, and each visible throughout an arc of 10 points, from right ahead to 2 points abaft the beam on its own side of the ship; but neither of those side-lamps is to be visible from the contrary side of the ship; and to prevent that, each of them is to have an in-board screen projecting at least three feet forward from the light:—

Sea-going steam-ships (but not sailing ships), in addition to the side-lamps, are to carry a white light at the foremast-head, visible at least five miles off in a dark night and clear atmostanding obliquely in opposite directions, so as to form a set of angular passages through the bulkhead of such a shape that they cannot be seen through. This is specially useful in hot climates. In all climates it is advisable that all bulkheads between decks should have apertures for ventilation at the top and bottom.

Foul air may be discharged through chimneys in any convenient position; their tops should always rise high above the level of the mouths of the wind-sails. Hollow iron and steel masts, and pipes leading into the funnels of steamers are sometimes used as chimneys for the discharge of foul air.

Where the construction of the ship is such as to make ordinary means of ventilation insufficient, fresh air is distributed, and foul air drawn off, by means of blowing-fans driven by steam-power, as shown in the various plans and sections of the inboard works of H.M.S. *Warrior*, Plate $\frac{B}{5}$, &c. In order that a blowing-fan may work with economy of power, and with as little noise as possible, the same conditions should be fulfilled as in a centrifugal pump: viz., the blades of the fan should cleave and not strike the air, and space should be given beyond the circumference of the fan for the violent motion at first impressed on the air to subside by degrees.

The thorough ventilation of every part of a ship is essential to the preservation of the timber from dry-rot, as well as to the health of those on board.

Foul air chimneys and stove chimneys should have hoods pointing to leeward.

According to the information collected by General Morin in his work on Ventilation, the supply of fresh air introduced into really well-ventilated places where large numbers of persons are assembled, varies from 0·4 *cubic foot* to 0·8 *cubic foot per head per second*, averaging about 0·6 *cubic foot per head per second*, except where there is some special cause of insalubrity (as in hospitals, and in places where unhealthy trades are carried on), and then it may be necessary to increase the supply per head per second to 1 cubic foot, or sometimes to 1·5 cubic foot.

The sizes of the openings and passages for admitting fresh air and taking away foul air are regulated by the quantity of air, and by the velocities which experience has shown to be the most proper for the current of air. According to the same authority, the following are the best velocities for the air in different positions:—

	Feet per Second.
At the outlets, or orifices where foul air escapes from a room, from	2·5 to 3·3
At the inlets, or orifices where fresh air enters a room, from	1·3 to 1·6 [*]
In tubes, trunks, chimneys, and other passages for fresh or foul air, about	12.

Fresh air distributes itself in the most uniform manner throughout a room when it is introduced at a number of openings at as high a level as possible.

When a fire is used, not to warm a room, but simply to produce a draught in a foul-air chimney, the area of fire-grate may be about $\frac{3}{10}$ of the area of the chimney; and the consumption of fuel should be at the rate of about 1 lb. of coal to each 20,000 cubic feet of air.

The supply of air required for steam-boiler furnaces will be considered in the Sixth Division.

83. *Warming.*—The heat of a fire is given out partly by radiation from the glowing fuel, and partly by conduction from the hot gases produced by the combustion. In the case of coal, about one-half of the heat is given out by radiation, and one-half by conduction; therefore if a cabin or other room is warmed by means of an open fire-place, so constructed that the radiant heat alone is made available, about one-half of the whole heat produced is wasted. Hence aboard ship, for the sake of economy of fuel, some kind of stove is commonly used. As warming by direct radiation, however, is more healthful than warming by conduction, a stove open in front, so that as much heat as possible shall be radiated, leaving that heat only which would otherwise be wasted to act by conduction, is preferable to a close stove, in which the radiant heat is absorbed by the metal of the stove, and afterwards given out by conduction to the surrounding air. To make the conducting surface act very efficiently in warming air, its extent should be about *one square foot* for each *cubic foot per second* of air to be warmed.

The most wholesome metal for the heating-surface of a stove is iron; for copper and brass, when hot, give out noxious fumes.

The expenditure of fuel required for thoroughly warming air in cold weather, may be roughly estimated at about 1 lb. of coal for each 3300 cubic feet of air.

84. *Water-supply.*—Salt water from the sea, or fresh water from a tank, can be supplied to any part of the ship where it may be required, by means of pumps and pipes, which need no special explanation. Water for cleansing the hold is admitted directly from the sea, when required, through the *sweetening-cock*.

Distilled water is obtained by condensing steam in a surface condenser. On board a steam-vessel, the steam may be taken from the engine boilers; in a sailing vessel a special boiler is required; and then, to promote economy of fuel, the water for feeding the boiler should be that which has been heated by the condensation of the steam in the surface condenser.

Distilled water, when condensed without proper precautions, is nauseous and unwholesome, owing to the presence of impurities, and the absence of the air which good water contains in a state of diffusion. The air diffused in good water contains proportionally more oxygen, and more carbonic acid, than the atmospheric air. In the apparatus of Dr. Normandy, the aëration of the distilled water is insured by retaining amongst the steam while it is in the act of condensing, not only the air which is disengaged from the water that is evaporated, but also the air that escapes from the whole of the water used for condensation: that additional quantity of air being necessary, because sea-water contains proportionally much less diffused air than good fresh water from lakes, springs, or rivers. The condensed water being thus well aërated, is filtered through animal charcoal to remove impurities, and at the end of the process is as good as that of the purest springs. In the process of Messrs. Chaplin, a supply of air is drawn into the condenser from the atmosphere. (See Jury Reports on the International Exhibition of 1862; also, Mr. D. K. Clark's "Exhibited Machinery of 1862.")

Mere filtration will not remove organic impurities from water, unless it has been first aërated.

Distilled water may be obtained from the jackets of the cylinders of a steam-vessel while the engines are working. To make it fit to be drunk, it should be aërated and filtered. In the screw-steamer *Lancefield*, already mentioned, the distilled

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[*] The velocity of the fresh air entering is thus restricted in order that the draught may not be unpleasant to the inmates of the rooms.

sphere, and throughout an arc of 20 points, extending from 2 points abaft the beam on the starboard side to 2 points abaft the beam on the port side :[*]—

Steam-vessels towing other vessels are to carry two such foremast-head lights vertically, in addition to the side-lamps :—

Vessels at anchor are to carry, at a height not exceeding 20 feet above the hull, a white light, visible at least one mile off all round the horizon.[†]

88. *Binnacles, &c.*—The construction and adjustment of compasses, and the correction of the errors caused in them by the iron of the ship, form a subject that can be explained in a satisfactory manner in a special treatise only; and it will therefore be not here further mentioned, except by referring for information regarding it to the "Admiralty Manual for ascertaining and applying the Deviations of the Compass caused by the Iron in a Ship," edited by F. J. Evans, Esq., R.N., F.R.S., and Archibald Smith, Esq., M.A., F.R.S. The steering-compasses are placed in strong metal or wooden boxes called *Binnacles* or *Bittacles*, of which a well-appointed ship has two or three. They have openings glazed with strong plate-glass, to see the compass through, and at night are lighted by lamps inside. They are securely fastened to the deck.

A *hanging* compass is one so fitted that the card can be seen and read from below. It is sometimes placed in the top of the commander's cabin, so that he can see, without quitting his cabin, which way the ship's head bears.

As to the smallest admissible equipment of compasses, see the "Rules of the Liverpool Registry."

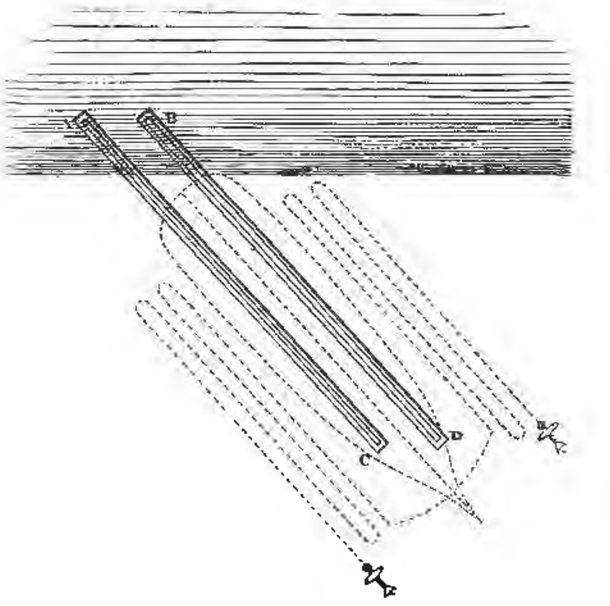
The *belfry* usually consists mainly of a pair of bitts or upright supports, between which the ship's bell swings. Its ordinary positions are exemplified in such of the Plates as show longitudinal sections of vessels.

CHAPTER VI.

LAUNCHING.

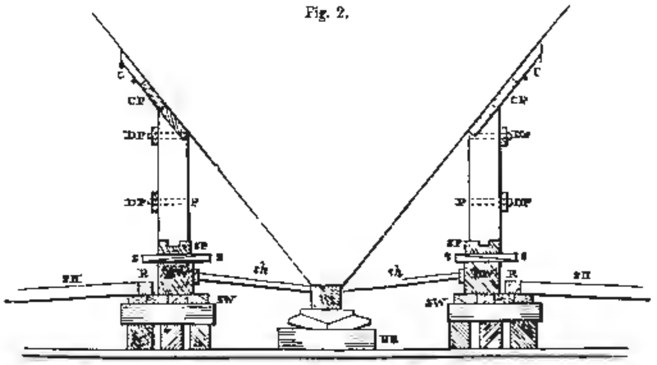
89. The *Launch* is a term used to comprehend the whole apparatus for launching the ship, together with the slip on which she is built and its equipments. The building-slip, with its blocks, &c., has been described in Article 57 of this Division; so that the apparatus specially connected with launching remains to be described. It may be divided into two principal parts: the *sliding-ways* or *slip-ways*, which rest on the floor of the slip, and present a smooth upper surface; and the *cradle*, being a temporary framework which rests and slides upon the slip-ways, and supports the ship during the launch.

Fig. 1.



In the sketch plan, Fig. 1, A C and B D are a pair of slip-ways, and the dotted outline marks the position of the ship. In the cross-section, Fig. 2, S W are the slip-ways, and the structure above them, giving temporary support to the ship, is the cradle.

Fig. 2.



90. The *Slip-ways*, S W, S W, Fig. 2 (also called *sliding-ways*), are a pair of parallel inclined platforms of timber, firmly founded on the floor of the slip, and kept steady in their positions by shores, marked S H. Their slope ranges from 1 in 12 for the smallest ships, to 1 in 24 for the largest. The planks which form the upper surfaces of the slip-ways should have their butt joints bevelled so as to lean a little forward, in order to prevent obstruction in the event of the sinking of the plank of the slide at the fore side of a butt. The ordinary breadth of each slip-way for large vessels is from 3 to 4 feet. The best method, however, of adjusting their breadth, is the following—the area of bearing surface of the *bilge-ways*, or lowest pieces of the cradle, upon the slip-ways should be such that the mean intensity of the pressure shall not exceed 50 lbs. on the

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[*] The inboard screens, as prescribed by the regulations, are by no means sufficient to insure that the side-lamps shall not be seen across the bow, unless those lamps are provided with proper lenses, which consist of a semicircular part forming the inboard half of the front of each lantern, and a cylindrical part extending from the centre of the front of the lantern, round the outboard side, to two points abaft the beam. Their effect is to concentrate the light in a horizontal layer, and to confine it to the required angular space. The mast-head light should have a cylindrical lens. The best lenses are of the form called "polyzonal," but may be cast in one piece. The colouring of the side-lights is usually effected by means of coloured glass chimneys. As red glass or other colouring medium absorbs more light than a green medium of equal depth of colour, it is advisable that the flame of the port side-lamp should be somewhat larger than that of the starboard side-lamp, in order that both may be visible with equal clearness at the same distance.

[†] For details regarding pilot-vessels, fishing-boats, &c., see the Regulations as issued by the Board of Trade.

23. *Iron* and *Steel* are used for making tubular masts, bowsprits, and yards, in the form of plates, angle-bars, and rivets; as to the strength and quality of which, see Division III., Article 75, and Division IV., Article 7; and also the Rules of Lloyd's and of the Liverpool Registry, quoted in the Appendix to Division III. According to the rules of the Liverpool Registry, steel for making yards is treated as being stronger than iron in the ratio of 4 to 3.

SECTION II.—FIGURES AND DIMENSIONS OF MASTS AND SPARS.

24. *Principal Diameters of Masts, Bowsprits, and Jib-booms.*—The bending load to which a mast is exposed is proportional to the area of canvas set upon it, which is roughly proportional to the square of the length of the mast; and the leverage with which that load acts is roughly proportional to the length of the mast; so that the bending moment may be roughly estimated as varying nearly as the cube of the length of the mast. The moment of resistance of the mast is proportional to the cube of its diameter (see Division III., Article 46, Rule IV.), and therefore the diameters of similarly situated masts ought to bear a nearly constant proportion to their lengths; and such is the rule followed in practice: the proper proportions in different cases having been ascertained by long experience.

The greatest diameter of a mast, bowsprit, yard, or any spar, is called the *given diameter*, and bears proportions to the length which are exemplified in the following table. The *end diameters* bear certain proportions to the given diameter.

	Position of given Diameter.	Ratio of given Diameter to Length from Heel to Hounds.	Ratios of end Diameters to given Diameters.	
LOWER OR STANDING MASTS:—				
Ships and brigs,......	At the partners of the wedging deck,	... $\frac{1}{36}$ to $\frac{1}{30}$ ...	Head, Hounds, Heel,	·67 to ·75 ·75 to ·80 ·83
Schooners,..............	do.	... $\frac{1}{30}$ to $\frac{1}{40}$ ...	Head, Hounds, Heel,	·5 to ·67 ·6 to ·75 ·83
Cutters,................	do.	... do. ...	Head, Hounds, Heel,	·67 to ·83 ·8 to ·86 ·83
Luggers,................	do.	... do. ...	Head, Hounds, Heel,	·58 ·75 ·83
Lateen rig,............	do.	... $\frac{1}{40}$ to $\frac{1}{50}$ ...	Head, Hounds, Heel,	·75 ·83 ·83
TOPMAST:—				
Square rigged, ...	At the cap of the lower mast,	... $\frac{1}{40}$ to $\frac{1}{50}$ ...	Head, Hounds,	·7 ·8
Fore-and-aft rigged,...	do.	... $\frac{1}{30}$ to $\frac{1}{45}$ ...	Head, Hounds,	·5 ·7
TOPGALLANT-MAST,......	At the cap of the topmast,	... $\frac{1}{36}$ to $\frac{1}{45}$ ...	Pole, Hounds,	·5 to ·55 ·8
BOWSPRIT:—				
Ships and brigs,.......	At the bed,	... $\frac{1}{26}$ to $\frac{1}{28}$ ...	Outer end, Heel,	·67 ·83
Cutters and schooners,	do.	... do. ...	Outer end, Heel,	·67 1·0
JIB-BOOM,...........	At the cap of the bowsprit,	... $\frac{1}{40}$ ...	Outer end, Inner end,	·67 to ·75 1·0
FLYING JIB-BOOM,.......	At the outer end of the jib-boom,	... $\frac{1}{40}$ ...	Outer end, Inner end,	·67 ·75

25. *Principal Diameters of Yards, Booms, and Gaffs.*—The part of a yard at or near the middle, by which it is slung, is called the *slings;* the two endmost parts, projecting beyond the head of the sail, the *arms;* and the parts intermediate between the slings and the arms, the *quarters.* The lower or foremost end of a gaff is called the *throat;* the upper or aftermost part, which projects beyond the sail, the *peak;* and the part intermediate between the throat and the peak, the *quarters.*

	Position of given Diameter.	Ratio of given Diameter to Length.	Ratios of end Diameters to given Diameters.	
SQUARE YARDS:—				
Lower,......................	At slings,	... $\frac{1}{40}$ to $\frac{1}{48}$ ...	Arms,	·5
Topsail,.....................	do.	... $\frac{1}{56}$ to $\frac{1}{60}$ ...	"	·5
Topgallant, royal, and studding sail, ...	do.	... $\frac{1}{55}$ to $\frac{1}{65}$ ...	"	·5
LUG-SAIL YARDS, ...	do.	... $\frac{1}{50}$ to $\frac{1}{65}$ ...	"	·5
LATEEN YARDS,..............	do.	... $\frac{1}{80}$ to $\frac{1}{100}$ ...	Fore end, After end,	·33 ·67
GAFFS:—				
For drivers, and fore-and-aft fore and main sails,... ...	Near throat,	... $\frac{1}{45}$ to $\frac{1}{55}$ ..	Peak,	0·5 to 0·6
For trysails,........	do.	... $\frac{1}{50}$ to $\frac{1}{55}$ ...	"	0·6
BOOMS:—				
Main-booms of cutters, schooners, and brigs, and driver-booms,.....	At sheet or taffrail, or about one-third of length from after end of boom,	$\frac{1}{50}$ to $\frac{1}{60}$ ...	Fore end, After end,	·67 ·75
Square-sail booms,.......	At middle,	... About $\frac{1}{60}$ ...	From	·75 to ·67
Studding-sail booms and ring-tail booms, ...	Throughout middle third of length,	... $\frac{1}{60}$ to $\frac{1}{70}$ ...	"	·75 to ·67

If the working modulus of stress on timber be taken at 1000 lbs. on the square inch, and the average area of sail spread on a yard as equal to the square of the length of the yard, it is easily deduced from the principles of Division Third, Article 46, that the diameters of yards used in practice are adapted to the following bending loads, in lbs. per square foot of canvas:—

Diameter = $\frac{1}{40}$ length, ... 432 lbs. per square foot.
" $\frac{1}{48}$ " ...... 250 " "
" $\frac{1}{60}$ " ...... 128 " "

The bending load upon a yard may be many times greater than the direct pressure of the wind on the sail, owing to the position and form of the sail.

