THE MARINERS' HANDBOOK

A CONVENIENT REFERENCE BOOK

FOR

Navigators, Yachtsmen, and Seamen of all classes, and for all persons interested in the Navy, the Merchant Marine, and Nautical Matters generally

BY

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

1st Edition, 13th Thousand, 3d Impression

SCRANTON, PA.
INTERNATIONAL TEXTBOOK COMPANY

PRINTED IN THE UNITED STATES

PREFACE

This handbook is intended as a book of reference to the young men in the merchant marine, as well as to those in the naval service. While the treatment of some of the subjects included is necessarily brief, the information given should nevertheless prove very useful and create a desire for further study and investigation.

Ambitious seamen trying to fit themselves for examination to higher rank in either service are often embarrassed by a lack or insufficient knowledge of logarithms; hence, we have incorporated a thorough and comprehensive article on that subject accompanied by tables of common logarithms.

In the subject of navigation, terrestrial and celestial, are included only the standard methods practiced by the up-to-date navigator, and for this reason the book should be of value to the student, as well as to the navigating officer. The treatment of these subjects does not consist merely of definitions of terms, but rules, formulas, and directions are given for each method, followed in every case by examples and carefully worked out solutions illustrating the process or method explained. Of equal importance to the student and the professional man should be the articles dealing with deviation, the compensation of compasses, and the manipulation of rope. All problems appearing throughout the book involving elements of time are worked out for values given in the Nautical Almanac of 1904.

It is hoped that the subject of the United States Navy and matters relating to the naval service will prove valuable and instructive not only to men directly connected with the Navy, but also to that great auxiliary of the Navy, the officers and men of the Merchant Marine, and that it will, in a measure, tend to draw closer the ties now existing between the two branches.

This handbook was prepared under the supervision of E. K. Roden, Principal of our School of Navigation.

International Correspondence Schools.

INDEX

K

L

M

TO THE READER:

This Handbook is issued by the International Correspondence Schools, of Scranton, Pa., that through its use you may judge of the thoroughness and practicability of I. C. S. Instruction Books which are prepared with the same regard for value, accuracy, and ease of application.

The information contained herein will be of constant help and will suggest the great benefit you can obtain from an I. C. S. Course of Instruction.

FREE! A Textbook on Navigation and Piloting

We qualify men for better positions and higher salaries. If you would like to know how we do this, about our method of teaching, prices, terms, etc., fill out and mail the coupon on the next leaf and our

Representative will call and present you free our copyrighted Instruction Book on "Piloting," containing 45 pages of text and 32 Illustrations. This is the easiest book published on this subject to learn from, remember, and apply.

We enable ambitious men to better their positions and salaries by giving them special training for advancement in their trades or professions, or in some occupation more congenial than that in which they are at present engaged. We do this without their losing time from their work.

The specially trained man is always sure of permanent employment, promotion, and increased earnings.

INTERNATIONAL CORRESPONDENCE SCHOOLS

Box 1520, Scranton, Pa.

I will be glad to accept a FREE copy of your Instruction Book on "Piloting."

Name ______________________________

Occupation ________________ *Age* ________

Street and No. ________________________

City ________________ *State* ________

- __ Ocean Navigation
- __ Lake Navigation
- __ Coastwise Navigation
- __ Marine Engineering
- __ Mathematics
- __ Bookkeeping and Business Forms
- __ Mechanical Drawing
- __ Refrigeration
- __ Electric Lighting
- __ Steam Heating
- __ Electricity
- __ Gas Engines
- __ Stenography
- __ Illustrating
- __ Spanish by the Phonograph

TAKE NOTICE.—If you are interested in a particular Course, mark an X before the name of Course in the list here given.

[illegible]

PLACE
ONE
CENT
STAMP
HERE

International Correspondence Schools

International Textbook Co., Proprietors

Box 1526

SCRANTON, PA., U. S. A.

MARINERS' HANDBOOK

USEFUL TABLES

WEIGHTS AND MEASURES

LINEAR MEASURE

12	inches (in.)	= 1 foot	ft.
3	feet	= 1 yard	yd.
5½	yards	= 1 rod	rd.
40	rods	= 1 furlong	fur.
8	furlongs	= 1 mile	mi.

in.	*ft.*	*yd.*	*rd.*	*fur.*	*mi.*
36 =	3 =	1			
198 =	16.5 =	5.5 =	1		
7,920 =	660 =	220 =	40 =	1	
63,360 =	5,280 =	1,760 =	320 =	8 =	1

SQUARE MEASURE

144	square inches (sq. in.)	= 1 square foot	sq. ft.
9	square feet	= 1 square yard	sq. yd.
30¼	square yards	= 1 square rod	sq. rd.
160	square rods	= 1 acre	A.
640	acres	= 1 square mile	sq. mi.

sq. mi.	*A.*	*sq. rd.*	*sq. yd.*	*sq. ft.*	*sq. in.*
1 =	640 =	102,400 =	3,097,600 =	27,878,400 =	4,014,489,600

CUBIC MEASURE

1,728	cubic inches (cu. in.)	= 1 cubic foot	cu. ft.
27	cubic feet	= 1 cubic yard	cu. yd.
128	cubic feet	= 1 cord	cd.
24¾	cubic feet	= 1 perch	P.

1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

MEASURE OF ANGLES OR ARCS

60 seconds (″)	= 1 minute	′
60 minutes	= 1 degree	°
90 degrees	= 1 rt. angle or quadrant	□
360 degrees	= 1 circle	ci ∵

1 cir. = 360° = 21,600′ = 1,296,000″

A quadrant is one-fourth the circumference of a circle, or 90°; a sextant is one-sixth of a circle, or 60°. A right angle contains 90°. The unit of measurement is the degree or $\frac{1}{360}$ of the circumference of a circle.

AVOIRDUPOIS WEIGHT

437½ grains (gr.)	= 1 ounce	oz.
16 ounces	= 1 pound	lb.
100 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,000 lb.	= 1 ton	T.

1 T. = 20 cwt. = 2,000 lb. = 32,000 oz. = 14,000,000 gr.

The avoirdupois pound contains 7,000 gr.

LONG-TON TABLE

16 ounces	= 1 pound	lb.
112 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,240 lb.	= 1 ton	T.

TROY WEIGHT

24 grains (gr.)	= 1 pennyweight	pwt.
20 pennyweights	= 1 ounce	oz.
12 ounces	= 1 pound	lb.

1 lb. = 12 oz. = 240 pwt. = 5,760 gr.

DRY MEASURE

2 pints (pt.)	= 1 quart	qt.
8 quarts	= 1 peck	pk.
4 pecks	= 1 bushel	bu.

1 bu. = 4 pk. = 32 qt. = 64 pt.

The U. S. struck bushel contains 2,150.42 cu. in. = 1.2444 cu. ft. By law, its dimensions are those of a cylinder 18½ in. in diameter and 8 in. deep. The heaped bushel is equal to 1¼ struck bushels, the cone being 6 in. high. The dry gallon contains 268.8 cu. in., being ⅛ struck bushel.

For approximations, the bushel may be taken as $1\frac{1}{4}$ cu. ft.; or 1 cu. ft. may be considered $\frac{4}{5}$ bu.

The British bushel contains 2,218.19 cu. in. = 1.2837 cu. ft. = 1.032 U. S. bushels.

LIQUID MEASURE

4 gills (gi.)	= 1 pint	pt.
2 pints	= 1 quart	qt.
4 quarts	= 1 gallon	gal.
$31\frac{1}{2}$ gallons	= 1 barrel	bbl.
2 barrels, or 63 gallons	= 1 hogshead	hhd.

1 hhd. = 2 bbl. = 63 gal. = 252 qt. = 504 pt. = 2,016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft., nearly, or 1 cu. ft. contains 7.481 gal. The following cylinders contain the given measures very closely:

	Diam.	*Height*		*Diam.*	*Height*
Gill	$1\frac{3}{4}$ in.	3 in.	Gallon	7 in.	6 in.
Pint	$3\frac{1}{2}$ in.	3 in.	8 gallons	14 in.	12 in.
Quart	$3\frac{1}{2}$ in.	6 in.	10 gallons	14 in.	15 in.

When water is at its maximum density, 1 cu. ft. weighs 62.425 lb. and 1 gal. weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to $7\frac{1}{2}$ gal., and 1 gal. as weighing $8\frac{1}{3}$ lb.

The British imperial gallon, both liquid and dry, contains 277.274 cu. in. = .16046 cu. ft., and is equivalent to the volume of 10 lb. of pure water at 62° F. To reduce British to U. S. liquid gallons, multiply by 1.2. Conversely, to convert U. S. into British liquid gallons, divide by 1.2; or, increase the number of gallons $\frac{1}{5}$.

MEASURES OF TIME

60 seconds (sec.)	= 1 minute	min.
60 minutes	= 1 hour	hr.
24 hours	= 1 day	da.
7 days	= 1 week	wk.
4 weeks	= 1 month	mo.
12 month	= 1 year	yr.
100 years	= 1 century	C.

sec.	*min.*	*hr.*	*da.*	*wk.*	*yr.*
60 =	1				
3,600 =	60 =	1			
86,400 =	1,440 =	24 =	1		
604,800 =	10,080 =	168 =	7 =	1	
31,556,936 =	525,948 =	8,765 =	365 =	52 =	1

TABLE OF DISTANCES

1 statute or land mile..............	= 5,280 ft.; 1,760 yd.; 320 rd.; 8 fur.
1 furlong..........................	= 40 rd.
1 league...........................	= 3 mi.
1 knot,* or nautical mile............	= 6,080 ft., or $1\frac{1}{6}$ mi.
1 nautical league...................	= 3 naut. mi.
1 fathom...........................	= 6 ft.
1 meter............................	= 3 ft. $3\frac{3}{8}$ in., nearly
1 hand.............................	= 4 in.
1 palm.............................	= 3 in.
1 span.............................	= 9 in.
1 cable's length....................	= 240 yd.
Austrian mile.........................	= 4.09 naut. mi.
Danish mile...........................	= 4.06 naut. mi.
French kilometre.....................	= .54 naut. mi.
German Ruthen.......................	= 4.06 naut. mi.
Italian mile..........................	= 1.00 naut. mi.
Norwegian mile......................	= 6.01 naut. mi.
Russian verst........................	= .57 naut. mi.
Swedish mile.........................	= 5.75 naut. mi.