From the principles of Article 48 of the Third Division, it appears that the longitudinal sections of the theoretical figures of uniform strength for yards and booms, and the dimensions of the frusta of cones which approach nearest to those figures, are as follows:—

	Yards.	Booms.
Index of the power of the distance from the end, to which the diameter of the theoretical figure is proportional,......................	$\frac{2}{3}$	$\frac{1}{3}$
Proportion of the smallest to the greatest diameter, in the conic frustum which approaches nearest to the theoretical figure, ...	$\frac{1}{4}$	$\frac{5}{8}$

Hence it appears, that the smaller diameters used in practice are always greater than those which would be necessary if the strength of the material were uniform throughout the length of the yard or boom. The reason is, that the tapered part of the yard or boom is more or less grain-cut, and consequently weakened.

26. *Tapering of Masts and Spars.*—The diameters of masts and spars at the *quarters*, or parts intermediate between the greatest and smallest diameters, are not regulated by any theoretical principle, but are merely laid off so as to give a fair convex curvature to the outline. The distance from the given diameter to the small diameter is divided into four equal intervals, and the points of division are called respectively the *first, second,* and *third quarters.* In a lower mast, the points of division between the partners and the heel are called the *lower quarters*, and those between the partners and the hounds the

The stations for the masts are nearly as follows, in fractions of the load-water-line from the middle:—

Mizenmast,		Mainmast,
Abaft,		Afore,
about ·4.	...	about ·11.

This style of rig is now little used. According to Fincham, it spreads a smaller area of sail, in proportion to the moment, than any other.

19. A *Ship* is a vessel with three square-rigged masts, each provided with the series of sails mentioned in Article 8, a bowsprit and jib-boom, with jibs and stay-sails, and a gaff-sail on the mizenmast, called the *spanker* or *driver*. To show the names given to the masts, spars, and sails of a ship, reference may be made to Plate $\frac{F}{4}$ (the rigging-plan of the *Formby*):—

MASTS AND SPARS.

A, bowsprit.
B, jib-boom.
C, flying jib-boom.
D, dolphin-striker.
E, foremast.
F, fore-topmast.
G_1, fore-topgallantmast. } One spar.
G_2, fore-royal pole. }
H, mainmast.
I, main-topmast.
J_1, main-topgallantmast. } One spar.
J_2, main-royal pole. }
K, main-skysail pole, or signal pole. (Some ships have a skysail pole or signal pole on each mast.)
L, mizenmast.
M, mizen-topmast.
N_1, mizen-topgallantmast. } One spar.
N_2, mizen-royal pole. }
O, fore-yard.
P, lower fore-topsail-yard. (Lower topsail-yards are of recent introduction, and are used in some ships only, in connection with a special method of reefing top-sails.)
Q, fore-topsail-yard, or upper fore-topsail-yard.
R, fore-topgallant-yard.
S, fore-royal-yard.
T, main-yard.
U, lower main-topsail-yard (see P, above).
V, main-topsail-yard, or upper main-topsail-yard.
W, main-topgallant-yard.
X, main-royal-yard.
Y, Cross-jack (or Cro'-jack) yard.
Z, Lower mizen-topsail-yard (see P, above).
AA, mizen-topsail-yard, or upper mizen-topsail-yard.
BB, mizen-topgallant-yard.
CC, mizen-royal-yard.
DD, main-trysail-gaff. (Some ships have a trysail-gaff on the foremast also.)
EE, spanker-boom, or driver-boom.
FF, spanker-gaff, or driver-gaff.

The following spars are not seen in the Plate.

In some ships, there is a *spritsail-yard*, crossing below the bowsprit a short way abaft the dolphin-striker; but in the present example that yard is not used. It does not carry a sail, but is used only for securing the rigging of the jib-boom and flying jib-boom. Sometimes instead of one spritsail-yard crossing the bowsprit horizontally, there are a pair of spars pointing obliquely downwards at opposite sides of it: these are called *spritsail-gaffs*.

Near the cat-heads, at the bow of the ship, two spars project, called the *boomkins* or *bumpkins*, for hauling out the weather-tack of the fore-sail in sailing near the wind. Sometimes, in small ships, the foot of the fore-sail is spread by the *fore-boom*, or *bentick-boom*.

The spanker and try-sails are sometimes bent to rings or hoops running on *trysail-masts*, parallel to, and close abaft the lower masts, to which they are fixed at the head and heel.

The *mizen-trysail-gaff*, smaller than the spanker-gaff, is used in stormy weather.

The *studding-sail booms*, when rigged out, project from the arms of the fore and main lower yards, and fore and main topsail-yards, to which each of them is secured by passing through a pair of rings called *boom-irons* (to be described in detail in a later chapter). Each of those booms serves to spread the foot of a studding-sail, and is named from that studding-sail; thus, the topgallant-studdingsail booms are carried by the topsail yard-arms, and the topmast-studdingsail booms by the lower yard-arms. The feet of the lower studding-sails are spread by means of booms called the *lower studding-sail booms*, or *swing-booms*. The heads of the studding-sails are bent to *studding-sail yards*, which are slung from the studding-sail booms, and from the fore and main topgallant yard-arms. For the reason stated in Article 7, there are no studding-sails on the mizenmast.

The *ringtail boom* is rigged out like a studding-sail boom, at the end of the spanker boom; and the *ringtail yard* is slung from the peak.

The *ensign-staff* is a pole fixed to the taffrail, and raking aft over the stern, for displaying the *ensign*, *jack*, or national flag of the ship, when the spanker is not bent. At other times the ensign is run up to the peak of the spanker-gaff, as shown in the Plate.

SAILS.

a, fore-staysail.
b, fore-topmast-staysail.
c, inner jib.
d, outer jib. (Most ships have only one jib, of an area about equivalent to the combined effective area of the two jibs in the present example.)
e, fore-topgallant-staysail.
f, flying jib.
g, fore-sail, or fore-course.
h, lower } fore-topsail;
i, upper }
being equivalent to an ordinary fore-topsail divided into two parts of equal depth.
j, fore-topgallant-sail.
k, fore-royal.
l, main-staysail.
m, main-topmast-staysail.
n, main-topgallant-staysail.
o, main-royal-staysail.
p, main-sail, or main-course.
q, lower } main-topsail.
r, upper }
(See *h* and *i*, above.)
s, main-topgallant-sail.
t, main-royal.
u, main-trysail, or main-spencer. Sometimes there is a trysail or spencer on the foremast also. Sometimes the place of the main-trysail is occupied by the *mizen-staysail*.
v, mizen-topmast-staysail.
w, mizen-topgallant-staysail.
x, mizen-course, or cro'-jack (seldom used).
y, lower } mizen-topsail.
z, upper }
(See *h* and *i*, above.)
aa, mizen-topgallant-sail.
bb, mizen-royal.
cc, spanker or driver (instead of which the *mizen-trysail* is hoisted in stormy weather).

The following additional sails are not seen in the Plate:—

Sky-sails, *sky-scrapers*, or *flying kites*, being small square-sails above the royals.

Studding-sails on the foremast and mainmast, already mentioned. (Lower studding-sails on the mainmast are seldom used.)

The *ringtail*, already mentioned, set beyond the leech of the spanker.

Water-sails, set in very light airs and smooth water, below the lower studding-sail booms.

The standing and running rigging, shown on the same Plate, will be explained in a later chapter.

In finding the centre of effort and moment of sail of a ship, it is usual to take the following sails only into account—*jib*, *fore and main courses*, *driver*, *three top-sails*, and *three top-gallant-sails*.

The following dimensions and proportions are founded chiefly on the examples and rules of Fincham, and on some other examples of more recent date:—

	Base of sail = line of flotation ×	from 1·6 in short full ships to 1·35 in long fine ships.
Sails set as above enumerated.	Leverage of sail = extreme breadth ×	from 1·75 to 2·00
	Height of centre of effort above base of sail = extreme breadth ×	“ 1·0 to 1·3
	Area of sail = area of load-water section ×	“ 3·0 to 3·9
	= line of flotation × extreme breadth ×	“ 2·2 to 2·9

Stations for Masts, in fractions of line of flotation from the middle:—

Mizenmast, Abaft,	Mainmast, Abaft,	Foremast, Afore,
from 0·4 to 0·3 ...	from 0·08 to 0·03 ...	from 0·4 to 0·3

The centres of the square-sails on a mast are about ·05 of the extreme breadth before the station of the mast.

Rake of foremast, aft,..................................	from 0 to 1 in 36
Rake of mainmast, aft,..................................	" 0 to 1 in 12
Rake of mizenmast, aft,..................................	" 0 to 1 in 12
Steeve of bowsprit,..	" 1 in 3 to 1 in 2

SAILS.

Nock of driver above base of sail = height of centre of effort above base of sail ×.............	from ·6 to ·75
Clew of driver abaft stern-post at load-water-line = line of flotation ×..............................	" ·23 to ·05
Foot of driver extends from clew to mizenmast, or mizen-trysail-mast.	
Head of driver = foot ×..............................	from ·7 to ·75
Leech of driver = luff ×..............................	from 1·5 (for a deep luff) to 2·0 (for a short luff).
Tack of jib afore stem at load-water-line = line of flotation ×..............................	from ·4 to ·3
Foot of jib = line of flotation ×....................	from ·27 to ·3
Luff of jib = length of jib-stay from foretopmast head to jib-boom end ×..............................	about ·8
Leech of jib = luff ×..............................	" ·8
Height of head of main-topsail above base of sail = height of centre of effort above base of sail ×	from 2·0 to 1·75
Depth of main-topsail = height of centre of effort above base of sail ×..............................	" 1·0 to 0·9
Depth of main-course determined from the position of the foot of the main-topsail.	
Depth of fore-course = depth of main-course ×	" 0·9 to 0·75
Depth of mizen-course determined by cro' jack yard being close above nock of driver.	
Depth of fore-topsail = depth of main-topsail ×	" 0·87 to 1·0
Depth of mizen-topsail = depth of main-topsail ×	" 0·75 to .65
Depths of topgallant-sails = depths of top-sails ×	" 0·5 to 0·6
Depths of royals = depths of topgallant-sails ×	about ·67
Head of main-course = line of flotation × (in short ships)..............................	from ·48 to .52
(in long ships)..............................	" ·36 to ·48
Head of fore-course = head of main-course ×...	" ·85 to 1·0
Head of mizen-course = head of main-course ×	" ·65 to ·75
Heads of top-sails = heads of courses ×..........	" ·7 to ·8
Heads of topgallant-sails = heads of courses ×...	" ·4 to ·6
Heads of royals = heads of courses ×............	" ·3 to ·45
Breadth of a studding-sail = breadth of sail beside which it is set ×..............................	" ·5 to ·6

Depth of canvas in a square-sail about $\frac{1}{30}$ part less than the total depth from centre to centre of the yards between which it is set.

The *roaching* or hollowing of sails at the foot, and other details, will be treated of in a later chapter.

Distribution of the Base of Sail, per cent.:—

	Driver,		Main-course,		Fore-course,		Jib,		Total.
from	22	+	31	+	28	+	19	=	100
to	20	+	29	+	29	+	22	=	100

BOWSPRIT, MASTS, AND SPARS.

Height of hounds of lower masts above heads of courses and nock of driver = depth of main-topsail ×.........	about $\frac{1}{8}$
Projection of jib-boom end beyond tack of jib = foot of jib ×..............................	" ·03
Length of jib-boom about 23 inches less than foot of jib.	
Projection of outer end of bowsprit beyond heel of jib-boom = length of jib-boom ×..............................	$\frac{1}{3}$
Heel of bowsprit steps on bowsprit partners, afore the fore-mast.	
Flying jib-boom = jib-boom ×......................	from 0·6 to 1·2
Projection of peak of gaff beyond peak of driver = head of driver ×..............................	at least about ·045
Additional length of peak for displaying signals,	from 3 to 6 feet
Hounded length of topmast = depth of topsail nearly.	
Hounded length of topgallantmast = depth of topgallant-sail nearly.	
Royal pole = topgallantmast hounded ×.........	about ·7
Skysail pole or signal pole = royal pole ×.......	" $\frac{1}{3}$
Length of each lower-mast head = hounded length of topmast ×..............................	about ·3
Length of each topmast-head = hounded length of topgallantmast ×..............................	" ·24
Each lower, topgallant, and royal yard-arm = head of sail ×..............................	" ·05
Each topsail yard-arm = excess of half-breadth of sail at the middle of its depth above half-breadth at the head + $\frac{1}{20}$ of head of the topsail.	
Spritsail-yard = fore-topsail-yard; or	
Each spritsail-gaff = fore-topsail yard ×........	" $\frac{1}{2}$
Mizen-trysail-gaff = driver-gaff ×................	" ·3
Main-trysail-gaff = driver-gaff ×................	" ·6
Swing-booms, each = main-yard ×..............	" ·6
Fore-boom = fore-yard.	

It may be observed that in one of the limiting cases given in the above statement, the upper sails and spars of the foremast and mainmast are of equal dimensions, the only difference being in the depths of the courses. The object of this in ships (as in brigs), is to enable the same spare spars and sails to answer for either of those masts. It is more practised now than it was in former times.

20. A *Barque* has three masts; the foremast and mainmast being square-rigged, like those of a ship, and the mizenmast fore-and-aft-rigged, like that of a schooner. The stations, dimensions, sails, and rig for the mainmast, foremast, and bowsprit, are the same as for a ship, except that the foremast, as well as the mainmast, has almost always a try-sail, and those try-sails are somewhat larger for a barque than for a ship.

The foot of the driver, and the driver-boom, may be laid-off as for a ship; but that sail is deeper than a ship's driver.

The following are the proportions peculiar to a barque:—

Nock of driver, nearly on a level with the centre of effort.	
Head of driver = foot ×..............................	from ·63 to ·75
Depth of gaff-topsail = depth of main-topsail ×	" ·9 to 1·0
Mizentopmast = maintopmast ×..................	" ·85 to ·9
Main-trysail-gaff = driver-gaff ×..................	" ·63 to ·71
Fore-trysail-gaff = driver-gaff ×......	" ·66 to ·78
Mizen-topsail-gaff = driver-gaff ×................	" ·25 to ·5

20 A. *Vessels with more than three masts* are uncommon, and are met with chiefly amongst steam-vessels, because of their great proportionate length, which sometimes makes it difficult to spread the required area of sail on three masts only. In a four-masted ship, the second or bonaventure mizenmast is always fore-and-aft rigged, like that of a barque.

21. *Steam-vessels.*—The propelling action of canvas and steam combined, has been considered in the First Division, Article 184.

The fore-and-aft rig is preferable to the square-rig for steamers, on account of the comparatively small resistance that the former style of rig meets with in steaming against the wind with sails furled. Hence the square-rig is in general used in steamers only partially, the commonest rig being that of two-masted or three-masted schooners; and even the largest steamers, and those most fully covered with canvas, are almost always rigged as schooners, brigantines, or barques, with two, three, or four masts, and seldom as full-rigged ships or as brigs.

A steam-vessel that is intended to make long voyages under canvas alone, or with little assistance from steam, is fitted with masts and sails equal to those of a sailing vessel of the same dimensions and rig; and such is usually the case with sea-going war steamers, how powerful soever their engines may be, with many steam-yachts, and with merchant vessels having "auxiliary" screw engines of small power. The chimneys are usually between the foremast and mainmast, being the place where they interfere least with the working of the sails. See, for example, H.M.S. *Warrior*, Plate $\frac{B}{7}$.

Steam-vessels in which steam is to act always as the principal propelling power, have in general a less area of sail than sailing vessels of the same dimensions. The *base of sail*, in particular, is proportionally short, as compared with the length of the line of flotation. Its ratio to that line varies very much; but the ordinary values may be estimated as ranging from 1 to 0·5. This shortening of the base of sail is in general produced chiefly by there being a gap in the middle of it, over the boiler-room; and sometimes also by the bowsprit being very short, or altogether wanting, as is often the case in a vessel with a long fine entrance. In many steam-vessels, the base of sail is nearly equal to that of a sailing vessel of a length equal to from 3½ to 5 times the extreme breadth of the steamer.

The shortened base of sail is distributed amongst the feet of the several sails nearly as in sailing vessels.

The *mean height of sail*, in many steamers, is as great proportionally to the extreme breadth of the vessel as it is in sailing vessels; and such is very generally the case in screw-steamers, where an important use of the sails is to steady the vessel in a seaway; and their power of doing so depends on their moment. In other examples, found chiefly amongst the swifter class of paddle-steamers, the mean height of sail is considerably less than in a sailing vessel of the same extreme breadth; being sometimes little more than half.

Vessels which always use steam as the chief means of propulsion are seldom provided with those sails which are serviceable in light winds only, such as flying kites, studding-sails, and royals. Some, indeed, are without upper sails, and have *stump masts;* that is, lower masts without tops.

The rigging plan of the *Hope*, Plate $\frac{G}{3}$, may be taken as an extreme example of a swift paddle-steamer having sails much smaller in both dimensions than those of a sailing vessel of the same length and breadth. She is rigged as a two-masted schooner, without a bowsprit; and the following are the spars and sails:—

A, foremast.
B, foretopmast.
C, mainmast.
D, maintopmast.
E, fore-gaff.
F, fore-gaff-topsail-yard.
G, main-boom.
H, main-gaff.
I, main-gaff-topsail-yard.

a, fore-staysail.
b, jib.
c, jib-topsail.
d, fore-sail.
e, fore-gaff-topsail.
f, main-staysail.
g, main-sail.
h, main-gaff-topsail.

The principal proportions are as follows:—

Line of flotation = extreme breadth ×	8·0
Base of sail = line of flotation ×	0·6
Depth of centre of lateral resistance below water = extreme breadth ×	0·114
Height of base of sail above centre of lateral resistance = extreme breadth ×	0·57
Leverage of sail = extreme breadth ×	1·23
Mean height of sail (centre of effort above base) = extreme breadth ×	0·66
Area of sail = line of flotation × extreme breadth ×	0·57
Centre of effort is nearly at middle of line of flotation.	
Distance between centres of head-sail and after-sail = line of flotation ×	·62
Centre of head-sail afore middle = line of flotation ×	·28
Centre of after-sail abaft middle = line of flotation ×	·34

Proportionate areas of—
After-sail : Head-sail
: : 14 : 17 nearly.

Distance of each mast from middle = line of flotation ×	0·28

The first instance of a ship with six masts is presented by the *Great Eastern*. She has no bowsprit; and the rig and order of the masts are as follows:—

Foremast—fore-and-aft rigged.
Second mast—square rigged.
Third mast—square-rigged.
Fourth mast—fore-and-aft rigged, but capable of being fitted with square sails also.
Fifth mast—fore-and-aft rigged.
Sixth mast—fore-and-aft rigged.

For details as to the *Great Eastern*, reference must be made to Mr. Scott Russell's treatise on "Naval Architecture."

CHAPTER II.

OF MASTS AND SPARS.

SECTION I.—MATERIALS FOR MASTS AND SPARS.

22. The *Timber* best suited for masts and spars consists of the stronger kinds belonging to the class of *Pine-wood*, or that produced by coniferous trees, such as pine, fir, larch, cowrie, &c.; because such timber combines strength with flexibility and lightness, and is to be had in long straight pieces. It has already been described in the Fourth Division, Articles 14, 15, and 16. The heavier and more resinous kinds, as red and yellow pine, are the best for lower masts and topmasts, and the larger yards; the lighter and less resinous kinds, as spruce or deal, are the best for the loftier and lighter spars, as topgallant masts and yards, studding-sail yards and booms, &c.

Pieces of timber suited for being made into masts and spars are called *sticks*. Special care is used in their inspection, to see that they are sound. They are divided into squared sticks, called *inch-masts*, which are described according to the number of inches in the side; and round sticks, described according to their girth at the butt, in *hands* of four inches, and called *hand-masts* if the girth is not less than six hands, and *spars* if the girth is less than six hands. Spars are further subdivided as follows:—

Name.	Girth at the butt.
Cant spars,	from 6 to 5 hands.
Barling spars,	" 5 to 4 "
Boom spars,	" 4 to 3 "
Middling spars,	" 3 to 2 "
Small spars,	" 2 to 1 "

Immersion in mud is considered to be the best way of preserving mast-timber until it is wanted for use.

23. *Iron* and *Steel* are used for making tubular masts, bowsprits, and yards, in the form of plates, angle-bars, and rivets; as to the strength and quality of which, see Division III., Article 75, and Division IV., Article 7; and also the Rules of Lloyd's and of the Liverpool Registry, quoted in the Appendix to Division III. According to the rules of the Liverpool Registry, steel for making yards is treated as being stronger than iron in the ratio of 4 to 3.

SECTION II.—FIGURES AND DIMENSIONS OF MASTS AND SPARS.

24. *Principal Diameters of Masts, Bowsprits, and Jib-booms.*—The bending load to which a mast is exposed is proportional to the area of canvas set upon it, which is roughly proportional to the square of the length of the mast; and the leverage with which that load acts is roughly proportional to the length of the mast; so that the bending moment may be roughly estimated as varying nearly as the cube of the length of the mast. The moment of resistance of the mast is proportional to the cube of its diameter (see Division III., Article 46, Rule IV.), and therefore the diameters of similarly situated masts ought to bear a nearly constant proportion to their lengths; and such is the rule followed in practice: the proper proportions in different cases having been ascertained by long experience.

The greatest diameter of a mast, bowsprit, yard, or any spar, is called the *given diameter*, and bears proportions to the length which are exemplified in the following table. The *end diameters* bear certain proportions to the given diameter.

	Position of given Diameter.	Ratio of given Diameter to Length from Heel to Hounds.	Ratios of end Diameters to given Diameters.	
LOWER OR STANDING MASTS:—				
Ships and brigs, ……	At the partners of the wedging deck,	… $\frac{1}{40}$ to $\frac{1}{36}$ …	Head, Hounds, Heel,	·67 to ·75 ·75 to ·80 ·83
Schooners, ……………	do.	… $\frac{1}{50}$ to $\frac{1}{45}$ …	Head, Hounds, Heel,	·5 to ·67 ·6 to ·75 ·83
Cutters, ………………	do.	… do. …	Head, Hounds, Heel,	·67 to ·83 ·8 to ·86 ·83
Luggers, ………………	do.	… do. …	Head, Hounds, Heel,	·58 ·75 ·83
Lateen rig, ……………	do.	… $\frac{1}{45}$ to $\frac{1}{36}$ …	Head, Hounds, Heel,	·75 ·83 ·83
TOPMAST:—				
Square rigged, ……	At the cap of the lower mast,	… $\frac{1}{40}$ to $\frac{1}{30}$ …	Head, Hounds,	·7 ·8
Fore-and-aft rigged, …	do.	… $\frac{1}{30}$ to $\frac{1}{48}$ …	Head, Hounds,	·5 ·7
TOPGALLANT-MAST, ……	At the cap of the topmast,	… $\frac{1}{38}$ to $\frac{1}{48}$ …	Pole, Hounds,	·5 to ·55 ·8
BOWSPRIT:—				
Ships and brigs, ……	At the bed,	… $\frac{1}{35}$ to $\frac{1}{30}$ …	Outer end, Heel,	·67 ·83
Cutters and schooners,	do.	… do. …	Outer end, Heel,	·67 1·0
JIB-BOOM, ………………	At the cap of the bowsprit,	… $\frac{1}{40}$ …	Outer end, Inner end,	·67 to ·75 1·0
FLYING JIB-BOOM, ……	At the outer end of the jib-boom,	… $\frac{1}{44}$ …	Outer end, Inner end,	·67 ·75

25. *Principal Diameters of Yards, Booms, and Gaffs.*—The part of a yard at or near the middle, by which it is slung, is called the *slings;* the two endmost parts, projecting beyond the head of the sail, the *arms;* and the parts intermediate between the slings and the arms, the *quarters.* The lower or foremost end of a gaff is called the *throat;* the upper or aftermost part, which projects beyond the sail, the *peak;* and the part intermediate between the throat and the peak, the *quarters.*

	Position of given Diameter.	Ratio of given Diameter to Length.	Ratios of end Diameters to given Diameters.	
SQUARE YARDS:—				
Lower, ……………………	At slings,	… $\frac{1}{50}$ to $\frac{1}{56}$ …	Arms,	·5
Topsail, ……………………	do.	… $\frac{1}{56}$ to $\frac{1}{60}$ …	"	·5
Topgallant, royal, and studding sail, …	do.	… $\frac{1}{55}$ to $\frac{1}{60}$ …	"	·5
LUG-SAIL YARDS, …………	do.	… $\frac{1}{55}$ to $\frac{1}{65}$ …	"	·5
LATEEN YARDS, ……………	do.	… $\frac{1}{70}$ to $\frac{1}{100}$ …	Fore end, After end,	·83 ·67
GAFFS:—				
For drivers, and fore-and-aft fore and main sails, …	Near throat,	… $\frac{1}{50}$ to $\frac{1}{55}$ …	Peak,	0·5 to 0·6
For trysails, …………	do.	… $\frac{1}{60}$ to $\frac{1}{65}$ …	"	0·6
BOOMS:—				
Main-booms of cutters, schooners, and brigs, and driver-booms, ……	At sheet or taff-rail, or about one-third of length from after end of boom,	$\frac{1}{50}$ to $\frac{1}{60}$ …	Fore end, After end,	·67 ·75
Square-sail booms, ……	At middle,	… About $\frac{1}{50}$ …	From	·75 to ·67
Studding-sail booms and ring-tail booms, …	Throughout middle third of length,	… $\frac{1}{60}$ to $\frac{1}{70}$ …	"	·75 to ·67

If the working modulus of stress on timber be taken at 1000 lbs. on the square inch, and the average area of sail spread on a yard as equal to the square of the length of the yard, it is easily deduced from the principles of Division Third, Article 46, that the diameters of yards used in practice are adapted to the following bending loads, in lbs. per square foot of canvas:—

Diameter = $\frac{1}{40}$ length, …… 432 lbs. per square foot.
" $\frac{1}{48}$ " …… 250 " "
" $\frac{1}{60}$ " …… 128 " "

The bending load upon a yard may be many times greater than the direct pressure of the wind on the sail, owing to the position and form of the sail.

From the principles of Article 48 of the Third Division, it appears that the longitudinal sections of the theoretical figures of uniform strength for yards and booms, and the dimensions of the frusta of cones which approach nearest to those figures, are as follows:—

	Yards.	Booms.
Index of the power of the distance from the end, to which the diameter of the theoretical figure is proportional, ……	$\frac{2}{3}$	$\frac{1}{3}$
Proportion of the smallest to the greatest diameter, in the conic frustum which approaches nearest to the theoretical figure, ……	$\frac{1}{3}$	$\frac{2}{3}$

Hence it appears, that the smaller diameters used in practice are always greater than those which would be necessary if the strength of the material were uniform throughout the length of the yard or boom. The reason is, that the tapered part of the yard or boom is more or less grain-cut, and consequently weakened.

26. *Tapering of Masts and Spars.*—The diameters of masts and spars at the *quarters,* or parts intermediate between the greatest and smallest diameters, are not regulated by any theoretical principle, but are merely laid off so as to give a fair convex curvature to the outline. The distance from the given diameter to the small diameter is divided into four equal intervals, and the points of division are called respectively the *first, second,* and *third quarters.* In a lower mast, the points of division between the partners and the heel are called the *lower quarters,* and those between the partners and the hounds the

upper quarters. Then dividing the whole taper, or difference between the given diameter and the small diameter, into sixteen equal parts, those parts are to be thus distributed, in order to give the fairest possible curvature:—

Diameter at first quarter = given diameter — $\frac{1}{16}$ whole taper.
" second " = " — $\frac{4}{16}$ "
" third " = " — $\frac{9}{16}$ "

Mast-makers often use the fractions $\frac{1}{15}$, $\frac{1}{5}$, and $\frac{1}{2}$, instead of $\frac{1}{16}$, $\frac{4}{16}$, and $\frac{9}{16}$; but the curvature which they thus obtain is less fair.

From the third quarter to the hounds, a mast is tapered the fore-and-aft way only, its thwartship diameter throughout that division being kept uniform. The object of this is to provide the projections called *hounds,* below the lower end of the head, for supporting the trestle-trees and other framing.

27. *Thickness of Iron and Steel Masts and Spars.*—The following rule is a consequence of the principles stated in the Third Division, Article 46, Rule IV., Examples III. and VIII. of the Table:—

To find the thickness of the shell of a hollow iron or steel mast or spar, which shall be equally strong with a solid wooden mast or spar of the same diameter: Divide the diameter by eight times the ratio in which the working modulus of strength for the iron or steel is greater than that for the wood.

In estimating the working modulus of strength for hollow iron or steel masts or spars, regard must be had to the fact, that thin tubes of iron or steel usually give way to a bending load by buckling at the compressed side.

If the working modulus for iron under these circumstances be estimated at 7½ times, and that for steel at 10 times, the working modulus for wood, the following results are obtained:—

$$\text{Iron,}\ldots\ldots\ldots\ldots \frac{\text{thickness}}{\text{diameter}} = \frac{1}{8 \times 7\frac{1}{2}} = \frac{1}{60};$$

$$\text{Steel,}\ldots\ldots\ldots\ldots \frac{\text{thickness}}{\text{diameter}} = \frac{1}{8 \times 10} = \frac{1}{80}.$$

The following are the proportions prescribed by Rule 21 and Table No. 8 of the Liverpool Registry (for which see the Appendix to the Third Division).

	$\frac{\text{Thickness.}}{\text{Diameter.}}$
Iron masts,..from	$\frac{1}{55}$ to $\frac{1}{70}$
Iron yards,.. "	$\frac{1}{55}$ to $\frac{1}{60}$
Steel yards,.. "	$\frac{1}{70}$ to $\frac{1}{80}$

SECTION III.—CONSTRUCTION AND FITTING OF MASTS AND SPARS.

28. *Heels and Steps—Bowsprit Partners.*—The heel of a wooden lower mast is formed into a rectangular tenon, measuring about two-thirds of the given diameter athwartships, and one-half of the given diameter fore-and-aft. This fits into a mortise of the same shape and dimensions in the top of the *step*—a piece of timber of siding and moulding nearly equal to the given diameter of the mast, and of a length equal to about twice the diameter of the mast, if the step rests on the keelson; or equal to once or twice the room and space of the deck-beams, if it rests on a deck. Fore and main steps always rest on and are coaked and bolted to the keelson; the mizen step sometimes rests on the keelson, and sometimes on two or three of the lower deck-beams; and in the latter case, those beams should be well supported from below by stanchions or pillars.

The heel of a wooden standing bowsprit is formed into a rectangular tenon, measuring about 0·6 of the given diameter athwartships, and 0·67 up and down; it abuts against and is mortised into a piece of timber called the *bowsprit partners,* of siding equal to the given diameter of the bowsprit, and moulding equal to from one-half to two-thirds of that diameter. The bowsprit partners stands raking aft, so as to be at right angles to the bowsprit; its lower end is fastened to and supported by a beam of the deck next below the heel of the bowsprit, and its upper end bears against and is fastened to a beam of the deck next above, which is usually the upper deck. (For an example of the position of the bowsprit partners, see Plate $\frac{B}{7}$.)

The step of an iron or steel mast usually consists of a plate of iron or steel of from 1½ times to double the diameter of the heel of the mast, resting on and bolted or rivetted to the keelson and the neighbouring floors. Upon its upper side is a circular rising ledge of L-shaped or T-shaped bar, rivetted to the plate, and inclosing a circular cavity into which the heel of the mast is fitted, and is kept steady by wooden wedges driven round it. (See Plates $\frac{D}{7}$ and $\frac{F}{I}$.) As in the case of wooden masts, the mizen step sometimes rests on the lower deck-beams. (See Plate $\frac{B}{7}$.) Iron masts are prevented from rotating, sometimes by having a square tenon on the heel, and sometimes by being bolted to the ledge of the step.

As to mast partners, see the Fourth Division, Article 40. It may be added, that iron or steel mast partners usually consist of a plate spanning over two or three deck-beams, and strengthened on the under side by fore-and-aft ribs or carlings of the same depth and thickness with the beams, or nearly so: in the plate is a circular hole of a size a little larger than the mast, and surrounded by a rising ledge or flange. (See Plates $\frac{B}{7}$ and $\frac{F}{I}$.)

The masts are usually wedged in the uppermost complete deck, which is called the *wedging-deck;* and it is here that the mast has the greatest or given diameter.

29. *Timber masts* are distinguished into *single-tree masts,* and *built* or *made masts.*

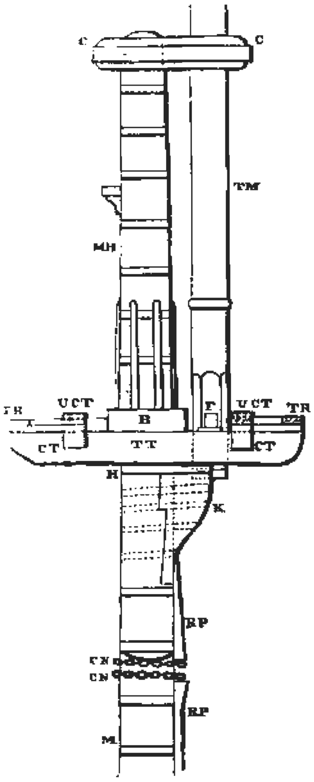
The stick for a single-tree mast should be about $\frac{1}{30}$ part longer than the total given length of the mast from heel to cap, and from 1 inch to 1½ inch greater in diameter. If the stick is curved, it is so placed that the curvature is in a fore-and-aft plane, with the convex side forward. As to its diameter and taper, see Articles 24 and 26 of this Division. It is at first trimmed square; and for a depth below the hounds equal to from ·4 to ·75 of the length of the mast-head, it is left square. The head is made square, with the corners rounded off. Below the square part, the mast is made round, by first trimming off the corners, so as to make it "eight-square," or octagonal; then trimming off the corners of the octagon so as to make it "sixteen-square," and so on till it is sensibly round. The round part is "hanced into" the square part; that is to say, the one form passes gradually into the other by a fair curved surface. In a cutter's or schooner's mast the square part below the hounds is only one-fifth of the length of the masthead.

Single-tree masts are hooped with about five hoops at the head, and from one to three at the heel.