MEASURES OF VOLUME

1 cubic foot............................	= 1,728 cu. in.
1 ale gallon............................	= 282 cu. in.
1 standard, or wine, gallon..............	= 231 cu. in.
1 dry gallon............................	= 268.8 cu. in.
1 bushel...............................	= 2,150.4 cu. in
1 British bushel........................	= 2,218.19 cu. in.
1 cord of wood.........................	= 128 cu. ft.

*A knot is really a measure of speed and not of distance; when used in this sense, it is equivalent to 1 naut. mi. in 1 hr. Thus, a vessel running 20 naut. mi. per hr. has a speed of 20 knots.

1 perch	=	24.75 cu. ft.
1 ton of round timber	=	40 cu. ft.
1 ton of hewn timber	=	50 cu. ft.

A box $12\frac{15}{16}$ in. long, wide, and deep contains 1 bu.
A box $19\frac{3}{8}$ in. long, wide, and deep contains 1 bbl.
A box $8\frac{1}{8}$ in. long, wide, and deep contains 1 pk.
A box $6\frac{7}{16}$ in. long, wide, and deep contains $\frac{1}{2}$ pk.
A box $4\frac{1}{16}$ in. long, wide, and deep contains 1 qt.

MEASURES OF MONEY

UNITED STATES MONEY

10 mills (m)	=	1 cent	ct.
10 cents	=	1 dime	d.
10 dimes	=	1 dollar	$
10 dollars	=	1 eagle	E.

m.	ct.	d.	$	E.
10 =	1			
100 =	10 =	1		
1,000 =	100 =	10 =	1	
10,000 =	1,000 =	100 =	10 =	1

The term legal tender is applied to money that may be legally offered in payment of debts. All gold coins are legal tender for their face value to any amount, provided that their weight has not diminished more than $\frac{1}{200}$. Silver dollars are also legal tender to any amount; but silver coins of lower denomination than $1 are legal tender only for sums not exceeding $10. Nickel and copper coins are legal tender for sums not exceeding 25 ct.

ENGLISH MONEY

4 farthings (far.)	=	1 penny	d.
12 pence	=	1 shilling	s.
20 shillings	=	1 pound, or sovereign	£

far.	d.	s.	£
4 =	1		
48 =	12 =	1	
960 =	240 =	20 =	1

VALUES OF FOREIGN MONEY

The monetary units of leading foreign nations and their equivalents in United States money are as follows; these rates are proclaimed each year by the secretary of the Treasury. The standard of each country is expressed as G or S denoting, respectively, gold and silver.

Countries	Standard	Monetary Unit		Value in U. S. Gold
Argentine Republic	G. and S.	Peso	=100 centesimos	$ .96
Austria-Hungary	G	Crown	=100 kreutzer	.20
Belgium	G. and S.	Franc	=100 centimes	.19
Brazil	G.	Milreis	=1,000 reis	.54
British North America (except Newfoundland)	G.	Dollar	=100 cents	1.00
British Honduras	G.	Dollar	=100 cents	1.00
Chile	G.	Peso	=100 centavos	.36
China	S.	Tael*	=1,000 cash	.66
Costa Rica	G.	Colon	=100 centavos	.46
Cuba	G. and S.	Peso	=100 centavos	.92
Denmark	G.	Krone	=100 öre	.27
Ecuador	G.	Sucre	=100 centavos	.48
Egypt	G.	Pound	=100 piasters	4.94
Finland	G.	Mark	=100 penni	.19
France	G. and S.	Franc	=100 centimes	.19
Germany	G.	Mark	=100 pfennig	.24

VALUES OF FOREIGN MONEY—(*Continued*)

Countries	Standard	Monetary Unit	Value in U. S. Gold
Great Britain	G.	Pound Sterling	$4.86
Greece	G. and S.	Drachma = 100 lepta	.19
Haiti	G.	Gourde = 100 cents	.96
India†	G.	Rupee = 16 annas	.32
Italy	G. and S.	Lira = 100 centesimi	.19
Japan	G.	Yen = 100 sen	.50
Liberia	G.	Dollar = 100 cents	1.00
Mexico	S.	Dollar = 100 centavos	.39
Netherlands	G. and S.	Florin = 100 cents	.40
Newfoundland	G.	Dollar = 100 cents	1.01
Peru	G.	Sol = 100 centesimos	.48
Portugal	G.	Milreis = 1,000 reis	1.08
Russia	G.	Ruble = 100 copecks	.51
Spain	G. and S.	Peseta = 100 centimos	.19
Sweden and Norway	G.	Krona = 100 öre	.27
Switzerland	G. and S.	Franc = 100 centimes	.19
Turkey	G.	Piaster = 40 paras	.04
Uruguay	G.	Peso = 100 centavos	1.03
Venezuela	G. and S.	Bolivar = 100 centimos	.19

*Value of the tael differs slightly in different provinces. The "British dollar" now coined and in circulation has the same legal value as the Mexican dollar in Hong Kong, The Straits Settlements, and Labuan.

†Value of the rupee to be determined by consular certificate.

The unit of English money is the **pound sterling**, the value of which in United States money is $4.8665. The fineness of English silver is .925; of the gold coins, .916$\frac{2}{3}$. What is called sterling silver when applied to solid silver articles has the same fineness. Hence the name *sterling silver.*

The other coins of Great Britain are the **florin** (=2 shillings), the **crown** (=5 shillings), the **half crown** (=2$\frac{1}{2}$ shillings), and the **guinea** (=21 shillings). The largest silver coin is the crown, and the smallest, the threepence ($\frac{1}{4}$ shilling). The shilling is worth 25 ct. (24.3+ct.) in United States money. The guinea is no longer coined. The abbreviation £ is written before the number, while s. and d. follow. Thus, £25 4s. 6d.=25 pounds 4 shillings 6 pence.

Rule.—*To reduce pounds, shillings, and pence to dollars and cents, reduce the pounds to shillings, add the shillings, if any, and multiply the sum by* .24$\frac{1}{3}$; *if any pence are given, increase this product by twice as many cents as there are pence.*

Example.—Reduce £4 7s. 14d. to dollars and cents.

Solution.—$(4\times 20+7)\times .24\frac{1}{3}+.28=\$21.45$. Ans.

Rule.—*To reduce pounds to dollars, and vice versa, exchange being at* $4.8665: *Multiply the number of pounds by* 73, *and divide the quotient by* 15; *the result will be the equivalent in dollars and cents. Or, multiplying the dollars by* 15 *and dividing the product by* 73 *will give its equivalent in pounds and decimals of a pound.*

Example.—Reduce £6 to dollars and cents.

Solution.— $6\times 73\div 15=\$29.20$. Ans.

Example.—Reduce $17 to pounds.

Solution.— $17\times 15\div 73=£3.493$. Ans.

THE METRIC SYSTEM

The **metric system** is based on the meter, which, according to the United States Coast and Geodetic Survey Report of 1884, is equal to 39.370432 in. The value commonly used is 39.37 in., and is authorized by the United States government. The meter is defined as one ten-millionth the distance from the pole to the equator, measured on a meridian passing near Paris, France.

There are three principal units—the *meter*, the *liter* (pronounced lee-ter), and the *gram*, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words deca (10), hecto (100), and kilo (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli ($\frac{1}{1000}$). These prefixes form the key to the entire system.

MEASURES OF LENGTH

10 millimeters	= 1 centimeter	=	.394 in.
10 centimeters	= 1 decimeter	=	3.937 in.
10 decimeters	= 1 meter	=	3.281 ft.
10 meters	= 1 decameter	=	32.809 ft.
10 decameters	= 1 hectometer	=	109.363 yd.
10 hectometers	= 1 kilometer	=	1,093.63 yd.

MEASURES OF SURFACE (NOT LAND)

100 sq. millimeters	= 1 sq. centimeter	=	.155 sq. in.
100 sq. centimeters	= 1 sq. decimeter	=	15.5 sq. in.
100 sq. decimeters	= 1 sq. meter	=	10.764 sq. ft.

MEASURES OF VOLUME AND CAPACITY

10 milliliters	= 1 centiliter	=	.61 cu. in.
10 centiliters	= 1 deciliter	=	6.10 cu. in.
10 deciliters	= 1 liter	=	61.02 cu. in.
10 liters	= 1 decaliter	=	.353 cu. ft.
10 decaliters	= 1 hectoliter	=	3.53 cu. ft.
10 hectoliters	= 1 kiloliter	=	35.31 cu. ft.

The liter is equal to the volume occupied by 1 cu. decimeter.

MEASURES OF WEIGHT

10 milligrams	= 1 centigram	=	.154 gr.
10 centigrams	= 1 decigram	=	1.54 gr.
10 decigrams	= 1 gram	=	15.43 gr.
10 grams	= 1 decagram	=	154.32 gr.
10 decagrams	= 1 hectogram	=	.220 lb., avoir.
10 hectograms	= 1 kilogram	=	2.204 lb., avoir.
1,000 kilograms	= 1 ton	=	2,204 lb., avoir.

The gram is the weight of 1 cu. cm. of pure distilled water at a temperature of 39.2° F.; the kilogram is the weight of 1 liter of water; the ton is the weight of 1 cu. m. of water.

METRIC EQUIVALENTS OF POUNDS, FEET, ETC.

The following table will be found valuable for reference by masters, officers, and stewards in their dealings with ship chandleries and other supply stores in countries where the metric system is used:

Pounds		*Kilos.*	*Pounds*		*Kilos.*
1	=	.454	60	=	27.270
2	=	.909	70	=	31.815
3	=	1.363	80	=	36.360
4	=	1.818	90	=	40.905
5	=	2.272	100	=	45.450
6	=	2.727	200	=	90.900
7	=	3.161	300	=	136.350
8	=	3.636	400	=	181.800
9	=	4.090	500	=	227.250
10	=	4.545	600	=	272.700
20	=	9.060	700	=	318.150
30	=	13.635	800	=	363.600
40	=	18.180	900	=	409.050
50	=	22.725	1,000	=	454.500

1,000 kilos. = 1 metric ton (Tonelada metrico).

		Centi-meters			*Centi-meters*
1 inch	=	2.54	7 feet	=	213.00
1 foot	=	30.48	8 feet	=	243.84
1 yard	=	91.44	9 feet	=	274.32
2 feet	=	61.00	10 feet	=	304.80
3 feet	=	91.44	11 feet	=	335.28
4 feet	=	122.00	12 feet	=	365.76
5 feet	=	152.00	13 feet	=	396.24
6 feet	=	182.88	14 feet	=	426.72

1 gill	=	.142 liter
1 pint	=	.568 liter
1 quart	=	1.136 liters
1 gallon	=	4.543 liters
1 peck	=	9.087 liters
1 bushel	=	36.347 liters
1 quarter	=	290.781 liters
1 ounce, avoir	=	2.83 decigrams
1 pound, avoir	=	.45 kilogram
1 hundredweight, avoir	=	50.80 kilograms
1 ton, avoir	=	1,016.05 kilograms
1 pennyweight, troy	=	1.55 grams
1 ounce, troy	=	31.10 grams
1 pound, troy	=	373.24 grams

NAUTICAL MILES TO KILOMETERS

Nautical Miles	Kilometers	Nautical Miles	Kilometers
1	1.8532	20	37.064
2	3.7064	30	55.596
3	5.5596	40	74.128
4	7.4128	50	92.660
5	9.2660	60	111.190
6	11.1190	70	129.720
7	12.9720	80	148.250
8	14.8250	90	167.880
9	16.7880	100	185.320
10	18.5320	110	203.850

KILOMETERS TO NAUTICAL MILES

Kilo-meters	Nautical Miles	Kilo-meters	Nautical Miles
1	.5396	20	10.792
2	1.0792	30	16.188
3	1.6188	40	21.584
4	2.1584	50	26.980
5	2.6980	60	32.375
6	3.2375	70	37.771
7	3.7771	80	43.167
8	4.3167	90	48.563
9	4.8563	100	53.959
10	5.3959	110	59.355

VALUE OF MISCELLANEOUS FOREIGN MEASURES

The following list contains the value of various foreign measures as given in Monthly Consular Reports published by the Department of Commerce and Labor. Many of the equivalents are probably only approximately correct.

Argentine Republic.—1 frasco = 2.5 qt., 1 baril = 20.1 gal., 1 libra = 1 lb., 1 vara = 34.1 in., 1 arroba (dry) = 25.3 lb. 1 quintal = 101.4 lb.

Belgium.—1 last = 85.1 bu.

Brazil.—1 arroba = 32.4 lb., 1 quintal = 130 lb.

Chile.—1 fanega (dry) = 2.5 bu., 1 vara = 33.3 in.

China.—1 catty = 1.3 lb., 1 picul = 133.3 lb., 1 chik = 14 in., 1 tsun = 1.4 in., 1 li = 2,115 ft.

Costa Rico.—1 manzana = 1.8 A.

Cuba.—1 vara = 33.4 in., 1 arroba (liquid) = 4.3 gal., 1 fanega (dry) = 1.6 bu., 1 libra = 1 lb.

Denmark.—1 tonde (cereals) = 3.9 bu., 1 centner = 110.1 lb.

Greece.—1 livre = 1.1 lb., 1 oke = 2.8 lb., 1 quintal = 123.2 lb.

Japan.—1 sun = 1.2 in., 1 shaku = 11.9 in., 1 ken = 6 ft., 1 sho = 1.6 qt., 1 to = 2 pk., 1 koku = 4.9 bu., 1 catty = 1.3 lb., 1 picul = 133.3 lb.

Mexico.—1 carga = 300 lb.; other measures same as Cuba and Argentine Republic.

Peru.—1 vara = 33.4 in., 1 libra = 1 lb., 1 quintal = 101.4 lb.

Portugal.—1 almuda = 4.4 gal., 1 arratel = 1 lb., 1 arroba = 32.4 lb.

Russia.—1 vedro = 2.7 gal., 1 korree = 3.5 bu., 1 chetvert = 5.7 bu., 1 funt = .9 lb., 1 pood = 36.1 lb., 1 berkovets = 361.1 lb., 1 verst = 0.66 mi.

Siam.—1 catty = 1.3 lb., 1 coyan = 2,667 lb.

Spain.—1 pie = .9 ft., 1 vara = .9 yd., 1 arroba (liquid) = 4.3 gal. 1 fanega (liquid) = 16 gal., 1 butt (wine) = 140 gal., 1 last (salt) = 4,760 lb.

Sweden.—1 tunna = 4.5 bu., 1 skålpund = 1.1 lb., 1 centner = 93.7 lb.

Turkey.—1 pik = 27.9 in., 1 oke = 2.8 lb., 1 cantar = 124.7 lb.

Uruguay.—1 cuadra = 2 A., 1 suerte = 2,700 cuadras, 1 fanega (single) = 3.8 bu., 1 fanega (double) = 7 7 bu.

Zanzibar.—1 frasila = 35 lb.

ARITHMETIC

COMMON FRACTIONS

Two numbers are required to express a fraction; one is called the **numerator** and the other the **denominator.** The numerator is the number that tells how many parts of a whole is taken. Thus, 2 is the numerator of $\frac{2}{3}$, as it shows that two of three parts into which the whole is divided are taken. The denominator of a fraction is the number that shows into how many parts the whole is divided. Thus, in the fraction $\frac{2}{3}$ the 3 is the denominator. A *common denominator* is a denominator that is common to two or more fractions. Thus, $\frac{1}{4}$ and $\frac{3}{4}$ have common denominators; and 12 is a common denominator for $\frac{1}{6}$, $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{2}$ as they are, respectively, equal to $\frac{2}{12}$, $\frac{4}{12}$, $\frac{3}{12}$, and $\frac{6}{12}$.

Addition of Fractions.—If of the same denominator, add together the numerators only. Thus, $\frac{1}{16}+\frac{3}{16}+\frac{5}{16}=\frac{9}{16}$.

If they have different denominators, change them to fractions with common denominators and then proceed as before.

Example.—What is the sum of $\frac{1}{3}+\frac{1}{4}+\frac{1}{5}$?

Solution.—We have $\frac{1}{3}=\frac{20}{60}$, $\frac{1}{4}=\frac{15}{60}$, and $\frac{1}{5}=\frac{12}{60}$; hence,

$$\frac{20}{60}+\frac{15}{60}+\frac{12}{60}=\frac{47}{60}.\quad \text{Ans.}$$

Subtraction of Fractions.—Reduce them to a common denominator, take the less from the greater, and reduce the result; as, $\frac{7}{8}$ in. $-\frac{9}{16}$ in. $=\frac{14-9}{16}=\frac{5}{16}$ in. If they are mixed numbers, subtract fractions and whole numbers separately, placing remainders beside one another; thus, $3\frac{7}{8}$ in. $-2\frac{1}{4}$ in. $=(3-2)+(\frac{7}{8}-\frac{2}{8})=1\frac{5}{8}$ in.

Multiplication of Fractions.—Multiply the numerators together for the numerator and the denominators for the denominator. Thus,

$$\frac{1}{2}\times\frac{3}{16}\times\frac{2}{3}=\frac{2\times 3}{2\times 16\times 3}=\frac{6}{96}=\frac{1}{16}$$

Division of Fractions.—Invert the divisor and multiply.

Example.—Divide $\frac{9}{64}$ by $\frac{2}{5}$.

Solution.— $\frac{9}{64}\times\frac{5}{2}=\frac{45}{128}$. Ans.

Reduction of Compound to Simple Fractions.—Multiply the integer by the denominator of the fraction and add the numerator for the new numerator and place it over the denominator.

Example.—Reduce $5\frac{2}{3}$ to a simple fraction.

Solution.— $5\times3+2=17$, which is the numerator, and the fraction is therefore $\frac{17}{3}$. Ans.

Reduction of Simple to Compound Fractions.—Divide the numerator by the denominator and use the remainder as the numerator of the remaining fraction.

Example.—Reduce $\frac{64}{9}$ to a compound fraction.

Solution.—

```
9 ) 6 4 ( 7
    6 3
    ---
      1
```

Hence, the compound fraction is $7\frac{1}{9}$. Ans.

Reduction of Fractions to Decimals.—Annex ciphers to the numerator, and divide by the denominator and point off as many decimals places in the quotient as there are ciphers used.

Example.—Reduce $\frac{9}{16}$ to decimals.