The *hounds-pieces* are coaked and bolted with five bolts on to the two sides of the mast just below the head; their length, in a vertical direction, is four-fifths of the length of the mast-head; their breadth, in a fore-and-aft direction, is equal to the fore-and-aft diameter of the mast added to that of the top-mast; the latter part of the breadth forms a pair of projections forward, called the *knees.*

Intermediate between single-tree masts and made masts are *checked single-tree masts*, used when the stick will not work to a sufficient breadth at the hounds. The *cheeks* are two pieces of timber coaked, bolted, and hooped to the mast at each side, in order to make up the required breadth in its upper part; and they extend from the cap down to midway between the hounds and the deck. The butt-ends of the cheek-pieces are usually placed upwards. The interval between the coaks, and that between the hoops, are nearly equal to the diameter of the mast. The hounds are made by cutting into the cheek-pieces to the proper thickness; and the knees are separate pieces, bolted and notched on to the fore sides of the cheeks.

Fig. 1.

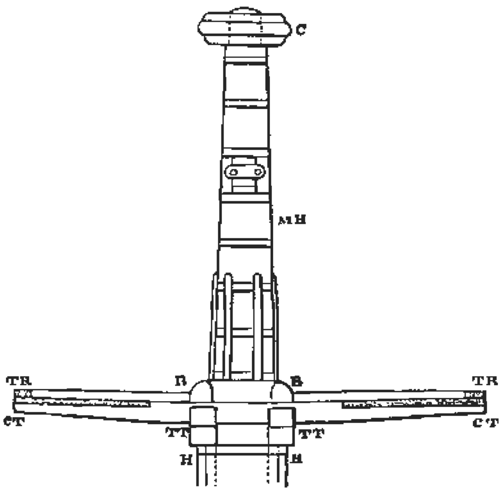


Made masts are built of several sticks, in thickness as well as in breadth. The number, shape, and arrangement of those pieces are varied in an indefinite number of ways, according to the size and shape of the mast required, and of the sticks available for making it; but the following general principles appear to be followed in almost every case:—

The pieces are coaked and bolted together at their faying surfaces, and the mast hooped in the intervals between the coaks; the length of such intervals being about equal to the diameter of the mast.

A piece of the mast, if necessary, may consist of two or three lengths, scarfed together, the length of the scarf being between two and three times the diameter of the mast, so that three hoops may pass round it; and in such cases the scarfs should break joint with each other.

Fig. 2.

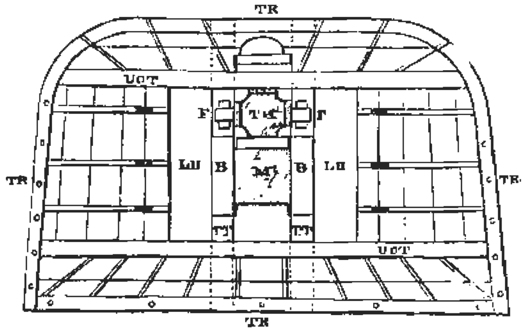


At the head of a ship's lower mast is a framing, of which Fig. 1 is a side or fore-and-aft view, Fig. 2 a thwartship view from aft, and Fig. 3 a plan. In these figures, M is the mast, M H its head, with a cleat at the aft side to support the slings of the lower yard; H the hounds, K the knees of the hounds.

T T are the *trestle-trees*, being two pieces of strong hard timber lying fore-and-aft, and supported by the hounds and knees. Half the breadth of each trestle-tree rests on the hounds-piece below; the other half projects. The trestle-trees are slightly tapered toward the ends.

C T are the *cross-trees*, lying athwartships, and supported by the trestle-trees, upon which they are scored down; two-thirds of the score being taken out of the trestle-trees, and one-third out of the cross-trees.

Fig. 3.



Between the fore cross-tree and the mast is a square hole large enough to admit of the topmast sliding freely through it.

B are the *bolsters*, to guard the upper sides of the trestle-trees from being worn by the rigging. They are covered with hides or canvas.

Upon the cross-trees and trestle-trees is supported the *top*, being a platform of a shape more or less like that shown in plan in Fig. 3; that is, having a curved front, and being somewhat narrower at the fore than at the after side, in order that it may interfere as little as possible with the sharp bracing of the top-sail. In Figs. 1 and 2 the top is shown in section. The *flat of the top* consists of two sets of planks lying respectively athwartships and fore-and-aft, and halved into each other where they cross; they are also bound together edgewise by horizontal bolts. On the upper side of the flat of the top is the *top-rim*, T R; and the *sleepers* or *upper cross-trees*, U C T, directly above and of the same breadth with the lower cross-trees, to which they are bolted, and about half the depth. In the centre of the top is a square hole; the two parts of this hole at the sides of the mast, between the trestle-trees and the flat of the top, are each called *lubber's hole* (L H in Fig. 3); and sometimes each lubber's hole is capable of being enlarged when required by lifting a hinged scuttle.

At the centre of the fore part of the top, in Fig. 3, is seen a semicircular hole, with its after edge guarded by a wooden or iron bolster, for the passage of the slings of the lower yard.

The side parts of the top-rim have iron plates bolted above and below them, called *futtock-plates*, and have oblong holes in them, from three to five in number at each side, for securing the upper ends of the *futtock-shrouds*. The after part of the top-rim has four or five sockets in it, to receive the lower ends of the stanchions of the *top-rail*. (The top-rail is not shown in the figure.)

C N, C N (Fig. 1), are two *chain-necklaces*, surrounding the lower mast just below the lower ends of the hounds-pieces, and serving to secure the lower ends of the futtock-shrouds (to be again mentioned in a later Chapter). R P is the *rubbing-paunch*, a piece of wood nailed on the fore side of the mast, to prevent yards or other spars, which are being raised or lowered, from being injured by the hoops.

C, in Figs. 1 and 2, is the *cap*, being a flat oval block of wood, hooped with iron (and sometimes of iron or of copper), which has in it two holes; the after hole is square, and fits upon a tenon on the top of the lower masthead; the forward hole is round, and of such a size that the *topmast*, T M, can slide easily through it. In the heel of the topmast is a square hole, called the *fid-hole*, through which passes a square pin or key of iron, called the *fid*, F; the two ends of the fid are supported by the trestle-trees, upon iron plates, called the *fid-plates;* and thus the weight of the topmast is borne.

The lower part of the lower masthead, just above the bolsters, B, is protected from the friction of the rigging by upright battens, shown in Figs. 1 and 2.

The details of the construction of tops vary very much in different vessels. Sometimes, instead of close platforms of planking, they have open gratings.

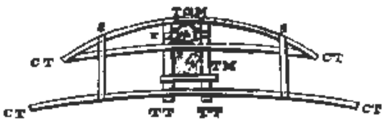
SUMMARY OF PROPORTIONS.

Hounds-pieces: height = height of masthead × .... about 0·8
" breadth, fore-and-aft, including knees = diameter of lower mast + diameter of topmast.
" thickness = hounded length of topmast × $\frac{1}{150}$
Mast-hoops: breadth, from 3 inches to 5 inches; thickness, from $\frac{3}{4}$ inch to $\frac{1}{2}$ inch.
" drift, from $\frac{1}{24}$ to $\frac{1}{100}$ of diameter of mast.
Coaks: diameter = diameter of mast × .... from $\frac{1}{6}$ to $\frac{1}{8}$
Bolts: diameter = diameter of mast × ....from ·08 to ·05
Trestle-trees: length = hounded length of topmast × 0·22
" depth = length × .... about $\frac{1}{2}$
" breadth = depth × .... " $\frac{2}{3}$
Cross-trees: length = hounded length of topmast × ...... " ·3
" breadth = breadth of trestle-trees.
" depth = breadth × .... " $\frac{2}{3}$
Bolts for trestle-trees: diameter = depth of trestle-tree × from $\frac{1}{12}$ to $\frac{1}{14}$
" for cross-trees: diameter = breadth of cross-tree × " $\frac{1}{6}$ to $\frac{1}{8}$
Flat of top: thickness, from 2 inches to 3 inches.
Top-rim: thickness = thickness of top × .... about $\frac{2}{3}$
Lubber's hole: length = length of trestle-trees × .... " 0·4
Futtock-plates: breadth, from $2\frac{1}{2}$ inches to 4 inches.
" thickness, from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch.
Top-rail: about 3 feet high; stanchions and rail about 1 inch diameter.
Cap of lower mast: length = $1\frac{1}{2}$ × diameter of lower masthead + 2 × diameter of topmast.
" " breadth = 2 × diameter of topmast.
" " thickness = $\frac{2}{3}$ × diameter of topmast.
" " square hole to fit tenon on lower masthead, tapered 1 in 12; round hole $\frac{7}{8}$ inch larger in diameter than topmast—viz., $\frac{3}{4}$ inch for leather, and $\frac{1}{8}$ for freedom.
" " Iron hoop, $\frac{1}{6}$ of depth of cap; thickness, $\frac{1}{2}$ in. to $\frac{5}{8}$ in.
Fid: length = given diameter of lower mast × $1\frac{1}{2}$.
" depth = diameter of topmast × $\frac{1}{6}$.
" breadth = $\frac{3}{4}$ depth.
Fid-plates: 1 inch thick.

30. *Topmasts.*—The position and mode of support of topmasts have been stated in the preceding Article. The fid-hole is lined with iron on the upper side. There is also commonly a sheave-hole near the lower end of the topmast, containing a sheave for the *top-rope*, or rope by means of which the topmast is raised and lowered. If necessary, the heel of the topmast is made to fit the hole between the trestle-trees, by nailing on filling-pieces, three of which are seen in Fig. 3.

The framework at the head of a topmast is illustrated by Fig. 4; in which T M is the topmast-head. The hounds-pieces are of elm or other wood of similar quality; their length is half of that of the topmast-head, and they are of such a thickness as to be able to pass through the hole in the cap of the lower mast. Each of them is secured to the topmast by coaks and bolts. Above the hounds are the *trestle-trees*, T T, and above the trestle-trees the *cross-trees*, C T, usually three in number; the foremost cross-tree forms a convex curve, and is secured to the middle cross-tree at the ends; and between them is a space, over the centre of which the heel of the topgallant-mast, T G M, is supported by means of a fid, F. The cross-trees are connected together by means of two or more iron straps, S. Close abaft the topmast is seen a *short cross-tree.* Sometimes, instead of the foremost long cross-tree, there is another short cross-tree. The upper sides of the trestle-trees are guarded by bolsters. The *cap* of the topmast is similar to that of the lower mast.

Fig. 4.



SUMMARY OF PROPORTIONS.

Trestle-trees: length = hounded length of topgallantmast × about 0·22
" depth = length × .... " $\frac{1}{6}$
" breadth = depth × .... " 0·56
Cross-trees: length of long cross-tree before the topmast = length of trestle-tree × 2
" length of long cross-tree abaft the topmast = length of trestle-tree × .... 2·1 nearly.
" length of short cross-trees = width over trestle-trees + 2 × breadth of trestle-tree.
" breadth = breadth of trestle-tree.
" greatest depth = breadth × .... about $\frac{5}{6}$

Long cross-trees are of a parallel depth for the middle third of their length, and taper on the under side to half that depth at their ends. Cross-trees are let down $\frac{4}{5}$ of their depth into trestle-trees; $\frac{2}{3}$ of score taken out of trestle-trees, and $\frac{1}{3}$ out of cross-trees. Diameter of bolts about $\frac{1}{12}$ of depth of trestle-tree.

Sometimes the spaces between the trestle-trees and under the cross-trees, close afore and abaft the topmast, are filled with chocks; and below those chocks and the trestle-trees is bolted or screwed a plate of iron, with a square hole for the mast.

Topmasts, if necessary, may be made or built of more than one stick, on the same principles with lower masts, but with fewer pieces.

31. *Topgallant* and *Royal Masts* are usually in one piece, and are round, except at the heel of the topgallantmast, which is eight-square. The fid-hole is in depth half the diameter of the topgallantmast, and in breadth two-thirds of its depth. Above it is a thwartship sheave-hole for the topgallant-rope, by means of which the mast is raised and lowered.

Just above the *stops* or *hounds* of the topgallantmast, is a copper *funnel*, or short hollow cylinder, fitting easily upon the pole above the stops, and having a projecting rim round its lower edge. The topgallant-rigging is fitted on this funnel; and when the topgallantmast is lowered or *struck*, the funnel, with the rigging attached, rests by means of its rim upon the cap of the topmast-head, and allows the pole to be lowered through it.

Just below the topgallant-stops, and just below the *royal stops* (above which the royal stays and backstays are attached), there are fore-and-aft sheave-holes.

When there is a separate or *fidded* royal mast, the head of the topgallantmast is fitted up like that of a topmast.

32. *Bowsprit and Jib-boom.*—A bowsprit, like a mast, may be of a single tree, or *made* of more than one tree. It is round throughout its length, except for one-ninth of its length at the outboard end, which is four-square on the top and sides, and rounded below. This part is called the *head* of the bowsprit,

and has bolted to its sides two pieces of hard wood, square, or nearly so, in section, and of half the dimensions of the bowsprit. These are called the *bee-blocks*, and have sheaves in them for certain ropes. At intervals along the outboard part of the bowsprit, square projections are left for the securing of certain other parts of the rigging. Beyond the extremity of the head projects a square tenon for the *cap*. The bowsprit cap is like that of a mast, except that it often stands vertically, and is traversed obliquely by its two holes. The lower hole is square, to fit tightly on the tenon of the bowsprit; and the upper cylindrical, for the jib-boom to slide through easily, with $\frac{3}{8}$ inch of play. The obliquity of the axis of the latter hole, to a line perpendicular to the fore-and-aft sides of the cap, is the same with the steeve of the bowsprit. The principal dimensions of the bowsprit-cap are—

Length = diameter of jib-boom × .... about 5
Breadth = " " × 2
Thickness = " " × .... $\frac{5}{8}$

At a distance of one-third of the length of the jib-boom, inward from the outer side of the bowsprit-cap, is fixed, on the upper side of the bowsprit, an iron *saddle*, for the heel or inner end of the jib-boom. Near the inner end of the jib-boom is a thwartship sheave-hole, for the *heel-chain* by which it is held out.

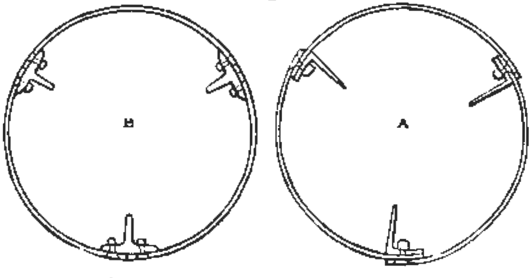
The *flying jib-boom* is sometimes in one piece with the jib-boom; and the jib-boom has a copper funnel for its rigging, like a topgallantmast. When separate, the jib-boom usually carries the flying jib-boom by means of a ring, called a *boom-iron*, projecting obliquely upwards and sideways from the upper part of the starboard side of the outer end of the jib-boom. The heel, or inner end of the flying jib-boom, either steps in a notch in the bowsprit-cap, or fits in an inner boom-iron.

A *cutter's bowsprit* is made to *reef*, or run in, so as to shorten the outboard part in stormy weather. The inboard part and the reefing part are made square, with the angles slightly rounded; the rest of the outboard part is made round. In the same manner, the bowsprits of ships of war with ram bows are now fitted to reef.

33. *Fore-and-aft-rigged masts*, as those of cutters and schooners, and the mainmasts of brigantines and mizenmasts of barques, have the hounds-pieces only one-fifth of the length of the masthead, and are sometimes fitted at the head with trestle-trees and cross-trees like those of a ship's topmast. Often, however, instead of a pair of trestle-trees, there is a *lower cap*, resting on the hounds, and similar to the cap on the head of the mast, except that the dimensions of the after part are somewhat greater, in order that the square hole may fit the masthead close above the hounds. The round hole in the fore part of the lower cap receives the heel of the topmast, which is supported there by means of a fid. Immediately before and abaft the mast, a pair of long cross-trees, like those of a ship's topmast, are supported by the lower cap, to which they are bolted. The upper surfaces of the side parts of the lower cap are protected against the friction of the rigging by means of bolsters, like those of a ship's trestle-trees.

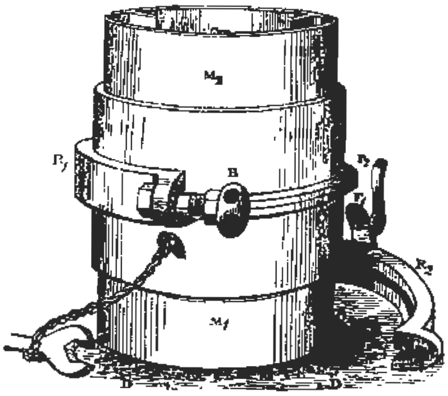
34. *Iron* and *Steel Masts* and *Spars* are of the same outside figure and dimensions, or nearly so, with the wooden masts which they replace, but are hollow; the thickness of the shell being regulated by the principles stated in Article 27. The seams or longitudinal joints of the shell are usually single-rivetted; the butts double-rivetted, except at the wedging-deck, where they are treble-rivetted; and the butts should break joint. Each breadth of plate in the circumference of the mast is usually stiffened by means of a longitudinal rib of L-iron or T-iron inside (see Fig. 5). These ribs in general run along the seams of the masts. If the seams are lap-jointed, L-shaped ribs may be used, as at A; if the seams are flush-jointed, as at B, T-shaped ribs are more suitable, placed so as to act both as stiffening ribs and as covering strips. Still further to stiffen the mast, the flanges of the ribs are sometimes connected together transversely by braces.

Fig. 5.