Solution.—

```
1 6 ) 9.0 0 0 0 ( .5 6 2 5.  Ans.
      8 0
      ---
      1 0 0
        9 6
      -----
          4 0
          3 2
          ---
            8 0
            8 0
            ---
```

TABLE OF FRACTIONS REDUCED TO DECIMALS

$\frac{1}{64}$	.015625	$\frac{17}{64}$	.265625	$\frac{33}{64}$	.515625	$\frac{49}{64}$	.765625
$\frac{1}{32}$	.03125	$\frac{9}{32}$	.28125	$\frac{17}{32}$	.53125	$\frac{25}{32}$	.78125
$\frac{3}{64}$	.046875	$\frac{19}{64}$	.296875	$\frac{35}{64}$	.546875	$\frac{51}{64}$	.796875
$\frac{1}{16}$	.0625	$\frac{5}{16}$	.3125	$\frac{9}{16}$	.5625	$\frac{13}{16}$	.8125
$\frac{5}{64}$	.078125	$\frac{21}{64}$	.328125	$\frac{37}{64}$	.578125	$\frac{53}{64}$	.828125
$\frac{3}{32}$	.09375	$\frac{11}{32}$	.34375	$\frac{19}{32}$	.59375	$\frac{27}{32}$	.84375
$\frac{7}{64}$	.109375	$\frac{23}{64}$	.359375	$\frac{39}{64}$	.609375	$\frac{55}{64}$	.859375
$\frac{1}{8}$	.125	$\frac{3}{8}$	.375	$\frac{5}{8}$	.625	$\frac{7}{8}$	.875
$\frac{9}{64}$	.140625	$\frac{25}{64}$	.390625	$\frac{41}{64}$	.640625	$\frac{57}{64}$	.890625
$\frac{5}{32}$	.15625	$\frac{13}{32}$	.40625	$\frac{21}{32}$	.65625	$\frac{29}{32}$	.90625
$\frac{11}{64}$	.171875	$\frac{27}{64}$	.421875	$\frac{43}{64}$	.671875	$\frac{59}{64}$	.921875
$\frac{3}{16}$	.1875	$\frac{7}{16}$	.4375	$\frac{11}{16}$	.6875	$\frac{15}{16}$	.9375
$\frac{13}{64}$	.203125	$\frac{29}{64}$	.453125	$\frac{45}{64}$	.703125	$\frac{61}{64}$	.953125
$\frac{7}{32}$	.21875	$\frac{15}{32}$	.46875	$\frac{23}{32}$	.71875	$\frac{31}{32}$	.96875
$\frac{15}{64}$	.234375	$\frac{31}{64}$	.484375	$\frac{47}{64}$	.734375	$\frac{63}{64}$	.984375
$\frac{1}{4}$	.25	$\frac{1}{2}$	.5	$\frac{3}{4}$	.75	1	1.0000

Decimal fractions have for their denominators 10 or a power of 10, but the denominator is usually omitted. Thus, $.1=\frac{1}{10}$; $.01=\frac{1}{100}$; $.001=\frac{1}{1000}$; etc.

Addition of Decimals.—Place the numbers in a column with whole numbers under whole numbers, tenths under tenths, hundredths under hundredths, etc., and proceed as in simple addition, placing the decimal point in the sum directly under the points above. Thus,

```
  .0075
  .6300
 1.0600
17.9342
-------
19.6317
```

Subtraction of Decimals.—Arrange the figures as in addition, and proceed as in simple subtraction. Thus,

```
5.96978
3.28694
-------
2.68284
```

Multiplication of Decimals.—Proceed as in simple multiplication, pointing off as many decimal places in the result as there are decimal places in both multiplicand and multiplier. Thus,

```
    4.6 7 5 3 1
          .0 5 3
  -------------
  1 4 0 2 5 9 3
2 3 3 7 6 5 5
---------------
.2 4 7 7 9 1 4 3
```

Division of Decimals.—Proceed as in simple division and point off as many decimal places in the quotient as the number of decimal places in the dividend exceeds those in the divisor.

Example.—Divide 4.7 5 6 by 3.3.

Solution.—

```
3.3 ) 4.7 5 6 0 0 ( 1.4 4 1 2 -   Ans.
      3 3
      ---
      1 4 5
      1 3 2
      -----
        1 3 6
        1 3 2
        -----
            4 0
            3 3
            ---
              7 0
              6 6
              ---
                4
```

Example.—Divide .006 by 20.

Solution.—

```
2 0 ) .0 0 6 0 ( .0 0 0 3.   Ans.
          6 0
          ---
```

PROPORTION

SIMPLE PROPORTION, OR SINGLE RULE OF THREE

A proportion is an expression of equality between equal ratios; thus the ratio of 10 to 5 = the ratio of 4 to 2, and is expressed thus: $10:5=4:2$.

There are four terms in proportion. The first and last are the **extremes**, and the second and third are the **means**.

Quantities are in proportion by **alternation** when antecedent is compared with antecedent and consequent with consequent. Thus, if 10:5=4:2, then 10:4=5:2.

Quantities are in proportion by **inversion** when antecedents are made consequents and the consequents antecedents. Thus, if 10:5=4:2, then 5:10=2:4.

In any proportion, the product of the means will equal the product of the extremes. Thus, if 10:5=4:2, then $5\times 4=10\times 2$.

A **mean proportional** between two quantities equals the square root of their products. Thus, a mean proportional between 12 and 3 is the square root of 12×3 or 6.

If the two means and one extreme of a proportion are given, we find the other extreme by dividing the product of the means by the given extreme. Thus, 10:5=4:(?) then $4\times 5\div 10=2$, and the proportion is 10:5=4:2.

If the two extremes and one mean are given, we find the other mean by dividing the product of the extreme by the given mean. Thus, 10 : (?) =4:2, then $10\times 2\div 4=5$, and the proportion is 10:5=4:2.

Example.—If 6 men unload 30 cars of ballast in a day, how many cars will 10 men unload?

Solution.—As 10 men will unload more than 6 men, the second term of the proportion must be greater than the first; hence, 6:10=30 : (?), then,

$$10\times 30\div 6=50 \text{ cars. Ans.}$$

COMPOUND PROPORTION, OR DOUBLE RULE OF THREE

1. The product of the simple ratios of the first couplet equals the product of the simple ratios of the second couplet. Thus,

$$\left\{\begin{matrix}4:12\\7:14\end{matrix}\right\}=\left\{\begin{matrix}5:10\\6:18\end{matrix}\right\}=\frac{4}{12}\times\frac{7}{14}=\frac{5}{10}\times\frac{6}{18}.$$

2. The product of all the terms in the extremes equals the product of all the terms in the means. Thus, in

$$\left\{\begin{matrix}4:12\\7:14\end{matrix}\right\}=\left\{\begin{matrix}5:10\\6:18\end{matrix}\right\}$$

we have, $4\times 7\times 10\times 18=12\times 14\times 5\times 6$

3. Any term in either extreme equals the product of the means divided by the product of the other terms in the extremes. Thus, in the same proportion, we have

$$4=\frac{5\times 6\times 12\times 14}{7\times 10\times 18}$$

4. Any term in either mean equals the product of the extremes divided by the product of the other terms in the means. Thus, in

$$\left\{\begin{matrix}4:12\\7:14\end{matrix}\right\}=\left\{\begin{matrix}5:10\\6:18\end{matrix}\right\}$$

we have, $5=(4\times 7\times 10\times 18)\div(6\times 12\times 14)$

Rule.—I. *Put the required quantity for the first term and the similar known quantity for the second term, and form ratios with each pair of similar quantities for the second couplet, as if the result depended on each pair and the second term.*

II. *Find the required term by dividing the product of the means by the product of the fourth terms.*

Example.—If 4 men can earn $24 in 7 da., how much can 14 men earn in 12 da.?

Solution.— Sum : $24 = $\left\{\begin{matrix}14:4\\12:7\end{matrix}\right\}$

$$\text{Sum}=\frac{24\times 14\times 12}{4\times 7}=\$144.\quad \text{Ans.}$$

Example.—If 12 men, in 35 da., can build a wall 140 rd. long, 6 ft. high, how many men can, in 40 da., build a wall of the same thickness 144 rd. long, 5 ft. high?

Solution.—

$$\left\{\begin{matrix}12:(\ )\\35:40\end{matrix}\right\}=\left\{\begin{matrix}140:144\\6\ :\ 5\end{matrix}\right\}=\frac{12\times 35\times 144\times 5}{40\times 140\times 6}=9.\quad \text{Ans.}$$

INVOLUTION

To Square a Number.—Multiply the number by itself. Thus, the square of $4=4\times 4$, or 16.

To Cube a Number.—Multiply the square of the number by the number. Thus, the cube of $4=16\times 4=64$.

To Find the Fourth Power of a Number.—Multiply the cube by the number. Thus, the fourth power of $4 = 64 \times 4 = 256$.

To Raise a Number to the Sixth Power.—Square its cube.

To Raise a Number to the Twelfth Power.—Square its sixth power.

(See logarithms for a shorter method.)

EVOLUTION

Rule for Extracting Any Root of Any Number.—I. *Point off the number into periods that shall contain as many figures as there are units in the index of the root, beginning with the decimal point.*

II. *Find the largest number that, when raised to the power indicated by an exponent having as many units as the index figure of the root, does not exceed the first period; the number thus obtained will be the first figure of the root.*

III. *Raise the first figure of the root to the power indicated by an exponent having as many units as the index figure of the root, and subtract the result from the first period; annex the first figure of the second period to the remainder, and call the result the first dividend.*

IV. *Raise the first figure of the root to that power indicated by an exponent that has one less unit than the index figure of the root; multiply the result by the index figure, and call the product the first divisor.*

V. *Divide the first dividend by the first divisor and obtain two figures of the quotient the second of which may be a decimal. If the quotient is less than* 10 *and the second figure is* 5 *or a greater number, write the first figure of the quotient as the second figure of the root; if less than* 5, *subtract* 1 *from the first figure of the quotient for the second figure of the root. If the divisor is greater than the dividend, write a cipher for the second figure of the root. If the dividend contains the divisor* 10 *or more times, try* 9 *for the second figure of the root; if* 9 *is also too large, try* 8; *and so on.*

VI. *Raise that portion of the root already found to the power indicated by an exponent having as many units as the* *index figure; subtract the result from the first two periods; annex the first figure of the third period to the remainder, and call the result the second dividend.*

VII. *Raise that portion of the root already found to the power indicated by an exponent having one less unit than the index figure; multiply the result by the index figure, and call the product the second divisor. Divide the second dividend by the second divisor (as described in* **V**) *for the third figure of the root.*

VIII. *Proceed as in* **VI** *and* **VII** *for the fourth figure of the root, and so on for more figures, if desired.*

NOTE.—The result obtained in V may be too large or too small; if so, it will be made evident in VI when getting the second dividend, and a smaller (or larger) number must be used for the second figure of the root. If the given number whose root is to be found is wholly decimal, take care that the first period contains as many figures (annexing ciphers, if necessary) as there are units in the index figure of the root. Thus, in extracting the seventh root of .02794, the first period would be .0279400, and the remaining periods, cipher periods.

Example.—Extract the square root of 1,971.14.

Solution.— 19′71.′14(44.398

	$4^2 = 16$	
1st divisor $= 4 \times 2 = 8$)	37	1st dividend
	4.6;	hence, 4 is second figure of root
	1971	1st and 2d periods
	$44^2 = 1936$	
2d divisor $= 44 \times 2 = 88$)	351	2d dividend
	3.9;	hence, 3 is third figure of root
	197114	1st, 2d, and 3d periods
	$443^2 = 196249$	
3d divisor $= 443 \times 2 = 886$)	8650	3d dividend
	9.76 +;	hence, 9 and 8 are, respectively, the fourth and fifth figures of root.

Required root is 44.398. Ans.

Example.—Extract the cube root of 2,571.14.

Solution.— 2′571.′14(13.69 +

$1^3 = 1$

1st divisor $= 1^2 \times 3 = 3$) 15 — 1st dividend

5.0 — It is evident that 4 as the second figure of the root is too large; hence, use 3

2571 — 1st and 2d periods

$13^3 =$ 2197

2d divisor $= 13^2 \times 3 = 507$) 3741 — 2d dividend

7.3 — hence, 6 is third figure of root

2571140 — 1st, 2d, and 3d periods

$13.6^3 =$ 2515456

3d divisor $= 13.6^2 \times 3 = 55488$) 556840 — 3d dividend

10. — hence, 9 is fourth figure of root

Required root is 13.69 +. Ans.

Example.— $\sqrt[5]{909,203,700,718,879,776} = ?$

	First Period	*Second Period*	*Third Period*	*Fourth Period*	
Solution.—	909	20370	07188	79776	(3906

$3^5 = 243$

1st divisor $= 3^4 \times 5 = 405$) 6662 *1st dividend*

16 +

Since 16 is greater than 10, we try 9.

90920370 *1st and 2d periods*

$39^5 =$ 90224199

2d divisor $= 39^4 \times 5 = 11567205$) 6961710 *2d dividend*

0

Since the divisor is greater than the dividend, we write 0 for the third figure of the root.

9092037007188 *1st, 2d, 3d periods*

$390^5 =$ 9022419900000

3d divisor $= 390^4 \times 5 = 115672050000$) 696171071887 *3d dividend*

6 +. Try 6.

909203700718879776 *1st, 2d, 3d, and 4th periods*

$3906^5 =$ 909203700718879776

0

NOTE.—After having obtained the first three figures of the root, the first figure of the quotient, obtained by dividing a dividend by its corresponding divisor, will always be the next figure of the root. If the given number is not a perfect power, find three figures of the quotient when dividing the third dividend by the third divisor, and write the first and second figures (increasing the second figure by 1 if the third figure is 5 or a greater digit) as the fourth and fifth figures of the root. It is seldom that more than five figures of the root are required.

PERCENTAGE

Percentage means by or on the hundred. Thus, 1% = 1 on 100, 3% = 3 on 100, 5% = 5 on 100, etc.

To Find the Percentage, Having the Rate and the Base. Multiply the base by the rate expressed in hundredths. Thus, 6% of 1,930 is found thus:

$$\begin{array}{r} 1930 \\ .06 \\ \hline 115.80 \end{array}$$

To Find the Amount, Having the Base and Rate.—Multiply the base by 1 plus the rate. Thus, to find the amount of $1,930 for 1 year, at 6%, we multiply 1,930 by 1.06.

$$\$1,930 \times 1.06 = \$2,045.80$$

To Find the Base, Having the Rate and the Percentage. Divide the percentage by the rate to find the base. Thus, if the rate is 6% and the percentage is 115.80, the base is $115.80 \div .06 = 1,930$.

To Find the Rate, Having the Percentage and the Base. Divide the percentage by the base. Thus, if the percentage is 115.80 and the base 1,930, the rate equals $115.80 \div 1,930 = .06$, or 6%.

MENSURATION

In the following formulas, the letters have the meanings here given, unless otherwise stated:

D = larger diameter;

d = smaller diameter;

R = radius corresponding to D;

r = radius corresponding to d;

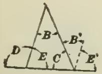
p = perimeter or circumference;

C = area of convex surface = area of flat surface that can be rolled into the shape shown;
S = area of entire surface = C + area of the end or ends;
A = area of plane figure;
π = 3.1416, nearly = ratio of any circumference to its diameter;
V = volume of solid;
The other letters used will be found on the cuts.

CIRCLE

$$p = \pi d = 3.1416\ d$$
$$p = 2\pi r = 6.2832\ r$$
$$p = 2\sqrt{\pi A} = 3.5449\sqrt{A}$$
$$p = \frac{2\ A}{r} = \frac{4\ A}{d}$$
$$d = \frac{p}{\pi} = \frac{p}{3.1416} = .3183\ p$$
$$d = 2\sqrt{\frac{A}{\pi}} = 1.1284\sqrt{A}$$
$$r = \frac{p}{2\pi} = \frac{p}{6.2832} = .1592\ p$$
$$r = \sqrt{\frac{A}{\pi}} = .5642\sqrt{A}$$
$$A = \frac{\pi d^2}{4} = .7854\ d^2$$
$$A = \pi r^2 = 3.1416\ r^2$$
$$A = \frac{p\,r}{2} = \frac{p\,d}{4}$$

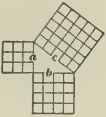
TRIANGLES



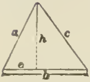
$D = B + C$ $\qquad E + B + C = 180°$
$B = D - C$ $\qquad E' + B + C = 180°$
$E' = E$ $\qquad B' = B.$

The above letters refer to angles.

For a right triangle, c being the hypotenuse,



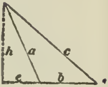
$$c=\sqrt{a^2+b^2}$$
$$a=\sqrt{c^2-b^2}$$
$$b=\sqrt{c^2-a^2}$$



c = length of side opposite an acute angle of an oblique triangle.

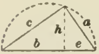
$$c=\sqrt{a^2+b^2-2be}$$
$$h=\sqrt{a^2-e^2}$$

c = length of side opposite an obtuse angle of an oblique triangle.



$$c=\sqrt{a^2+b^2+2be}$$
$$h=\sqrt{a^2-e^2}$$

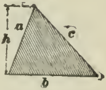
For a triangle inscribed in a semicircle; i. e., any right triangle,



$$c:b=a:h$$
$$h=\frac{ab}{c}=\frac{ce}{a}$$
$$a:b+e=e:a=h:c$$

For any triangle,

$$A=\frac{bh}{2}=\tfrac{1}{2}bh$$
$$A=\frac{b}{2}\sqrt{a^2-\left(\frac{a^2+b^2-c^2}{2b}\right)^2}$$

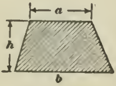


RECTANGLE AND PARALLELOGRAM

$$A=ab$$
$$A=b\sqrt{c^2-b^2}$$

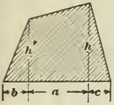
TRAPEZOID

$$A=\tfrac{1}{2}h(a+b)$$



TRAPEZIUM

Divide into two triangles and a trapezoid.



$$A = \tfrac{1}{2}bh' + \tfrac{1}{2}a(h' + h) + \tfrac{1}{2}ch$$

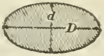
or, $A = \tfrac{1}{2}[bh' + ch + a(h' + h)]$

Or, divide into two triangles by drawing a diagonal. Consider the diagonal as the base of both triangles; call its length l; call the altitudes of the triangles h_1 and h_2; then

$$A = \tfrac{1}{2}l(h_1 + h_2)$$

ELLIPSE

$$p^* = \frac{\pi(D+d)}{2}\left[\frac{64 - 3\left(\frac{D-d}{D+d}\right)^4}{64 - 16\left(\frac{D-d}{D+d}\right)^2}\right]$$



$$A = \frac{\pi}{4}Dd = .7854\ Dd$$

SECTOR

$$A = \tfrac{1}{2}lr$$

$$A = \frac{\pi r^2E}{360} = .008727\ r^2E$$

l = length of arc

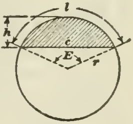
SEGMENT

$$A = \tfrac{1}{2}[lr - c(r - h)]$$

$$A = \frac{\pi r^2E}{360} - \frac{c}{2}(r - h)$$

$$l = \frac{\pi rE}{180} = .0175\ rE$$

$$E = \frac{180l}{\pi r} = 57.2956\frac{l}{r}$$



* The perimeter of an ellipse cannot be exactly determined without a very elaborate calculation, and this formula is merely an approximation giving close results.