It is sometimes necessary for the safety of a ship during a storm to let the masts go overboard. A *parting-joint* for iron or steel masts, contrived for that purpose by Messrs. Finch & Heath, is represented in Fig. 6. D, D is the weather-deck. M_1 is the lower, and M_2 the upper, division of a tubular iron or steel lower mast. Each of those divisions is strengthened at their junction by a collar, provided with a flange. F_1 is the flange of the lower division, and F_2 that of the upper division; and those flanges are accurately fitted to each other, so that they may be firmly and steadily clasped together by means of an internally-grooved ring, of which one half, R_1, is represented in position, and the other half, R_2, as lying on the deck. When both halves of the ring are in position, being held together by the screw-bolt, B, the parting-joint is at least as strong as any other part of the mast. So soon as the bolt is unscrewed, the ring falls off, and the mast goes overboard.

Fig. 6.



34A. *Tripod Masts* (the invention of Captain Coles, R.N.) are made of iron or steel, and consist of three equal, or nearly equal, diverging legs; one stepping on the keelson amidships, and answering the ordinary purposes of a lower mast, and the other two spreading at equal angles abaft of the first leg, and stepping on the floor. All three legs are so fastened to the ship's bottom and to the decks which they traverse, as to resist tension as well as thrust; and thus standing rigging is rendered unnecessary. The principal ropes of the running rigging required in action (viz., lower and topsail braces, and topsail tyes), are led down to between decks through the tubular legs, so as to be worked by men under cover, and to be themselves in a great measure protected from shot.

35. *Yards*, when of wood, may be either *single-tree* or *made*, according to their size, and the size of the sticks available for them. Iron and steel yards are like masts, thin hollow tubes stiffened by longitudinal ribs inside.

Lower yards are usually made eight-square for the middle half of their length, and topsail yards for the middle fourth part. Upon the upper and lower, and forward and aft faces of the eight-square part, are nailed hardwood *battens*, of a thickness equal to about one-eighth of the diameter of the yard, to protect the *bunt*, or middle part of the yard, from being chafed.

Wooden yards are strengthened by being hooped; the interval between the hoops over the battens is about twice the diameter of the yard, and the spaces between the battens and under the hoops are filled with chocks or filling pieces. On other parts of the yard, the distribution of the hoops is regulated mainly by the knots in the stick; but on lower and topsail yards, two of the hoops are so placed as to support the *inner boom-irons*, or *quarter-irons*, which are rings for supporting the inner ends of the studding-sail booms. The usual station for the quarter-irons is $\frac{3}{16}$ of the length of the yard from the outer end. The *outer boom-irons*, or *yardarm-irons*, are carried by necks projecting from straps or sockets at the yard-arm ends.

Along the upper side of a yard runs the *jackstay*, to which the sail is bent; being usually a rib of hard wood, with a series of oblong holes at its lower edge; or an iron rod passing through a row of eye-bolts; or for iron or steel yards, an L-shaped or T-shaped flange, with holes in it.

Made Yards may be constructed in various ways. For example, two trees, each of two-thirds of the required length, may be scarfed together butt-end to butt-end, the plane of the scarf being vertical, and its length the middle third of the length of the yard; or two trees, each of one-half of the length of the yard, may be placed end to end, and connected together by means of a pair of fish-pieces—the length of the fish-pieces being the middle half of the length of the yard. The scarf or fish-joints, as the case may be, are to be secured by coaks of about one-third of the whole diameter, and by hoops, at intervals of from once and a half to twice the diameter.

The slings, or middle part of a lower yard, is usually connected with and held near to the mast by means of a *truss*, consisting of a clasp-hoop round the mast, connected by an universal-jointed link with a hoop or a pair of hoops round the yard. In the case of upper yards, the same connection is made by means of a horse-shoe-shaped strap of rope or iron, called a *parral*, which fits loosely round the mast, so as to slide up and down when the yard is raised and lowered.

The following statement of dimensions for the principal iron fittings on yards is condensed from Fincham's table:—

Hoops on yards: breadth from 3 inches to 4 inches; thickness $\frac{1}{4}$ inch to $\frac{1}{2}$ inch.

Yard-arm irons: shank or neck, diameter $1\frac{3}{4}$ in. to 3 in.
" strap; breadth $2\frac{1}{4}$ in. to 5 in.; thickness $\frac{1}{4}$ in. to $\frac{5}{8}$ in.
" ring; breadth $1\frac{1}{4}$ in. to $3\frac{3}{4}$ in.; thickness $\frac{1}{4}$ in. to $\frac{3}{4}$ in.
" bolts in straps; diameter $\frac{5}{8}$ in. to $\frac{7}{8}$ in.
" hoops on straps; breadth $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in.; thickness $\frac{3}{16}$ in. to $\frac{1}{2}$ in.

Quarter-irons, clasp and ring: breadth 2 in. to $4\frac{1}{2}$ in.; thickness $\frac{3}{8}$ in. to $\frac{1}{2}$ in.

Ferrules on ends of yards that have no boom-irons: breadth $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in.; thickness $\frac{3}{16}$ in. to $\frac{1}{4}$ in.

Eyes on the ferrules: diameter from $\frac{5}{8}$ in. to 1 in.

36. *Booms and Gaffs.*—Upper studding-sail booms, and fixed booms or outriggers, are carried by boom-irons. Lower studding-sail or swing-booms, and sometimes also the booms and gaffs of gaff-sails, have at the inner end a *goose-neck*, or iron shank with an eye on the end of it, which is shackled to a fixed eye-bolt, so as to make a sort of universal joint. The more usual fitting, however, for the inner end of a gaff, or of the boom of a driver or other gaff-sail, consists of *jaws*, forming a semicircle about one inch greater in diameter than the mast. The jaws are commonly of hard and tough wood, and are scarfed, and fastened with three or four hoops, on to the two sides of a tapering tongue formed at the inner end of the boom or gaff. The length of the scarf is about three times the diameter of the mast.

36A. A *trysail-mast* is usually from one-third to one-half of the diameter of the lower mast to which it belongs. It is of uniform diameter, and round from head to heel. The head is secured with a fid or bolt above the trestle trees; the heel steps either on the partners, or on a step, or on an eye carried by a clasp-hoop fastened round the lower mast.

37. A *Rolling Spar* is a spar upon which a sail is rolled for the purpose of reefing or furling it. This invention, the most useful of recent improvements in rigging, is due to Captain Cunningham, R.N. It has been applied chiefly to topsails; but it has been proposed to apply it also to other sails.

In one method of reefing and furling topsails (that of Mr. Cunningham), the topsail-yard itself is the rolling-spar. The yard-arms turn easily in two hoops which hang by the ropes called *lifts;* and the slings or centre of the yard forms a sheave, which is slung in the bight of a chain, whose two parts pass over two sheaves that revolve either in blocks hung from the topmast trestle-trees, or in sheave-holes in the topmast. By hauling on one or other part of that chain, the yard is made to revolve in either direction as required. In general, the forward part of the chain is made fast; so that lowering the after part of the chain at once lowers the yard and rolls up the sail; and hauling up the after part of the chain at once hoists the yard and unrolls the sail; a sort of action of the chain upon the yard known as *parbuckling.* The aperture required in the middle of the sail to allow the chain to work, and which divides the sail into two parts, is closed by a cloth called the *bonnet*, which is carried by travellers, and self-acting. The quarters of the yard are brought to an uniform outside diameter by properly shaping the battens. A small spar, in one or two lengths, of about one-third of the diameter of the yard, called the *chafing-spar*, hangs parallel to and abaft the yard, being connected with the parral and the lift-hoops; it serves to carry the boom-irons, and some blocks and other furniture that could not be properly carried by the rolling spar.

According to another method (that of Messrs. Colling & Pinkney), the rolling spar is distinct from the yard. It is supported directly in front of the yard, at its ends, by two journals, which turn in eyes at the ends of short arms projecting from hoops clasped round the yard; and also at about one-eighth of its length on each side of its middle point, by a pair of *crutches*, each of which is like a hoop with rollers on its inner surface, large enough to inclose the rolling spar with the whole sail rolled upon it, and having a gap or opening in front to allow the sail to pass through. Thus the sail is rolled and unrolled all in one piece. The rolling spar is slightly swelled in the middle; it has four battens upon its surface, one of which is of hard-wood and serves for a jackstay; and it is made to revolve by the parbuckling action of two chains passing round its ends or arms.

37A. *Half-yards* are an invention of Mr. Cunningham, which have been tried on a small scale. Each sail resembles a square-sail; but its yard consists of two equal parts jointed in the middle, so as to be capable of swinging independently to any required angle with a fore-and-aft plane. The two halves of the sail are bent to rings running on the two halves of the yard, and are set and furled independently by hauling them out and in. When the lee-half of a sail is set alone, it acts as a fore-and-aft sail; when both halves are set, as a square-sail. (See Transactions of the Institution of Naval Architects, 1862.)

CHAPTER III.

OF RIGGING AND SAILS.

SECTION I.—STANDING RIGGING.

38. *Channels* are flat ledges of wood or iron projecting outboard from the ship's sides, for spreading the shrouds or standing rigging at each side of the mast. The straining force to which they are subjected is principally compressive, and exerted inwards, and is represented by the arrow, V, in Fig. 6 of Chapter II., Third Division, Article 71, page 155; and to provide suitable means of resistance to that straining force, the channels should be on a level with the upper-deck beams. The *extent of projection* of the channels is made sufficient to carry the lower shrouds some five inches clear of the hammock-rails, either outboard or inboard. Formerly the shrouds always passed outboard of the hammock-rails; now they are often made to pass inboard of them, and are housed in the hammock berthing.

For an example of the position of the channels, see H.M.S. *Warrior*, Plates $\frac{B}{1}$, $\frac{B}{7}$.

Ships are often made without channels, the chain-plates being secured to the gunwale, or to the sheer-strake. For an example of this, see the *Formby*, Plate $\frac{F}{4}$.

The foremost end of the channels is usually so placed as to be nearly abreast of the fore side of the lower mast to which they belong. The foremost shrouds cross the channels nearly abreast of or a little abaft of the after side of the same mast.

The *length* of the channels, in a fore-and-aft direction, is on an average about one-half of the length above deck of the lower mast to which they belong, *including its head*—in other words, one-half of its length from upper deck to cap. About one-half of the length of the mast *from deck to hounds* is the length of the part of the channels occupied by the spread of the lower shrouds.

The thickness of the channels is about once and a half that of the skin of the ship's side where they are fastened on, supposing the material to be the same. Wooden channels are made from one-third to one-fourth thinner than this at the outer edge, which is sometimes bound with an iron bar or plate of the same depth, called the *guard-plate*. Channels are bolted to the ship's side edgewise with thwartship bolts at intervals of about three feet, and are supported from below by wrought-iron knees or brackets at about the same interval apart. The planks of which wooden channels are built are coaked together at their edges with coaks at about the same interval apart also.

39. The *Materials for Standing Rigging* are chiefly hempen ropes, coir ropes, iron-wire ropes, and iron chains.

Hempen ropes are classed according to the number and arrangement of their strands: the following are the kinds chiefly used in rigging (see Division IV., Article 72):—

Hawser-laid rope = ... 3 strands.
Cable-laid rope = 3 hawser-laid ropes = ... 9 strands.
Shroud-laid rope = core or heart surrounded by 4 strands.

The *sizes* of rope are described by stating the girth in inches.

Coir ropes are made of cocoa nut fibres, and are useful where great lightness is required, because they float in water.

Wire rope consists generally of six strands laid or spun round a hempen core, each strand consisting of six wires laid the contrary way round a smaller hempen core. The spinning mechanism is so contrived that neither the wires nor the strands are twisted.

There are also wire ropes of three strands, each strand consisting of three wires. The following are approximately the sectional areas of metal contained in the several sorts of wire strands and ropes just mentioned:—

	Area = Girth² ×
Six wires and hemp core,..	0·056.
Six strands each of six wires,....................................	0·038.
Three wires,..	0·059.
Three strands each of three wires,.............................	0·052.

Rigging Chain is usually of the unstudded or open-linked kind, with oval links. Its size is described by stating the diameter of the bolts of which the links are made.

The outside breadth of the links of a chain is about $3\frac{1}{2}$ times the diameter of the bolts of which it is made.

On account of the shocks and irregular strains to which rigging is exposed, a large factor of safety is allowed, the proof strength being *four times* the working load.

The following are the ordinary rules for calculating the proof strength and weights of ropes and chains, in *tons;* the dimensions being in inches:—

Rope or Chain.	Dimensions.	Multiplier for Proof Strength.	Multiplier for weight of 100 Fathoms.	Proof Strength in fathoms of Rope or Chain.
HEMPEN ROPE:—	Inches.	Tons.	Tons.	
Hawser-laid,......	Girth squared,	0·1875	0·0103	1820
Shroud-laid,......	do.	0·15	0·01	1500
Cable-laid,........	do.	0·12	0·0096	1250
WIRE ROPE (36 wires):—				
Iron,.................	do.	0·75	0·039	1923
Steel,*..............	do.	1·125	0·04	2812
RIGGING CHAIN,....	Diameter of bolt squared,	12·00	2·9	414

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* The estimates of the comparative strength of iron and steel wire ropes here given, are founded upon some experiments by Messrs. Jones, Quiggin, & Co., on the ultimate tenacity of steel-wire ropes, and experiments by the Editor of this Treatise, on the ultimate tenacity of charcoal iron-wire ropes; from which it appears that steel ropes are about once and a half the strength of iron ropes of the same girth. The proof strength is taken in each case, agreeably to ordinary practice, at about three-sevenths of the mean breaking load.

The breaking load may be estimated as ranging, for iron, from 2 to 2½ times, and for hemp, from 2 to 3 times, the proof loads given in the preceding table, which are taken as nearly as possible at half the *least* ultimate strength of good material.

The following table gives the comparative dimensions of chains and ropes of equal strength:—

Chain.		Wire Rope.				Hempen Rope.				
Diameter of Bolt.		Steel. Girth.		Iron. Girth.		Hawser-laid. Girth.		Shroud-laid. Girth.		Cable-laid. Girth.
1	...	3½	...	4	...	8	...	9	...	10

Wire and chain rigging is preserved by galvanizing, or coating with zinc. That process makes wire ropes somewhat softer and more extensible, but does not diminish their tenacity. Hempen rigging is preserved by means of tar. Both wire and hempen ropes for standing rigging are often protected against chafing by *worming;* that is, winding spun yarn round the rope, so as to fill the hollows between the strands; *parcelling*, that is, covering the rope with a narrow strip of tarred canvas wound spirally round it; and *serving*, or winding spun yarn round it against the lay in close coils, so as to cover it completely. Ropes are usually wormed and parcelled before being served.

Ropes are connected with each other, and with spars and blocks, by means of various sorts of splices, hitches, bends, knots, seizings, &c., the art of making which belongs properly to seamanship, and not to shipbuilding, and will therefore not be described here in detail; but the following general principles may be stated:*—

I. A *short splice*, in which the strands of two ropes, or of two parts of the same rope, are interwoven for a length equal to from once to twice the girth of the rope, is nearly, if not quite, as strong as the original rope, if well made, whether in hemp or wire. A wire rope requires a somewhat longer splice than a hempen rope, because the friction is less.

II. A *long splice*, in which the strands of two repes are interwoven for a length of from half a fathom to a fathom, with pieces of different lengths cut off the ends of those strands, so that the splice is of the same thickness with the original rope, may be estimated as equal in strength to the original rope, less one strand.

III. An *eye-splice*, in which the end of a rope is bent round into an eye, and spliced into the "standing part" of the same rope, if well made in hemp or in wire, is as strong as the original rope, or nearly so; and is the strongest way of securing a rope round a spar, block, dead-eye, thimble, &c. An eye made by *seizing* the end of a rope to the standing part (that is, placing them alongside of each other, and lashing them together) is not so strong. An *iron socket*, rivetted on the end of a wire rope, injures the rope, and makes a weak fastening.†

IV. *Knots* are not applicable to wire ropes. The principle of a secure knot for a hempen rope is, that no two parts of the rope, which would move in the same direction if the rope were to slip, should lie alongside of and touching each other. When applied to knots for joining two lengths of rope, this principle leads to the rule, that *the standing part of one rope, and the end of the other, should not lie side by side;* and this is what distinguishes the knots used by seamen (as the "sheet bend," "bowline knot," "carrick bend," "reef knot," &c.), from what they call "granny's knots" and "slippery hitches."

40. *General Description of Standing Rigging.*—Standing rigging consists mainly of ropes in two sorts of positions: in a fore-and-aft vertical plane, when they are called *stays;* and in an oblique position, extending downwards and backwards in pairs from the head of a mast, when they are called *shrouds* and *backstays.* The general nature of the straining action brought upon the masts and standing rigging, by the pressure of the wind on the sails, has already been shown in Fig. 6 of Chapter II. of the Third Division, Article 71, page 155; and that action always produces thrust on the mast, and tension on the standing rigging. When the sails are filled, and braced directly athwartships, the tension is equally divided between the shrouds and backstays at either side of the mast; when the sails are braced obliquely, the tension is greatest on the rigging at the weather side; and when the sails are braced up very sharp, the whole tension falls upon the weather rigging. When the sails are laid aback, the tension is thrown upon the stays, sometimes assisted more or less by the foremost of the shrouds at the weather side.

In practice, the moment of the pressure of the wind on the sails is usually resisted partly by the combination of direct thrust along the mast with tension along the rigging, as already described, and partly by the resistance of the mast to bending, exerted with maximum moment at the partne , where the mast is wedged into the deck. The latter kind of action involves much more severe stress on the material of the mast than the former; and accordingly, it is in general at the partners that masts are found to be "sprung," or overstrained.‡

The following is a description of the standing rigging of a full-rigged ship, as shown in Plate $\frac{V}{4}$. Vessels of less complex rig differ from this example only in having fewer parts in their rigging.

1, Bowsprit-shrouds.
2, Bob-stay.
3, Fore-stay, with fore-preventer-stay alongside of it: one to act if the other is carried away.
  The term *preventer* is applied to any part of the rigging intended to act in the event of another part being lost or disabled.
4, Fore-topmast-stay (with preventer-stay).
5, Inner jib-stay.
6, Outer jib-stay.
7, Fore-topgallant-stay.
8, Flying jib-stay.
9, Fore-royal-stay.
10, Martingales and back-ropes.
11, Fore, 23, Main, 35, Mizen shrouds.
12, " 24, " 36, " futtock-shrouds.
13, " 25, " 37, " topmast-shrouds.
14, " 26, " 38, " topgallant-shrouds.
15, " 27, " 39, 42, " topmast-backstays.
16, " 28, " 40, " topgallant-backstays.
17, " 29, " 41, " royal-backstays.
30, Main-skysail-pole backstays.
  Crossing the shrouds are seen the *ratlines*, forming the ladders by which men go aloft.
18, Main-stay (with preventer-stay alongside of it).
19, Main-topmast-stay (with preventer-stay).
20, Main-topgallant-stay.
21, Main-royal-stay.
22, Main-skysail-pole stay.
31, Mizen-stay.
32, Mizen-topmast-stay.
33, Mizen-topgallant-stay.
34, Mizen-royal-stay.
35, Foot-ropes.

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* For information on these matters, see Darcy Lever's "Young Sea Officer's Sheet Anchor;" Nares "On Seamanship;" Biddlecombe's "Art of Rigging;" Kipping's "Rudimentary Treatise on Masting and Rigging;" Boyd's "Naval Cadet's Manual," &c.

† In a series of experiments made by the Editor of this Treatise on the tenacity of iron-wire ropes, an eye-splice round a dead-eye or thimble was found to be the only fastening which neither weakened the rope nor gave way before it. Rivetting into an iron socket was found to weaken the rope; and seizings always gave way to a load less than the breaking load of the rope.

‡ Mr. Lamport, in a paper in the Transactions of the Institution of Naval Architects for 1863, recommends that masts should not be wedged, but left fitting easily in the partners; in order that they may be relieved from bending stress, and subjected to direct thrust only.

The following parts are not seen in the Plate:—

The *heel-chain*, for holding out the jib-boom, and the *crupper-chain*, for lashing it down to the bowsprit.

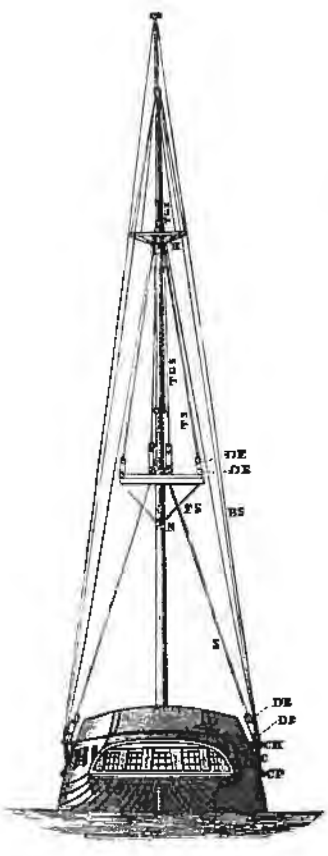
Gammonings, or chains for lashing the bowsprit to the knee of the head, through the holes shown in Division IV., Chapter II., Fig. 2, page 184.

In an iron or steel vessel, whose bowsprit is supported by a tube, or by a pair of rings framed to thwartship bulkheads, gammonings are unnecessary.

Jib-guys and *flying jib-guys*, from the jib-boom end and flying jib-boom end to the ends of the spritsail-yard (or spritsail-gaffs, as the case may be); and *after guys* and *jumpers*, from the ends of the spritsail-yard (or gaffs) to the ship's bows: these ropes act as shrouds to the jib-boom and flying jib-boom; also *spritsail-yard* or *gaff-topping-lifts*, from the ends of those spars to the bowsprit-cap.

Fore, main, and *mizen mast-head pendants*, being short ropes, with blocks at the end, hanging from the lower mast-heads: usually four each to the foremast and mainmast, and two to the mizenmast. They are used in setting up masts and rigging.

Fig. 1.



Fore, main, and *mizen topmast burton pendants*, two to each mast, hanging from the topmast-heads, for similar purposes to the above.

Horses, or *ridge-ropes*, two in number, from the knight-heads to the upper part of the bowsprit-cap, for the safety of men walking out upon the bowsprit in rough weather.

41. *Fitting, Securing, and Setting up of Standing Rigging.*—The standing rigging of masts is usually fitted on the mast-head; that of lower masts immediately above the bolsters, where the mast-head is guarded by battens (see Article 29 of this Division); and that of topmasts, topgallant-masts, and royalmasts, upon the copper funnels, mentioned in Articles 30 and 31. *Mast-head pendants*, and most of the *shrouds* and *backstays*, are put on in pairs, each pair being one rope; the bight of the rope forms a seized eye that fits over the mast-head, and the pair of shrouds or of backstays come down at the same side of the mast. The aftermost shroud of a mast at each side (called the *after swifter*) is usually an odd one, and has an eye-splice at the upper end fitting over the mast-head. When there is an odd backstay, it is usually the foremost one.

Stays are usually forked at the upper end, the two parts of the fork having eyes at their ends, which are lashed together at the after side of the mast-head.

The rigging of a mast is usually put on in the following order:—Mast-head pendants; shrouds, starboard and port alternately, commencing with the foremost pairs and ending with the after swifters; backstays, commencing with the foremost; lower and topmast stays; but topgallant and royal stays are put on before the shrouds and backstays.

The lower ends of the standing rigging are usually secured by means of a pair of *dead-eyes*, of *hearts*, or of *thimbles*, drawn together by means of three or four turns of a rope called a *lanyard*. A *dead-eye* is a round block of some very hard, tough, and durable wood (lignum-vitæ being almost always employed in the merchant navy, and elm in the Royal navy), or of cast iron,* with three or four holes in it for the lanyard, and a *score* or groove round its circumference for the shroud or backstay (several dead-eyes are shown in Plates $\frac{B}{1}$ and $\frac{F}{4}$). A *heart* differs from a dead-eye chiefly in having one large hole, with scores at the end for the turns of the lanyard. A *thimble* is an iron ring fitting into an eye at the end of a stay. In some cases, a *purchase*, consisting of two blocks with revolving sheaves drawn together by a lanyard, is used for setting-up a stay. Each row of upper dead-eyes are kept in their places by a *stretcher* or sheer-pole seized to the shrouds.

Sometimes, for setting-up iron rigging, a right and left handed screw coupling is used instead of a lanyard and dead-eyes.

ORDINARY NUMBERS OF SHROUDS, BACKSTAYS, AND BOBSTAYS.

MASTS, each:	Backstays.		Shrouds.
Royal, ...	2	....	0
Topgallant,.................................	2 to 4	....	4
Topmast,....................................	4 to 6	....	6 to 10
Lower,..	0	....	8 to 18
	Bobstays.		Bowsprit Shrouds.
BOWSPRIT,..................................	3 to 1	....	4 to 2

Lower Shrouds are secured at the channels, as shown in Fig. 1; where S is a lower shroud; D E, D E, a pair of dead-eyes connected by a lanyard: one of the dead-eyes is "turned in," as it is called, at the lower end of the shroud; the other is secured at the upper end of one of the *chains*, C, being an iron rod or bar which passes through a notch in the edge of the channel, C H, and ends at the *chain-plate*, C P, where it is fastened to the ship's side with two bolts. The backstays, B S, are secured in the same way, but with smaller dead-eyes and chain-plates.

Each *topmast shroud*, T S, is set up at its lower end by means of a pair of dead-eyes and a lanyard; the lower dead-eye being secured to the upper end of a *futtock-shroud*, F S, being an iron rod which passes through a hole in the top-rim. The lower ends of the futtock-shrouds are fastened alternately to the upper and lower of the two chain-necklaces at N. The angle which the futtock-shrouds usually make with the axis of the mast is 45°.

The *topgallant-shrouds*, T G S, consisting of two pairs, reeve through holes in the *horns*, or ends, of the topmast cross-trees, and then round rollers in the *fairleader-hoop*, H; after which the lower ends of each pair of shrouds are spliced together, and the bight thus formed made to reeve through a thimble in the strop of a block, which is connected by a lanyard with a lower block, fastened to the eye of one of the lower shrouds. The object of this arrangement is to insure equal tension on the two shrouds of each pair.

The *fore-stays* are set up to collars on the bowsprit, or straps on the bow; the *main-stays* to the knight-heads, or to a cross-piece before the fore-bitts, or to a plate-bolt in the deck, each

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* Cast iron dead-eyes were first used by Mr. J. R. Napier.

with a pair of hearts and four turns of a lanyard; the *mizen-stay* has usually a forked end, set up to a pair of eye-bolts in the deck.

The *fore-topmast-stays* are rove through holes in the bee-blocks of the bowsprit, and set up to the knight-heads with lanyards.

The *jib-stay* and *fore-topgallant-stay* are rove through holes in the jib-boom end, and the *flying-jib-stay* and *fore-royal-stay* through holes in the flying-jib-boom end; and then all four are rove through holes in the dolphin-striker, and set up to the knight-heads with lanyards.

The *main-topmast-stays* are set up with lanyards to bolts in the deck before the foremast, and sometimes in the knight-heads.

The *mizen-topmast-stay* is set up to the mainmast-head.

The *main* and *mizen topgallant* and *royal stays* are each usually rove through a sheave at the head sometimes of the next lower division, and sometimes of the next again, of the mast next before the mast to which they belong, and thence led down to the tops, where they are set up to the eyes of lower shrouds.

Gammonings are made of seven, nine, or eleven turns of chain, shackled at one end to the bowsprit. Each successive turn is taken outside the preceding turn over the *gammoning-fish* on the top of the bowsprit, and inside the preceding turn through the gammoning-hole in the knee of the head. Each turn is separately bowsed taut with a purchase before passing the next turn, and stoppered by driving large nails through the links of the chain into the gammoning-fish; and the end of the chain is wound or *frapped* round all the parts of the gammoning from the knee of the head up to the bowsprit, so as to bind them together. There are usually two gammonings, and the outer one is put on first; because, as it has most leverage, it would, if it were put on last, cause the inner gammoning to become slack.

Bobstays and *bowsprit-shrouds* are very often of chain. They are shackled to bolts or holes in the cutwater and to bolts at the bows respectively, and are set up at their outer ends, being secured with a pair of hearts and a lanyard to collars on the bowsprit-head. In armed vessels, the bowsprit-shrouds are secured to the bolts in the bow with slip-hooks, in order that they may be let go when the bow-guns are to be fired.

The *jib-guys* and *flying-jib-guys* are fitted with eye-splices on the ends of the jib-boom and flying-jib-boom respectively, and are secured at their inner ends to the spritsail-yard or spritsail-gaffs, as the case may be. They are set up by setting taut the jumpers and after-guys, which lead from the spritsail yard or gaffs to the bows.

The *jib-martingale* is secured at its ends to the jib-boom end and to the dolphin-striker, and is set up by setting taut the *back-ropes* of the dolphin-striker, which lead to the bows. The *flying-jib-martingale* is rove through a hole in the dolphin-striker, and set up in the head of the ship.

The *spritsail-gaff topping-lifts* are rove through blocks on the bowsprit-cap, and set up to the knight-heads.

The *heel-chain* is in two pieces, a longer and a shorter, shackled to opposite sides of the bowsprit-cap. The longer piece passes round abaft the heel of the jib-boom, and is secured to the shorter piece with a chain-slip. The *crupper-chain* passes round the bowsprit and the heel of the jib-boom, and is secured at one side of the bowsprit with a chain-slip. (In the vessel represented in Plate $\frac{F}{4}$, there is no heel-chain nor crupper-chain; as the heel of the jib-boom is held down to the bowsprit with a hoop, and abuts against a block that is bolted to the upper side of the bowsprit.)

As a general rule in the setting up of rigging, *the rope which acts with the greatest leverage on a spar should be set up taut first;* otherwise the setting of it up will slacken those which have been set up before it with less leverage.

42. *Fore-and-aft-rigged Masts.*—The masts of cutters and schooners have usually from four to eight *shrouds*, the most common number being six, a *stay*, and (to the foremast of schooners and mast of cutters) a *preventer-stay*. The *fore-stay* of a cutter, and the *fore-preventer-stay* of a schooner, are set up to the stem; the *fore-stay* of a schooner, to a collar on the bowsprit. The bowsprit has usually two shrouds and a bobstay; in a cutter, which has a running bowsprit, these are hauled in by purchases when the bowsprit is run in. The cutter's bowsprit is run out by a *heel-chain*. The *main-stay* of a schooner leads from the cap of the mainmast to the cap of the foremast, so as not to be in the way of the foresail-gaff. Sometimes the mainmast has a pair of *jumper-stays*, that is, moveable stays, leading from the head of the mainmast to a pair of eye-bolts in the deck close to the after-part of the fore-rigging, the weather jumper-stay alone being set up.

The *jib-stay* of a cutter leads from the mast-head to a traveller on the bowsprit; that of a schooner, from the head of the foremast to the jib-boom end, where it reeves through a sheave-hole, thence through the end of the dolphin-striker, and thence inboard.

The topmasts have usually four shrouds, fitted like the topgallant-shrouds of a ship (see Article 41), being rove through the cross-trees, and set up at the channels; a stay; and from two to four backstays.

The *topmast-stay* of a cutter reeves through a sheave-hole in the end of the bowsprit, and is thence led inboard; the *fore-topmast-stay* of a schooner reeves through the ends of the jib-boom and dolphin-striker, and is thence led inboard.

43. *Dimensions of Standing Rigging.*—To find the length of any part of the standing rigging, when its projections on a fore-and-aft and a thwartship rigging plan are given, Rule III. of Article 9 of the Second Division is to be used.

The following general rules as to the proportionate sizes of standing rigging are condensed from the tables given in the works of Biddlecombe and Kipping. When not otherwise specified, these proportions apply to the girths of bempen ropes, hawser-laid or shroud-laid; and the sizes of iron or steel wire ropes, or of chains, of equal strength, can be calculated by the aid of the table of proportions given in Article 39 of this Division:—

BOWSPRIT:—	About
Gammoning and bowsprit-shrouds—iron chain: diameter of bolts = diameter of bowsprit ×	$\frac{1}{36}$.
Bobstays—iron chain: diameter of bolts = diameter of bowsprit ×	$\frac{1}{30}$.
Lanyards—shroud-laid ropes: girth = diameter of chain-bolts, × 4.	
Horses or man-ropes = lanyards of bobstays.	
JIB-BOOM:—	
Stay and guys: girth = diameter of boom ×	0·40
Martingale stay = " "	0·50
" back-ropes = " "	0·35
Foot-ropes = " "	0·25
Heel-chain: diameter of iron = diameter of boom, ×	0·04
FLYING JIB-BOOM:—	
Stay and guys: girth = diameter of boom ×	0·35
Martingale = " "	0·40
Foot-ropes = " "	0·30
Heel-lashing = " "	0·25

	About
Lower Masts, square-rigged:—	
Shrouds and pendants: girth = diameter of mast ×	0·375
Stays = shrouds ×	1·50
Lanyards = "	0·50
Ratlines = "	0·15
Topmasts, square-rigged:—	
Shrouds: girth = diameter of mast ×	0·375
Stays and backstays: " " ×	0·45
Lanyards = shrouds ×	0·50
Ratlines: "	0·15
Pendants: diameter of mast ×	0·30
Futtock-shrouds—single iron rods: diameter = diameter of mast ×	0·03
Topgallantmasts:—	
Shrouds, stays, and backstays: girth = diameter of mast ×	0·50
Lanyards = shrouds ×	0·50
Royal-stay and backstays = topgallant-stay ×	0·50
Lanyards of do. = royal-backstays ×	0·40
Schooner's Bowsprit:—	
Shrouds and bobstays—iron chain: diameter of bolts = diameter of bowsprit ×	0·05
Cutter's Bowsprit:—	
Shrouds—iron wire: girth = girth of bowsprit ×	0·12
Bobstay pendants—iron wire: girth = girth of bowsprit ×	0·16
Schooner's Jib-boom:—	
Jib-stay and guys: girth = diameter of boom ×	0·625
Martingale-stay—chain: diameter of bolt = diameter of boom ×	0·06
Martingale-back-ropes: girth = diameter of boom ×	0·56
Foot-ropes = " " ×	0·30
Heel-chain: diameter of iron = " " ×	0·05
Lower Masts, fore-and-aft-rigged:—	
Shrouds, pendants, and schooner's jumper main-stays: girth = diameter of mast ×	0·45
Stays: girth = diameter of mast ×	0·64
Fore-storm-stay of schooners,	0·32
Topmasts, fore-and-aft-rigged:—	
Shrouds, stays, and backstays: girth = diameter of mast ×	0·40
Any lanyard; girth = girth of rope set up by it ×	$\frac{1}{2}$
Length of rope for a shroud-eye = girth of mast-head ×	$1\frac{1}{4}$
Diameter of a dead-eye = girth of hempen shroud ×	$1\frac{1}{2}$
All hempen standing rigging to be *stretched* before being fitted until its length is increased to original length ×	$1\frac{1}{12}$

Ratlines apart, from 15 to 16 inches.

44. The *Standing Rigging of a yard* consists mainly of the jackstay, head-earing strops, parral and truss, slings, foot-ropes and stirrups, and Flemish horses.