CYLINDER

$$C = \pi dh$$
$$S = 2\pi rh + 2\pi r^2$$
$$= \pi dh + \frac{\pi}{2} d^2$$
$$V = \pi r^2 h = \frac{\pi}{4} d^2 h$$
$$V = \frac{p^2 h}{4\pi} = .0796 p^2 h$$

FRUSTUM OF CYLINDER

$h = \frac{1}{2}$ sum of greatest and least heights

$$C = ph = \pi dh$$
$$S = \pi dh + \frac{\pi}{4} d^2 + \text{area of elliptical top}$$
$$V = Ah = \frac{\pi}{4} d^2 h$$

PRISM OR PARALLELOPIPED

$$C = Ph$$
$$S = Ph + 2A$$
$$V = Ah$$

For prisms with regular polygon as bases, P = length of one side $\times$ number of sides.

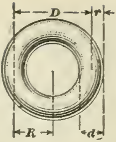
To obtain area of base, if it is a polygon, divide it into triangles, and find sum of partial areas.

FRUSTUM OF PRISM

If a section perpendicular to the edges is a triangle, square, parallelogram, or regular polygon, $V = \frac{\text{sum of lengths of edges}}{\text{number of edges}} \times$ area of right section.

SPHERE

$$S = \pi d^2 = 4\pi r^2 = 12.5664 r^2$$
$$V = \frac{1}{6}\pi d^3 = \frac{4}{3}\pi r^3 = .5236 d^3 = 4.1888 r^3$$

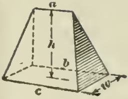


CIRCULAR RING

D = mean diameter;
R = mean radius.

$S = 4\pi^2 Rr = 9.8696Dd$

$V = 2\pi^2 Rr^2 = 2.4674Dd^2$



WEDGE

$V = \frac{1}{6}wh(a+b+c)$

LOGARITHMS

EXPONENTS

By the use of logarithms, the processes of multiplication, division, involution, and evolution are greatly shortened, and some operations may be performed that would be impossible without them. Ordinary logarithms cannot be applied to addition and subtraction.

The *logarithm* of a number is that *exponent* by which some fixed number, called the *base*, must be affected in order to equal the number. Any number may be taken as the base. Suppose we choose 4. Then the logarithm of 16 is 2, because 2 is the exponent by which 4 (the base) must be affected in order to equal 16, since $4^2 = 16$. In this case, instead of reading 4^2 as 4 square, read it 4 exponent 2. With the same base, the logarithms of 64 and 8 would be 3 and 1.5, respectively, since $4^3 = 64$, and $4^{1.5} = 4^{\frac{3}{2}} = 8$. In these cases, as in the preceding, read 4^3 and $4^{1.5}$ as 4 exponent 3, and 4 exponent 1.5, respectively.

Although any positive number except 1 *can* be used as a base and a table of logarithms calculated, but two numbers have ever been employed. For all arithmetical operations (except addition and subtraction) the logarithms used are called the *Briggs*, or *common*, logarithms, and the base used is 10. In abstract mathematical analysis, the logarithms used are variously called *hyperbolic*, *Napierian*, or *natural* logarithms, and the base is 2.718281828+. The common logarithm of any number may be converted into a Napierian logarithm by multiplying the common logarithm by 2.30258509+, which is usually expressed as 2.3026, and sometimes as 2.3. Only the common system of logarithms will be considered here.

Since in the common system the base is 10, it follows that, since $10^1=10$, $10^2=100$, $10^3=1{,}000$, etc., the logarithm (exponent) of 10 is 1, of 100 is 2, of 1,000 is 3, etc. For the sake of brevity in writing, the words "logarithm of" are abbreviated to "log." Thus, instead of writing logarithm of 100=2, write log 100=2. When speaking, however, the words for which "log" stands should always be pronounced in full.

From the above it will be seen that, when the base is 10,

since $10^0=1$, the exponent $0=\log 1$;
since $10^1=10$, the exponent $1=\log 10$;
since $10^2=100$, the exponent $2=\log 100$;
since $10^3=1{,}000$, the exponent $3=\log 1{,}000$; etc.

Also,

since $10^{-1}=\frac{1}{10}=.1$, the exponent $-1=\log .1$;
since $10^{-2}=\frac{1}{100}=.01$, the exponent $-2=\log .01$;
since $10^{-3}=\frac{1}{1000}=.001$, the exponent $-3=\log .001$; etc.

From this it will be seen that the logarithms of exact powers of 10 and of decimals like .1, .01, and .001 are the whole numbers 1, 2, 3, etc., and −1, −2, −3, etc., respectively. Only numbers consisting of 1 and one or more ciphers have whole numbers for logarithms.

Now, it is evident that, to produce a number between 1 and 10, the exponent of 10 must be a fraction; to produce a number between 10 and 100, it must be 1 plus a fraction; to produce a number between 100 and 1,000, it must be 2 plus a fraction, etc. Hence, the logarithm of any number between 1 and 10 is a fraction; of any number between 10 and 100, 1 plus a fraction; of any number between 100 and 1,000, 2 plus a fraction, etc. A logarithm, therefore, usually consists of two parts; a whole number, called the *characteristic*, and a fraction, called the *mantissa*. The mantissa is always expressed as a decimal. For example, to produce 20, 10 must have an exponent of approximately 1.30103, or $10^{1.30103}=20$, very nearly, the degree of exactness depending on the number of decimal places used. Hence, log 20 $=1.30103$, 1 being the characteristic, and .30103, the mantissa.

Referring to the second part of the preceding table, it is clear that the logarithms of all numbers less than 1 are negative, the logarithms of those between 1 and .1 being -1 plus a fraction. For, since log $.1=-1$, the logarithms of .2, .3, etc. (which are all greater than .1, but less than 1) must be greater than -1; i. e., they must equal -1 plus a fraction. For the same reason, to produce a number between .1 and .01, the logarithm (exponent of 10) would be equal to -2 plus a fraction, and for a number between .01 and .001, it would be equal to -3 plus a fraction. Hence, the logarithm of any number between 1 and .01 has a negative characteristic of 1 and a positive mantissa; of a number between .1 and .01, a negative characteristic of 2 and a positive mantissa; of a number between .01 and .001, a negative characteristic of 3 and a positive mantissa; of a number between .001 and .0001, a negative characteristic of 4 and a positive mantissa, etc. The negative characteristics are distinguished from the positive by the $-$ sign written over the characteristic. Thus, $\bar{3}$ indicates that 3 is negative.

It must be remembered that in all cases the mantissa is positive. Thus, the logarithm 1.30103 means $+1+.30103$, and the logarithm $\bar{1}.30103$ means $-1+.30103$. Were the minus sign written in front of the characteristic, it would indicate that the entire logarithm was negative. Thus, $-1.30103=-1-.30103$.

Rule for Characteristic.—Starting from the unit figure, count the number of places to the first (left-hand) digit of the given number, calling unit's place zero; the number of places thus counted will be the required characteristic. If the first digit lies to the left of the unit figure, the characteristic is positive; if to the right, negative. If the first digit of the number is the unit figure, the characteristic is 0. Thus, the characteristic of the logarithm of 4,826 is 3, since the first digit, 4, lies in the 3d place to the left of the unit figure, 6. The characteristic of the logarithm of 0.0000072 is -6 or $\bar{6}$, since the first digit, 7, lies in the 6th place to the right of the unit figure. The characteristic of the logarithm of 4.391 is 0, since 4 is both the first digit of the number and also the unit figure.

TO FIND THE LOGARITHM OF A NUMBER

To aid in obtaining the mantissa of logarithms, tables of logarithms have been calculated, some of which are very elaborate and convenient. In the Table of Logarithms, the mantissas of the logarithms of numbers from 1 to 9,999 are given to five places of decimals. The mantissas of logarithms of larger numbers can be found by interpolation. The table contains the mantissas only; the characteristics may be easily found by the preceding rule.

The table depends on the principle, which will be explained later, that all numbers having the same figures in the same order have the same mantissa, without regard to the position of the decimal point, which affects the characteristic only. To illustrate, if $\log 206 = 2.31387$, then,

$\log 20.6 = 1.31387$; $\log .206 = \bar{1}.31387$;

$\log 2.06 = .31387$; $\log .0206 = \bar{2}.31387$; etc.

To find the logarithm of a number not having more than four figures:

Rule.—*Find the first three significant figures of the number whose logarithm is desired, in the left-hand column; find the fourth figure in the column at the top (or bottom) of the page; and in the column under (or above) this figure, and opposite the first three figures previously found, will be the mantissa or decimal part of the logarithm. The characteristic being found as previously described, write it at the left of the mantissa, and the resulting expression will be the logarithm of the required number.*

Example.—Find from the table the logarithm: (*a*) of 476; (*b*) of 25.47; (*c*) of 1.073; (*d*) of .06313.

Solution.—(*a*) In order to economize space and make the labor of finding the logarithms easier, the first two figures of the mantissa are given only in the column headed 0. The last three figures of the mantissa, opposite 476 in the column headed N (N stands for number), are 761, found in the column headed 0; glancing upwards, we find the first two figures of the mantissa, viz., 67. The characteristic is 2; hence, log 476=2.67761. Ans.

NOTE.—Since all numbers in the table are decimal fractions, the decimal point is omitted throughout; this is customary in all tables of logarithms.

(*b*) To find the logarithm of 25.47, we find the first three figures, 254, in the column headed N, and on the same horizontal line, under the column headed 7 (the fourth figure of the given number), will be found the last three figures of the mantissa, viz., 603. The first two figures are evidently 40, and the characteristic is 1; hence, log 25.47=1.40603. Ans.

(*c*) For 1.073; in the column headed 3, opposite 107 in the column headed N, the last three figures of the mantissa are found, in the usual manner, to be 060. It will be noticed that these figures are printed *060, the star meaning that instead of glancing upwards in the column headed 0, and taking 02 for the first two figures, we must glance downwards and take the two figures opposite the number 108, in the left-hand column, i. e., 03. The characteristic being 0, log 1.073=0.03060, or, more simply, .03060. Ans.

(*d*) For .06313; the last three figures of the mantissa are found opposite 631, in column headed 3, to be 024. In this case, the first two figures occur in the same row, and are 80. Since the characteristic is $\bar{2}$, log .06313=$\bar{2}$.80024. Ans.

If the original number contains but one digit (a cipher is not a digit), annex mentally two ciphers to the right of the digit; if the number contains but two digits (with no ciphers between, as in 4,008), annex mentally one cipher on the right before seeking the mantissas. Thus, if the logarithm of 7 is wanted, seek the mantissa for 700, which is .84510; or, if the logarithm of 48 is wanted, seek the mantissa for 480, which is .68124. Or, find the mantissa of logarithms of numbers between 0 and 100, on the first page of the tables.

The process of finding the logarithm of a number from the table is technically called *taking out the logarithm.*

To take out the logarithm of a number consisting of more than four figures, it is inexpedient to use more than five figures of the number when using five-place logarithms (the logarithms given in the accompanying table are five-place). Hence, if the number consists of more than five figures and the sixth figure is less than 5, replace all figures after the fifth with ciphers; if the sixth figure is 5 or greater, increase the fifth figure by 1 and replace the remaining figures with ciphers. Thus, if the number is 31,415,926, find the logarithm of 31,416,000; if 31,415,426, find the logarithm of 31,415,000.

Example.—Find log 31,416.

Solution.—Find the mantissa of the logarithm of the first four figures, as explained above. This is, in the present case, .49707. Now, subtract the number in the column headed 1, opposite 314 (the first three figures of the given number), from the next greater consecutive number, in this case 721, in the column headed 2. $721-707=14$; this number is called the *difference*. At the extreme right of the page will be found a secondary table headed P. P., and at the top of one of these columns, in this table, in bold-face type, will be found the difference. It will be noticed that each column is divided into two parts by a vertical line, and that the figures on the left of this line run in sequence from 1 to 9. Consulting the difference column headed 14, we see opposite the number 6 (6 is the last or fifth figure of the number whose logarithm we are taking out) the number 8.4, and we add this number to the mantissa, found above, disregarding the decimal point in the mantissa, obtaining $49{,}707 + 8.4 = 49{,}715.4$. Now, since 4 is less than 5, we reject it, and obtain for our complete mantissa .49715. Since the characteristic of the logarithm of 31,416 is 4, log 31,416 = 4.49715. Ans.

Example.—Find log 380.93.

Solution.—Proceeding in exactly the same manner as above, the mantissa for 3,809 is 58,081 (the star directs us to take 58 instead of 57 for the first two figures); the next greater mantissa is 58,092, found in the column headed 0, opposite 381 in column headed N. The difference is $092-081=11$. Looking in the section headed P. P. for column headed 11, we find opposite 3, 3.3; neglecting the .3, since it is less than 5, 3 is the amount to be added to the mantissa of the logarithm of 3,809 to form the logarithm of 38,093. Hence, $58{,}081+3=58{,}084$, and since the characteristic is 2, log 380.93 = 2.58084. Ans.

Example.—Find log 1,296,728.

Solution.—Since this number consists of more than five figures and the sixth figure is less than 5, we find the logarithm of 1,296,700 and call it the logarithm of 1,296,728. The mantissa of log 1,296 is found to be 11,261. The difference is $294-261=33$. Looking in the P. P. section for column headed 33, we find opposite 7, on the extreme right, 23.1; neglecting the .1, the amount to be added to the above mantissa is 23. Hence, the mantissa of log 1,296,728 $=11,261+23=11,284$; since the characteristic is 6, log $1,296,728=6.11284$. Ans.

Example.—Find log 89.126.

Solution.—Log $89.12=1.94998$. Difference between this and log $80.13=1.95002-1.94998=4$. The P. P. (proportional part) for the fifth figure of the number 6 is 2.4, or 2. Hence, log $89.126=1.94998+.00002=1.95000$. Ans.

Example.—Find log .096725.

Solution.— Log $.09672=\bar{2}.98552$. Difference $=4$.
P. P. for $5=\quad 2$

Hence, log $.096725=\bar{2}.98554$. Ans.

To find the logarithm of a number consisting of five or more figures:

Rule.—I. *If the number consists of more than five figures and the sixth figure is* 5 *or greater, increase the fifth figure by* 1 *and write ciphers in place of the sixth and remaining figures.*

II. *Find the mantissa corresponding to the logarithm of the first four figures, and subtract this mantissa from the next greater mantissa in the table; the remainder is the difference.*

III. *Find in the secondary table headed P. P. a column headed by the same number as that just found for the difference, and in this column, opposite the number corresponding to the fifth figure (or fifth figure increased by* 1) *of the given number (this figure is always situated at the left of the dividing line of the column), will be found the P. P. (proportional part) for that number. The P. P. thus found is to be added to the mantissa found in* II, *as in the preceding examples, and the result is the mantissa of the logarithm of the given number, as nearly as may be found with five-place tables.*

TO FIND A NUMBER WHOSE LOGARITHM IS GIVEN

Rule.—I. *Consider the mantissa first. Glance along the different columns of the table which are headed* 0, *until the first two figures of the mantissa are found. Then, glance down the same column until the third figure is found* (*or* 1 *less than the third figure*). *Having found the first three figures, glance to the right along the row in which they are situated until the last three figures of the mantissa are found. Then, the number that heads the column in which the last three figures of the mantissa are found is the fourth figure of the required number, and the first three figures lie in the column headed N, and in the same row in which lie the last three figures of the mantissa.*

II. *If the mantissa cannot be found in the table, find the mantissa that is nearest to, but less than, the given mantissa, and which call the next less mantissa. Subtract the next less mantissa from the next greater mantissa in the table to obtain the difference. Also, subtract the next less mantissa from the mantissa of the given logarithm, and call the remainder the P. P. Looking in the secondary table headed P. P. for the column headed by the difference just found, find the number opposite the P. P. just found* (*or the P. P. corresponding most nearly to that just found*); *this number is the fifth figure of the required number; the fourth figure will be found at the top of the column containing the next less mantissa, and the first three figures in the column headed N and in the same row that contains the next less mantissa.*

III. *Having found the figures of the number as above directed, locate the decimal point by the rules for the characteristic, annexing ciphers to bring the number up to the required number of figures if the characteristic is greater than* 4.

Example.—Find the number whose logarithm is 3.56867.

Solution.—The first two figures of the mantissa are 56; glancing down the column, we find the third figure, 8 (in connection with 820), opposite 370 in the N column. Glancing to the right along the row containing 820, the last three figures of the mantissa, 867, are found in the column headed 4; hence, the fourth figure of the required number is 4, and the first three figures are 370, making the figures of the required number 3,704. Since the characteristic is 3, there are three figures to the left of the unit figure, and the number whose logarithm is 3.56867 is 3,704. Ans.

Example.—Find the number whose logarithm is 3.56871.

Solution.—The mantissa is not found in the table. The next less mantissa is 56,867; the difference between this and the next greater mantissa is 879 − 867 = 12, and the P. P. is 56,871 − 56,867 = 4. Looking in the P. P. section for the column headed 12, we do not find 4, but we do find 3.6 and 4.8. Since 3.6 is nearer 4 than 4.8, we take the number opposite 3.6 for the fifth figure of the required number; this is 3. Hence, the fourth figure is 4; the first three figures 370, and the figures of the number are 37,043. The characteristic being 3, the number is 3,704.3. Ans.

Example.—Find the number whose logarithm is 5.95424.

Solution.—The mantissa is found in the column headed 0, opposite 900 in the column headed N. Hence, the fourth figure is 0, and the number is 900,000, the characteristic being 5. Had the logarithm been $\bar{5}.95424$, the number would have been .00009. Ans.

Example.—Find the number whose logarithm is .93036.

Solution.—The first three figures of the mantissa, 930, are found in the 0 column, opposite 852 in the N column; but since the last two figures of all the mantissas in this row are greater than 36, we must seek the next less mantissa in the preceding row. We find it to be 93,034 (the star directing us to use 93 instead of 92 for the first two figures), in the column headed 8. The difference for this case is 039 − 034 = 5, and the P. P. is 036 − 034 = 2. Looking in the P. P. section for the column headed 5, we find the P. P., 2, opposite 4. Hence, the fifth figure is 4; the fourth figure is 8; the first three figures 851, and the number is 8.5184, the characteristic being 0. Ans.

Example.—Find the number whose logarithm is $\bar{2}.05753$.

Solution.—The next less mantissa is found in column headed 1, opposite 114 in the N column; hence, the first four figures are 1,141. The difference for this case is 767 − 729 = 38, and the P. P. is 753 − 729 = 24. Looking in the P. P. section for the column headed 38, we find that 24 falls between 22.8 and 26.6. The difference between 24 and 22.8 is 1.2, and between 24 and 26.6 is 2.6; hence, 24 is nearer 22.8 than it is to 26.6, and 6, opposite 22.8, is the fifth figure of the number. Hence, the number whose logarithm is $\bar{2}.05753$ is .011416. Ans.

In order to calculate by means of logarithms, a table is absolutely necessary. Hence, for this reason, we do not explain the method of calculating a logarithm. The work involved in calculating even a single logarithm is very great, and no method has yet been demonstrated, of which we are aware, by which the logarithm of a number like 121 can be calculated directly. Moreover, even if the logarithm could be readily obtained, it would be useless without a complete table, such as that which is here given, for the reason that after having used it, say to extract a root, the number corresponding to the logarithm of the result could not be found.