Jackstays of wood and iron have already been mentioned in Article 35. When of hempen rope, the jackstay, in two lengths, runs along the upper side of the yard, through a series of eye-bolts at intervals of about twice the diameter of the yard; and is set up taut by means of lanyards at the slings of the yard. At the outer ends of the jackstay are the *head-earing strops*, for bending the upper corners of the sail to.

Parrals and *trusses* have been mentioned in Article 35.

The *slings* of a yard consist of a double strop of rope or chain, passing round the bunt, or middle of the length of the yard. In lower yards, the slings are always of chain, and form a bight at the upper end which passes over a chock at the after side of the lower mast-head.

Foot-ropes for the men to stand upon are shown in Plate $\frac{F}{4}$, and marked 55. They are hung from the yards by means of *stirrups*. *Flemish horses* are short separate foot-ropes for the yard-arms.

Ordinary Dimensions:—	About
Jackstay: (hempen) girth = diameter of yard ×	0·25
Slings: " "	0·42
Parral: " "	0·33
Foot-ropes: " "	0·30
Stirrups: " "	0·25

Dimensions for wire-ropes and for chains of equal strength may be computed by the aid of the proportions given in Article 39.

SECTION II.—SAILS.[*]

45. *Materials of Sails.*[†]—A sail is made up of strips of canvas, called *cloths*. These are from 18 to 24 inches broad, 24 inches being the most common width; and of various thicknesses, usually numbered from 0 to 8, No. 0 being the thickest. A *bolt* of canvas is from 39 to 40 yards long. The best canvas is made of long-fibred flax of the strongest quality; British and Irish flax being preferred. Inferior qualities are made of tow or short-fibred flax, hemp, and cotton. The yarns are carefully washed and boiled before being woven, to prevent mildew; and for the same reason no dressing is used. The following Table shows the weight and strength of British Royal Navy canvas.

Number of Canvas.	Length of a Bolt.	Weight of a Bolt 24 inches wide.		Tenacity, by Testing Machine. (see Note, p. 246.) Weft.	Warp.	Use.
	yards.	lbs.		lbs.	lbs.	
0	39	48		—	—	Courses, lower staysails, trysails.
1	39	46	1 inch wide.	480	340	Courses, lower stay-sails, try-sails, awnings.
2	39	43		460	320	Courses, topsails, lower stay-sails, try-sails, spankers, awnings.
3	39	40		440	300	Courses, topsails, spankers, jibs, lower and topmast stay-sails.
4	39	36		400	280	Topsails, topgallant-sails, spankers, jibs, topmast stay-sails.
5	39	33		370	260	Topsails, lower and topmast studding-sails, spankers, jibs, upper stay-sails, gaff-topsails.
6	39	30		350	250	Topgallant-sails, studding-sails, jibs, flying jibs, upper stay-sails, gaff-topsails, cutters' and schooners' cross-jack-sails and square topsails, sails of boats.
7	40	27	1½ inches wide.	390	330	Topgallant-sails, studding-sails, flying jibs, royal stay-sails, cutters' and schooners' top-sails, sails of boats.
8	40	25		380	310	Royals, skysails, topgallant and royal studding-sails, cutters' and schooners' topgallant-sails, save-alls, sails of boats.

The second quality of canvas, called "Merchant Navy," is fully one-third weaker than Royal Navy canvas of the same weight. Cotton canvas is from $\frac{6}{10}$ to $\frac{3}{4}$ of the strength of Royal Navy canvas of the same weight.

The durability of canvas, in store, depends upon its being kept clean, dry, and in pure air.

The linings, or doublings, of sails are made of canvas from one to three numbers lighter than the body of the sail.

The *twine* with which sails are sewed weighs at the rate of from 360 to 430 fathoms to the ℔.; and on an average one ℔. of twine is required to sew 160 yards of seam.

The average weight of a ship's sails is at the rate of from 2200 to 1800 yards of canvas, 24 inches wide, to the ton.

46. *Parts of a Sail.*—Some of the principal parts of a sail have been mentioned in Article 6 of this Division, as the head, foot, and leeches; the clews of a square-sail, and the clew and tack of a fore-and-aft sail; the peak and nock (or throat) of a trysail or spanker; &c.

The *bunt* of a square-sail means the middle part.

The *bolt-rope* is a rope sewed round the edges of a sail to

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[*] For detailed information on the subject of sails, see "Sail-making as practised in the Royal Navy," and Mr. Kipping's "Elementary Treatise on Sails and Sail-making."

[†] The information here given respecting canvas, is for the most part extracted from a paper by Mr. Peter Carmichael, of Messrs. Baxter Brothers & Co, Dens Works, Dundee, which will probably be published in the "Transactions of the Institution of Engineers in Scotland, with which is incorporated the Scottish Shipbuilders' Association," for 1865–66.

strengthen it. At the head of the sail it is called the *head-rope*, at the leeches the *leech-ropes*, at the foot the *foot-rope*. At each of the lower corners or *clews* of a sail, a ring is made for attaching the *sheet*, either by making an eye on the bolt-rope, with or without an iron thimble, or by having separate eyes and thimbles on the leech-rope and foot-rope, connected with each other by means of an iron ring. A square-sail is roped on the after side, and a fore-and-aft sail on the port side. A sail is bent to a yard or gaff, with the roped side to the spar.

Sails are lined or doubled with an additional thickness of canvas called the *tabling*, on the roped side. On square-sails this extends all round inside the bolt-ropes; on fore-and-aft sails it usually extends only to the luff, the head, and the lower part of the weather leech. Courses and topsails have also a doubling of canvas on the after side at each of the *reef-bands* (Plate $\frac{F}{4}$, 53), at the *belly-band*, which runs horizontally midway between the lowest reef-band and the foot of the sail, and at the *bunt-line cloths*, from two to four in number, which run up and down from the belly-band to the foot of the sail. A topsail is moreover doubled at the middle of its lower part with a piece of canvas called the *top-lining*, to protect it against being chafed by the top; and near the middle of each leech with a piece called the *reef-tackle patch*.

Loops called *cringles* are worked into and round the bolt-ropes of sails. Those at the upper corners of a square-sail are called *head-cringles*, and have spliced or otherwise secured to them loops of rope called the *head-earings*, which are lashed to the head-earing strops on the yard-arms. The other cringles are for parts of the running rigging to be specified further on.

The head-rope of the sail is secured to the jackstay on the yard with *robands* passing through eyelet-holes; those are pieces of a sort of rope called *sennit*, made by plaiting yarns together; and they are in number from one and a half to two to each cloth of the sail.

In each reef-band there is a row of eyelet-holes, usually one to each cloth of the sail, through which are rove either a row of *reef-points*, or two *reef-lines*. A course has usually two reefs; a topsail four; a spanker, or a trysail, three.

Reef-points are like robands, and measure in length about twice round the yard. They hang half before and half abaft the sail, and are stitched by the middle to the upper edge of the hole in square-sails, and the lower edge in fore-and-aft sails. Reef-lines pass back and forward through the holes like a lacing; in reefing the sail, the forward parts of the reef-lines are tied to the after parts over the yard with a row of pieces of sennit called *reef-beckets*, which hang from the jackstay. In reefing by means of a rolling spar those parts are not wanted, with the exception of the close-reef points, to be used in shifting a split sail. When there are an upper and lower topsail (as in Plate $\frac{F}{4}$) the upper topsail is lowered before being reefed or furled so as to hang to leeward of the lower; and furling the upper topsail answers instead of close-reefing.

47. *Figures of sails.*—In addition to the statements in Chapter I. of this Division regarding the figures and dimensions of sails, the following explanations have to be made:—

The edges of sails which are bent to spars, such as the heads of square-sails and gaff-sails, the luffs of gaff-sails, and their feet when laced to their booms, are made straight. The leeches of square-sails are usually straight; but those of topsails are sometimes slightly hollowed.

The *roach* of a sail is the concave curve to which the foot of it is sometimes cut. Courses are usually roached to a depth equal to about one-eighth of the depth of the sail, and are straight for the middle three-fifths of the foot. Upper square-sails, when they are not straight at the foot, are roached to such a depth as may be required in order to clear the stays that pass below them. Square-topsails of cutters and schooners are often very deeply roached, because of the cross-jack yards being far below the fore-stay, and in light winds the roach is filled up by means of a small sail called a *save-all*. All unnecessary roaching of sails is an evil, as it diminishes the area of canvas to no purpose. Spankers and other gaff-sails are sometimes cut to a convex curve at the foot, being an arc of a circle whose radius is nearly equal to the sum of the lengths of the fore and after leeches of the sail. Their after-leeches are often made slightly convex; and so also are the fore and after leeches and feet of jibs. The use of the slight convexity sometimes given to the edges of fore-and-aft sails appears to be to counteract the tendency to become hollow at the edges, which arises from the canvas undergoing greater tension near the corners of the sail than elsewhere; and in particular, the convexity given to the fore-leech of a jib prevents the tension of the jib-sheet from producing an inward deflection of the stay.

The old practice in sailmaking is, by suitably varying the breadths of the seams, to make the sail have a *belly* or *bag* towards the middle, in order to increase the concavity of the surface that it presents to the wind. This may slightly increase the efficiency of sails in running before the wind; but it greatly diminishes their efficiency when close-hauled; and the most efficient sails on the whole are those whose figures, when not strained by the pressure of the wind, are perfectly flat.

48. *Dimensions of Canvas for Sails.*—The dimensions of a sail, as determined by the principles stated in Chapter I. of this Division, and shown on a sail-draught, are those to which the sail is ultimately to come by stretching. The sail when newly made must have its dimensions less than the intended ultimate dimensions, by a fraction sufficient to allow for that stretching. That fraction may be estimated as ranging, for the head and leeches of a sail, from $\frac{1}{30}$ to $\frac{1}{20}$, and for the foot from $\frac{1}{15}$ to $\frac{1}{10}$.

In computing the number of cloths of canvas required in order to make a given width of sail, regard must be had to the breadth taken up by the seams. This may be done by making a deduction from the total breadth of a cloth of canvas, so as to leave an effective breadth, by which the width of sail required is to be divided, in order to find the number of cloths. For example, the total breadth of a cloth being 24 inches, the following may be taken as the effective breadths for different classes of sails (according to Mr. Kipping):—

Courses and top-sails,	22	inches.
Topgallant-sails and royals,	22½	"
Foot of try-sails,	21½	"
Foot of jibs,	22·7	"

The tablings of the leeches of a square-sail are about one cloth in breadth; that of the foot, half a cloth; the reef-bands, one-third of a cloth.

Cloths which are cut obliquely at the ends are said to be *gored*.

The seams of square-sails run vertically; hence their cloths are not gored at the head. At the foot they are gored to the extent of the roach, if there is any; if the leeches are inclined, there are gored cloths between them and the foot.

In studding-sails, the seams usually run parallel to the inner leech. Lower studding-sails are commonly rectangular, so that there are no gored cloths in them; in upper studding-sails, the cloths are gored at the head, foot, and outer leech.

In fore-and-aft sails, the seams most commonly, though not always, run parallel to the after leech; and the cloths in most cases are gored at the head, foot, and luff. In what are called "angulated jibs," of which examples are shown in Plate $\frac{F}{4}$, there are two sets of seams, parallel respectively to the foot and to the after leech.

The foot and leech ropes of square-sails are from 0·5 to 0·6 of the girth of the shrouds of the masts to which those sails belong: the head-ropes, about half the girth of the foot and leech ropes. The bolt-ropes of fore-and-aft sails are in girth about 0·6 of the foot and leech ropes of square-sails suited for the same masts.

SECTION III.—RUNNING RIGGING.

49. The *Materials of Running Rigging* are hempen ropes and iron chains, as to the weight and strength of which, see Article 39. Wire ropes are not well suited for running rigging, because of their stiffness.

The following parts of the running rigging are almost always made of chain: *slings* of the lower yards; *topsail-tyes*, for hoisting and lowering topsail-yards; *topsail-sheets*, for hauling out the clews of the topsails. Other parts are sometimes made of chain, especially the lower and heavier parts, and those which remain nearly always taut. The chief advantage of chain is its flexibility, and consequent freedom from the waste of work which takes place in overcoming the stiffness of ropes. For the lighter and loftier parts, and for those which may have to hang slack, chain is too heavy.

50. *Blocks, Tackle, and Purchases.*—A *block* consists of an oval *shell*, usually of elm or metal, containing one or more pulleys called *sheaves*, of lignum-vitæ or metal, turning upon a wrought-iron *pin*. The round hole in the centre of a wooden sheave is lined with a gun-metal tube called the *bouching*. The part of the sheave-hole through which the rope reeves is called the *swallow*. In the bottom and sides of a block is a groove called the *score*, into which fits the *strop* or *strapping* of rope or iron by which the block is hung or secured to its place.

Ordinary blocks containing one pin are called *single*, *double*, *treble*, &c., according to the number of sheaves that turn on that pin side by side. Each sheave turns in a separate hole in the shell. The size of a block is described by its length, which is usually *three times the girth* of the rope that reeves through it. For the detailed description of various kinds of blocks, reference must be made to books on seamanship.

A combination of blocks and ropes is called a *tackle* or *purchase*. The mechanical action of a purchase depends on the principle of the equality of energy and work (stated in Article 64 of the first Division). In the absence of friction, the load lifted or useful resistance overcome by any purchase, would be to the effort exerted on the hauling part precisely in the inverse ratio of the velocities of the points of application of those forces; but as some work is always expended wastefully in overcoming friction, the resistance overcome by a given effort is less, and the effort required to overcome a given resistance greater, than that rule would give.

The simplest purchase is a *single whip*, in which a rope reeves through a single fixed block; and the resistance (neglecting friction) is simply equal to the effort: the only use of the block being to change the direction of the rope.

In any more complex tackle, the *purchase gained* (or ratio in which the resistance overcome is greater than the effort exerted, neglecting friction) is simply equal to *the number of parts* (that is, plies) *of the rope that reeve through or lead to the running or fly block.* One of those parts is always a *standing part:* when the whole number of parts is even, the standing part is secured to the fixed block or to a fixed point near it; when odd, to the running block, or a point near it in the object to which it is fastened.

The number of sheaves in a block is half the number of parts of the rope that lead to it, if the latter number is even; and if it is odd, half the next less even number.

Sometimes the running block of one tackle has its strop secured to the hauling part of another, so as to haul upon the latter rope; and then the purchase gained is the *product* of the numbers expressing the purchase gained by the two tackles separately. In such cases, the rope which has the running block fixed to it is usually called the *pendant*, and the rope that is directly hauled upon by hand, the *fall*.

In complex combinations of tackle, the purchase gained can always be found by considering how many times faster the *hauling part* of the rope, where the effort is exerted, moves than the point where the useful work is done.

For various special names given to purchases used on board ship, reference must be made to treatises on seamanship. Amongst them are—a *single-whip*, already mentioned; a *double-whip*, for a twofold purchase; a *luff-tackle*, for a threefold purchase; a *gun-tackle*, for a fourfold purchase.

The *dead-eyes*, *hearts*, and *thimbles*, mentioned under the head of standing rigging, are blocks without sheaves; but they are not considered as purchases, because of the greatness of the friction in them.

51. *Description of the Running Rigging of a Ship.*—Plate $\frac{F}{4}$ shows most of the more important parts of the running rigging of a ship, as follows:—

43, 45, 47, Starboard fore, main, and mizen tacks. (Port-tacks not seen.)
44, 46, 48, Slings of fore, main, and cross-jack yards.
49, Starboard-vangs of main try-sail and spanker gaffs. (The port-vangs are not seen.)
50, Spanker-boom-sheets, or quarter-guys.
51, Peak-halliards of gaffs. (The throat-halliards are not seen.)
52, Peak and mizen signal-halliards. (The main and fore signal-halliards are not seen.)
53, Reef-points on fore and main courses, top-sails, and spanker.
54, Jib and stay-sail sheets (each sail has a pair, port and starboard).
56, Lifts (a pair to each yard).
57, Braces (each yard has a pair; but the starboard-braces only of the lower and top-sail yards are seen).
57,* Starboard upper mizen-topsail preventer-brace.
58, Reef-tackles of fore and main courses and of top-sails.
59, Clew-garnets of courses.
60, Clew-lines of upper square-sails.
61, Brails of spanker.
62, Tripping-line of spanker.
63, Spanker outhaul.
64, Spanker-boom topping-lifts.

To the parts of the running rigging already mentioned as not being seen in the Plate, the following have to be added, whose use will be explained further on:—Mast-head tackles, yard-arm tackles, top-tackles, mast-ropes, heel-ropes, jeers, tyes, halliards, downhauls, outhauls, inhauls, sheets, tacks, bow-lines, bunt-lines, leech-lines, slab-lines, and running rigging of studding-sails.

In running rigging, each rope is led once, twice, or any required number of times, between the yard or sail to be moved, and the point towards which it is to be moved; then led through a fixed block secured at or near the latter point, and thence led down on deck; where it is *belayed* (or temporarily secured) to *bitts*, *cleats*, or *belaying-pins*. The halliards of some of the lighter and loftier sails of ships are sometimes belayed in the tops, instead of on deck. Belaying-bitts are smaller than riding-bitts, and consist, like them, of a pair of upright posts and a cross-piece. They serve to belay the largest ropes; and are usually placed on deck, near the lower masts. Belaying-cleats are T-shaped, with a short neck, and long arms, or *horns*. They are fixed, usually with two bolts, in any position where they may be required, as inside the bulwarks, on the flat of the weather-deck, and round the lower masts, near the deck. Sometimes they are seized to shrouds, and are then I-shaped, and called *shroud-cleats*. A large belaying-cleat is called a *kevel*.

Belaying-pins (which are of wood, iron, or mixed metal) are moveable, and fit into holes in rails called *racks*, which are fixed in any convenient position—such as round the lower masts, inside the bulwarks, seized to the shrouds, &c. In Plate $\frac{B}{T}$, belaying-cleats are seen in various positions inside the bulwarks, and racks with belaying-pins near the chains of the lower rigging of each of the three masts. Bitts also are seen on the upper deck, near the masts.

A *toggle* is a short wooden pin, tapering towards both ends; it passes through an eye on a rope, and is used for hitching it to a larger eye in another rope, or on a sail.

52. The *running rigging of masts* and *jib-booms* consists chiefly of the following parts:—

The *masthead-tackles* of the lower masts, and *burton-tackles* of the topmasts, are purchases hanging from the pendants already mentioned under the head of standing rigging. Those of the lower masts are usually fourfold; those of the topmasts, threefold. They are for setting up rigging, assisting sometimes to stay the masts, and occasionally for sending heavy bodies aloft.

The *top-tackles*, for raising and lowering the topmasts, consist of the following parts:—The *top-tackle-pendants* are ropes, of which there are a pair each to the fore and main topmasts, and one to the mizentopmast. Each pendant has its standing part hitched to a bolt at one side of the lower mast cap. It then passes below a sheave in the heel of the topmast; then up again to the other side of the cap, and through a fixed single block (thus making a twofold purchase). The hauling part of the pendant goes straight down beside the mast, and ends in an eye, hooked to the running block of the *top-tackle-fall*, usually a sixfold purchase, the fixed block of which is hooked to a bolt in the main deck. The purchase gained is thus 2 × 6 = 12-fold.

The *topgallantmast ropes*, for raising and lowering those masts, are usually one to each mast only. Each of those is fitted similarly to a top-tackle-pendant, except that its hauling part is led directly down to the deck, and has no additional purchase on it; so that the purchase is twofold only. The *topgallant-lizard* is a rope with one end hitched to a hole in the royal-pole, and the other spliced round a thimble on the hauling part of the mast-rope: it keeps the mast from turning over when its head comes below the topmast-cross-trees.

The *jib heel-rope*, for hauling out the jib-boom, forms a twofold purchase: its standing part is secured to one side of the bowsprit-cap; it then passes round a sheave in the heel of the jib-boom, then back to the other side of the cap, and through a fixed block, and thence to the forecastle. The *flying-jib heel-rope* is single; it goes from the heel of the flying-jib-boom to a block at the jib-boom-end, and thence to the forecastle.

53. *Running Rigging of Square Sails and Yards.*—The lower yards are *swayed* (or hoisted) and *struck* (or lowered) by purchases called *jeers*, usually fourfold. The upper jeer-block usually hangs from the trestle-trees.

The topsail-yards are hoisted and lowered by *topsail-tyes*, usually of chain: of these the fore and main topsail-yards have usually a pair; the mizen topsail-yard, one only. The standing part of each topsail-tye is secured to the topmast-head or trestle-trees; thence it passes through a *tye-block* (single) on the topsail-yard, and up again to the topmast-head, forming a twofold purchase; then through a hanging block. To the hauling part is attached the fly-block, being the upper block of a twofold or threefold purchase leading down the channels, which latter tackle is called the *topsail-halliards*. The purchase gained is thus fourfold or sixfold. Sometimes there are a lighter and a heavier purchase, leading to the channels at opposite sides of the ship.

A topsail-tye for Cunningham's rolling yard is, as already stated in Article 37, a chain with the yard hanging in the hight of it. Both parts of the chain pass through blocks at the mast-head, and thence are led downwards, and have purchases or halliards at their lower ends, leading to the channels.

Topgallant and royal yards are hoisted and lowered by *halliards*, which are either single ropes or twofold purchases, and lead to the deck.

The *lifts* are the ropes or tackles, of which there are a pair to each yard, supporting its ends. They run from the yard-arms to the caps of the lower masts, and to blocks in the rigging of the upper masts, and are led thence downwards: the lower lifts, to the deck; the topsail-lifts, to the channels; the topgallant and royal lifts, to the tops. Fore and main lifts are usually threefold purchases; fore and main topsail lifts, twofold; crossjack, topgallant, and royal lifts, single ropes.

The *braces* are the ropes or tackles which trim the yards to various angular positions, according to the relative direction of the wind and the ship's course. Each yard has at least a pair, called respectively the starboard and port brace, or if the direction of the wind is referred to, the lee and weather brace; and the main-yard has generally a second pair, called the preventer main braces. Lower and topsail braces are double; topgallant braces generally single, sometimes double; royal braces, single. The points to which braces are usually led directly from the yard-arms are shown in Plate $\frac{F}{4}$; the hauling parts are always led down to the deck, and belayed there. The Plate does not show the *preventer main braces*, which are led to the foremast below the trestle-trees, and thence to the deck, and are alone used for trimming the yard; the *main braces*, which are led to the ship's quarters, are used for resisting the pressure of the wind only.

The clews of the courses are hauled forward by *tacks*, and aft by *sheets*, all of which are double, reeving through blocks shackled to the clews of the courses, and called *tack-blocks* and *sheet-blocks*. The fixed blocks for the fore-tacks are at the bumpkin ends, whence the hauling parts of those ropes are led inboard; the fixed blocks for the other tacks and sheets of the courses are at suitable points of the ship's sides. Sometimes a pair of *spiders*, or projecting iron arms abaft the main channels, are required in order to carry the fixed blocks for the main sheets.

The *sheets* of the upper sails are for hauling out the clews of each sail, so as to spread its foot along the yard next below. On the after side of that yard, close to the yard-arms, are bolted a pair of *cheeks*, each containing a sheave; the sheet leads from the clew of the sail through the cheek and round the sheave; thence along the after side of the yard to a *quarter-block* near the middle of the yard, and thence directly down—topsail and topgallant sheets to the deck, royal sheets to the top. Royal and topgallant sheets are usually single; topsail sheets, if of rope, double, reeving through a block shackled to the clew, and the standing part secured round the lower yard-arm: if of chain (as they almost always are), topsail-sheets are single.

Clew-garnets for the courses, and *clew-lines* for the upper sails, are ropes abaft the sails which haul their clews up to the bunt of the yards in furling. They lead from the clews of the sails to *quarter-blocks* near the middle of the yards, and thence to the deck, for all except royal clew-lines, which are commonly worked in the tops. Clew-garnets and topsail clew-lines are double, reeving through blocks shackled to the clews; the rest single.

Each square-sail (except, in most cases, the royals) has a pair of *bow-lines*, one to haul each leech to windward. The *bow-line-bridles* form a set of branching legs from the bowline to the cringles on the leech of the sail. The bowlines are led forward: those of the sails on the foremast to sheaves at convenient points on the jib-boom and bowsprit, and thence inboard; those of the upper after sails to the heads of the masts next before and below them, and thence to the deck; those of the main course to bitts on the deck.

Bunt-lines and *leech-lines* are ropes in front of a square-sail, for hauling up the foot and leeches respectively (to which they are toggled) towards the bunt of the yard. *Slab-lines* are fitted like leech-lines, but abaft the sail.

Gaskets are made of three or four strands, plaited together, and are used for tying up the furled sail.

Reef-tackles have a twofold purchase, and are used for hauling up the leeches of courses and topsails to the yard-arms before reefing the sails.

Downhauls haul the upper yards directly down; for topsail-yards they are usually twofold, and often of chain, and are essential to the working of rolling-spars.

Yard-tackles are threefold purchases, which hang from pendants at the lower yard-arms, for lifting boats and other weights. When not in use, they are triced up to the lower rigging below the futtock-shrouds.

53. *Running Rigging of Studding-sails.*—A lower studding-sail boom or swing-boom is supported at its inner end, as already stated, by a goose-neck hinged to the channels; at its outer-end, it is supported by a *topping-lift*, which leads from the boom to the top of the lower mast, and thence to the deck or chains. The topping-lift reeves through a block or thimble on the end of the *long lizard*, a rope by means of which it can be hauled out towards the yard-arm, while the boom is being rigged out. The boom is trimmed and kept steady by ropes like braces in their position and use—the *fore-guy*, leading from the boom-end to the spritsail-gaff, thence to the heel of the bowsprit, and thence inboard; and the *after-guy*, leading from the boom-end aft to a sheave in the ship's side, and thence inboard.

A topmast studding-sail boom is rigged out and in by means of the *boom-jigger*, a twofold purchase, the running block of which is hooked to the inner end of the boom, and the fixed block to the boom-iron for hauling out, and to the top of the lower mast for hauling in.

Studding-sail halliards are usually a single rope, leading from the studding-sail yard through a block, which for lower studding-sails hangs from the topmast studding-sail boom end, and for upper studding-sails from the yard-arm above (being then called a *jewel-block*), and thence to the deck; the upper studding-sail halliards passing on the way through a block at the head of the mast next below, and the lower studding-sail halliards through a block hung by a pendant from the lower mast head. Lower studding-sails have also *inner halliards*, twofold, from the inner head cringle of the sail to the top, and thence to the deck.

Studding-sail sheets are for spreading the inner clew inwards. A lower studding-sail has two; one leading to the channels, the other inboard over the bulwarks. A topmast studding-sail has two; the *short sheet*, leading through a block on the inner boom-iron to the top; the *long sheet*, down before the course to the deck. A topgallant-studding-sail has one, led down into the top.

Studding-sail tacks are for spreading the outer clew outwards. They are single, toggled to the outer clew, rove through the *tack-block* at the boom-end, and thence led aft; the lower tacks inboard through sheaves in the ship's side; the topmast-studding-sail tacks to the deck; the topgallant-studding-sail tacks to the tops next abaft.

The *lower-studding-sail tripping-line* leads from the tack of the sail through a thimble at its centre, and a block at its inner yard-arm, to a block under the top of the mast, and thence to the deck. The *topmast-studding-sail downhaul* leads from the outer head cringle of the sail through thimbles on the outer leech, to a block at the tack, and thence to the deck. The *topgallant-studding-sail downhaul* leads from the inner head cringle of the sail to the top of the lower mast.

The fore-topmast-studding-sail booms have *boom-braces* of twofold purchase, leading to the main rigging.

54. *Running Rigging of Fore-and-aft sails, Gaffs, and Booms.* The boom of a fore-and-aft sail is hung from the trestle-trees by one or more ropes called *topping-lifts* (see Plate $\frac{F}{4}$); for a ship's spanker boom there are usually two, one at each side of the sail; and each of those two is double, being secured near the after end of the boom, thence led through a cheek on the trestle-tree, thence through a cheek near the middle of the boom, and thence forward to a threefold purchase, by which it is set up to the fore end of the boom.

The *boom-sheet* is sometimes one strong purchase, connecting the boom with the centre of the taffrail; for ship's spanker booms, there are usually a pair of boom-sheets, sometimes called *quarter-guys*, fivefold, leading to the two quarters.

The throat of a gaff is hoisted and lowered by the *throat-halliards*, usually a threefold purchase; the lower block hooked to the throat, the upper supported by the trestle-trees; the hauling part leads down to the deck.

The peak of a gaff is hoisted and lowered by the *peak-halliards*, usually fourfold; rove through two single blocks at different points of the gaff and a double block or two single blocks at the cap or mast-head; the hauling part led to the deck.

The *vangs* lead from the gaff-end to the ship's quarters, and are usually pendants with a twofold purchase.

A standing gaff (as that of a try-sail usually is) is swayed aloft by the top-burton-tackles, and slung by two pendants; one from the throat, hooked to a bolt between the trestle-trees, and one from the peak, hooked to a bolt in the after side of the mast-head. It has vangs like a spanker-gaff.

Spankers and gaff main-sails are laced to the gaff, and bent to *hanks* or hoops on the mast, or on a try-sail mast. The tack is hauled down and forward by the *tack-tackle*, usually threefold and toggled to the tack. It can be triced up towards the throat of the gaff by the *tack tricing line*, usually a double whip. The clew is hauled out to the end of the boom by the *outhaul*, usually twofold.

The foot of a boom main-sail is sometimes laced to the boom. The *reef-tackles* haul down the reef-cringles to the boom-end, previous to reefing.

Try-sails are bent to rings upon the gaff, and the head clew or peak of the sail is hauled out to the gaff-end or in towards the throat by the *outhaul* and *inhaul*. The outhaul reeves through a sheave in the end of the gaff; then through a block at the mast-head, and is then led down to the deck with a double purchase. The inhaul reeves through a block on the throat of the gaff.

The *brails* of a gaff-sail are for hauling the after-leech of the sail forward previous to furling, towards the head (peak brails), nock (throat brails), and luff (foot brails). They are in pairs, usually five in number; each pair consists of a single rope, seized at the middle of its length to the after-leech; the two parts are led upwards and forwards, at each side of the sail, through blocks at the head, throat, or luff, as the case may be, and thence to the deck. The lee brails are hauled upon in furling.

A *trysail-sheet* for hauling aft the clew of a try-sail, is usually a threefold purchase; it is hooked to an eye-bolt at the lee side of the deck, and shifted when the ship goes about.

When there are two stays near each other, a *stay* and a *preventer-stay*, the stay-sail hangs from the preventer-stay. Jibs and other stay-sails are either bent to hanks which run on the stay, or are laced to the stay with a spiral lacing passing through eyelet-holes in the sail, and round the stay in the contrary direction to its lay. They are hauled up by the *halliards*, and down by the *downhaul*. The halliards are usually single or double, the downhaul single; the downhaul leads from the head of the sail, through three or four thimbles on the fore-leech, through a block at or near the tack of the sail, and thence aft. Sometimes the halliards are bent to a *head-stick*, or short yard, in length about equal to the breadth of a cloth. The jibs and stay-sails on the bowsprit and jib-booms have *tack-lashings*, to secure their tacks to the bowsprit or boom; other stay-sails have *tack-tackles*, leading obliquely downwards and forwards, and, finally, to the deck. The clew of every jib or other stay-sail has two *sheets* to haul it aft, single or twofold purchases, leading respectively to the two sides of the vessel; except sometimes the fore-sails of cutters and smacks, which have but one sheet leading to a ring or *traveller*, that fits loosely on a round iron rod called a *horse*, stretching athwart the deck just before the mast. The tack of a cutter's jib is often secured to a ring or traveller on the bowsprit, hauled out and in by an *outhaul* and *inhaul;* and the jib has no stay. This arrangement facilitates the bending of jibs of different sizes, to suit the state of the weather.

55. *Dimensions of Running Rigging.*—The following proportions of running rigging are founded upon and condensed from the examples given by Biddlecombe and Kipping. When references are made to standing rigging, see Article 43.

Masthead-tackles: girth = girth of pendants ×	from	0·4 to 0·5
Jib-boom heel-rope: girth = diameter of boom ×	about	0·25
Mast-ropes: girth = diameter of mast ×	"	0·40
COURSES:—		
Lifts, braces, bowlines, and bridles: girth = diameter of yard ×	"	0·25
Tacks and sheets: girth = diameter of yard ×	"	0·30
Clew-garnets: " = " " ×	"	0·22
Bunt-lines, studding-sail halliards, tacks, and sheets: girth = diameter of yard ×	"	0·20
Leech-lines: girth = diameter of yard ×	"	0·15
Slab-lines: " = " " ×	"	0·12
TOPSAILS:—		
Tyes and sheets: diameter of iron for chain = diameter of yard ×	"	0·05
Halliards, braces, bunt-lines, bow-lines, reef-tackles: girth = diameter of yard ×	"	0·25
Lifts, clew-lines, studding-sail halliards, tacks, and sheets: girth = diameter of yard ×	"	0·30
Studding-sail downhauls, boom-jiggers: girth = diameter of yard ×	"	0·20
TOPGALLANT-SAILS and ROYALS:—		
Halliards and sheets: girth = diameter of yard ×	"	0·40
Lifts: girth = diameter of yard ×	"	0·35
Braces: " = " " ×	"	0·25
Clew-lines, bow-lines, studding-sail halliards, tacks, and sheets: girth = diameter of yard ×	"	0·22
Studding-sail downhauls: girth = diameter of yard ×	"	0·20
SPANKERS and other GAFF-SAILS:—		
Boom topping-lifts, sheets, and guys: girth = diameter of boom ×	"	0·40
Throat and peak halliards: girth = diameter of gaff ×	"	0·40
Trysail-sheets, vang-pendants, outhauls: girth = diameter of gaff ×	"	0·35
Tack-tackle, tricing-line: " = " " ×	"	0·25
Brails: girth = diameter of gaff ×	"	0·20
JIBS:—		
Halliards and sheets: girth = girth of stay ×	"	0·60
Downhaul: girth = girth of stay ×	"	0·45
STAY-SAILS:—		
Halliards and sheets: girth = girth of stay ×	"	0·45
Downhaul: girth = girth of stay ×	"	0·35
(Girth of lower staysail-stay = girth of principal stay × about 0·4.)		

56. *Positions of Tacks and Sheets.*—It is evident that, in order that tacks and sheets may bring a sail as nearly as possible into a state of uniform tension, their directions should pass through the centre of the sail, found as explained in Article 10 of this Division. This principle is usually attended to as far as practicable; and in jibs without stays, it applies to the halliards also.

NOTE TO ARTICLE 45.—The ultimate tenacity of Royal Navy canvas, as given in the Table, is equivalent to the weight of the following lengths of its own material:—Mean of Nos. 1 to 6, weft, 30,790 feet; warp, 21,550 feet: mean of Nos. 7 and 8, weft, 32,000 feet; warp, 27,200 feet.

RIGGING PLAN OF [illegible] SAILING SHIP [illegible]