MULTIPLICATION BY LOGARITHMS

The principle upon which the process is based may be illustrated as follows: Let X and Y represent two numbers whose logarithms are x and y. To find the logarithm of their product, we have, from the definition of a logarithm,

$$10^x = X \qquad (1)$$

and

$$10^y = Y \qquad (2)$$

Since both members of (1) may be multiplied by the same quantity without destroying the equality, they evidently may be multiplied by equal quantities like 10^y and y. Hence, multiplying (1) by (2), member by member,

$$10^x \times 10^y = 10^{x+y} = X\,Y$$

or, by the definition of a logarithm, $x+y=\log X\,Y$. But $X\,Y$ is the product of X and Y, and $x+y$ is the sum of their logarithms; from which it follows that the sum of the logarithms of two numbers is equal to the logarithm of their product. Hence,

To multiply two or more numbers by using logarithms:

Rule.—*Add the logarithms of the several numbers, and the sum will be the logarithm of the product. Find the number corresponding to this logarithm, and the result will be the number sought.*

Example.—Multiply 4.38, 5.217, and 83 together.

Solution.— Log 4.38 = .64147
Log 5.217 = .71742
Log 83 = 1.91908

Adding, 3.27797 = log (4.38 × 5.217 × 83)

Number corresponding to 3.27797 = 1,896.6. Hence, 4.38 × 5.217 × 83 = 1,896.6, nearly. Ans.

By actual multiplication, the product is 1,896.5818, showing that the result obtained by using logarithms was correct to five figures.

When adding logarithms, their algebraic sum is always to be found. Hence, if some of their numbers multiplied together are wholly decimal, the algebraic sum of the characteristics will be the characteristic of the product. It must be remembered that the mantissas are always positive.

Example.—Multiply 49.82, .00243, 17, and .97 together.

Solution.—

Log 49.82 = 1.69740
Log .00243 = $\bar{3}.38561$
Log 17 = 1.23045
Log .97 = $\bar{1}.98677$

Adding, 0.30023 = log (49.82 × .00243 × 17 × .97)

Number corresponding to 0.30023 = 1.9963. Hence, 49.82 × .00243 × 17 × .97 = 1.9963. Ans.

In this case the sum of the mantissas was 2.30023. The integral 2 added to the positive characteristics makes their sum $= 2 + 1 + 1 = 4$; sum of negative characteristics $= \bar{3} + \bar{1} = \bar{4}$, whence $4 + (-4) = 0$. If, instead of 17, the number had been .17 in the above example, the logarithm of .17 would have been $\bar{1}.23045$, and the sum of the logarithms would have been $\bar{2}.30023$; the product would then have been .019963.

It can now be shown why all numbers with figures in the same order have the same mantissa, without regard to the decimal point. Thus, suppose it were known that log 2.06 = .31387. Then, log 20.6 = log (2.06 × 10) = log 2.06 + log 10 = .31387 + 1 = 1.31387. And so it might be proved with the decimal point in any other position.

DIVISION BY LOGARITHMS

As before, let X and Y represent two numbers whose logarithms are x and y. To find the logarithm of their quotient, we have, from the definition of a logarithm:

$$10^x = X \quad (1)$$

and

$$10^y = Y \quad (2)$$

Dividing (1) by (2), $10^{x-y} = \frac{X}{Y}$, or, by the definition of a logarithm, $x-y = \log \frac{X}{Y}$. But $\frac{X}{Y}$ is the quotient of $X \div Y$, and $x-y$ is the difference of their logarithms, from which it follows that the difference between the logarithms of two numbers is equal to the logarithm of their quotient. Hence, to divide one number by another by means of logarithms:

Rule.—*Subtract the logarithm of the divisor from the logarithm of the dividend, and the result will be the logarithm of the quotient.*

Example.—Divide 6,784.2 by 27.42.

Solution.— Log 6,784.2 = 3.83150
Log 27.42 = 1.43807
difference = 2.39343 = log (6,784.2 ÷ 27.42)

Number corresponding to 2.39343 = 247.42. Hence, 6,784.2 ÷ 27.42 = 247.42.

When subtracting logarithms, their algebraic difference is to be found. The operation may sometimes be confusing, because the mantissa is always positive, and the characteristic may be either positive or negative. *When the logarithm to be subtracted is greater than the logarithm from which it is to be taken, or when negative characteristics appear, subtract the mantissa first, and then the characteristic, by changing its sign and adding.*

Example.—Divide 274.2 by 6,784.2.

Solution.— Log 274.2 = 2.43807
Log 6,784.2 = 3.83150
$\bar{2}.60657$

First subtracting the mantissa .83150 gives .60657 for the mantissa of the quotient. In subtracting, 1 had to be taken from the characteristic of the minuend, leaving a characteristic of 1. Subtract the characteristic 3 from this, by changing its sign and adding $1-3=\bar{2}$, the characteristic of the quotient. Number corresponding to $\bar{2}.60657=.040418$. Hence, $274.2\div 6{,}784.2=.040418$. Ans.

Example.—Divide .067842 by .002742.

Solution.— Log $.067842=\bar{2}.83150$
Log $.002742=\bar{3}.43807$
difference $=1.39343$

Since $.83150-.43807=.39343$ and $-2+3=1$, number corresponding to $1.39343=24.742$. Hence, $.067842\div .002742=24.742$. Ans.

The only case that is likely to cause trouble in subtracting is that in which the logarithm of the minuend has a negative characteristic, or none at all, and a mantissa less than the mantissa of the subtrahend. For example, let it be required to subtract the logarithm 3.74036 from the logarithm $\bar{3}.55145$. The logarithm $\bar{3}.55145$ is equivalent to $-3+.55145$. Now, if we add both $+1$ and -1 to this logarithm, it will not change its value. Hence, $\bar{3}.55145 = -3-1+1+.55145 = \bar{4}+1.55145$. Therefore, $\bar{3}.55145-3.74036=$

$$\begin{array}{r} \bar{4}+1.55145 \\ 3+\ \ .74036 \\ \hline \end{array}$$
$$\text{difference}=\bar{7}+\ .81109=\bar{7}.81109$$

Had the characteristic of the above logarithm been 0 instead of $\bar{3}$, the process would have been exactly the same. Thus, $.55145=\bar{1}+1.55145$; hence,

$$\begin{array}{r} \bar{1}+1.55145 \\ 3+\ \ .74036 \\ \hline \end{array}$$
$$\text{difference}=\bar{4}+\ .81109=\bar{4}.81109$$

Example.—Divide .02742 by 67.842.

Solution.— Log $.02742=\bar{2}.43807=\bar{3}+1.43807$
Log $67.842=1.83150=1+\ .83150$
difference $=\bar{4}+\ .60657=\bar{4}.60657$

Number corresponding to $\bar{4}.60657=.00040417$. Hence, $.02742\div 67.842=.00040417$. Ans.

Example.—What is the reciprocal of 3.1416?

Solution.—Reciprocal of $3.1416 = \frac{1}{3.1416}$, and $\log \frac{1}{3.1416} = \log 1 - \log 3.1416 = 0 - .49715$. Since $0 = -1 + 1$,

$$\begin{array}{r} \bar{1} + 1.00000 \\ .49715 \\ \hline \end{array}$$

$$\text{difference} = \bar{1} + .50285 = \bar{1}.50285$$

Number whose logarithm is $\bar{1}.50285 = .31831$. Ans.

INVOLUTION BY LOGARITHMS

If X represents a number whose logarithm is x, we have, from the definition of a logarithm,

$$10^x = X$$

Raising both numbers to some power, as the nth, the equation becomes $$10^{xn} = X^n$$

But X^n is the required power of X, and xn is its logarithm, from which it follows that the logarithm of a number multiplied by the exponent of the power to which it is raised is equal to the logarithm of the power. Hence, to raise a number to any power by the use of logarithms:

Rule.—*Multiply the logarithm of the number by the exponent that denotes the power to which the number is to be raised, and the result will be the logarithm of the required power.*

Example.—What is: (*a*) the square of 7.92? (*b*) the cube of 94.7? (*c*) the 1.6 power of 512, that is, the value of $512^{1.6}$?

Solution.—(*a*) Log $7.92 = .89873$; exponent of power $= 2$. Hence, $.89873 \times 2 = 1.79746 = \log 7.92^2$. Number corresponding to $1.79746 = 62.727$. Hence, $7.92^2 = 62.727$, nearly. Ans.

(*b*) Log $94.7 = 1.97635$; $1.97635 \times 3 = 5.92905 = \log 94.7^3$. Number corresponding to $5.92905 = 849{,}280$, nearly. Hence, $94.7^3 = 849{,}280$, nearly. Ans.

(*c*) Log $512^{1.6} = 1.6 \times \log 512 = 1.6 \times 2.70927 = 4.334832$ or 4.33483 (when using five-place logarithms) $= \log 21{,}619$. Hence, $512^{1.6} = 21{,}619$, nearly. Ans.

If the number is wholly decimal, so that the characteristic is negative, *multiply the two parts of the logarithm separately by the exponent of the number. If, after multiplying the mantissa, the product has a characteristic, add it, algebraically, to the negative characteristic multiplied by the exponent, and the result will be the negative characteristic of the required power.*

Example.—Raise .0751 to the fourth power.

Solution.—Log $.0751^4 = 4 \times \log .0751 = 4 \times \bar{2}.87564$. Multiplying the parts separately, $4 \times \bar{2} = \bar{8}$ and $4 \times .87564 = 3.50256$. Adding the 3 and $\bar{8}$, $3 + (-8) = -5$; therefore, log $.0751^4 = \bar{5}.50256$. Number corresponding to this = .00003181. Hence, $.0751^4 = .00003181$. Ans.

A decimal may be raised to a power whose exponent contains a decimal as follows:

Example.—Raise .8 to the 1.21 power.

Solution.—Log $.8^{1.21} = 1.21 \times \bar{1}.90309$. There are several ways of performing the multiplication.

First Method.—Adding the characteristic and mantissa algebraically, the result is $-.09691$. Multiplying this by 1.21 gives $-.1172611$, or $-.11726$, when using five-place logarithms. To obtain a positive mantissa, add $+1$ and -1; whence, log $.8^{1.21} = -1 + 1 - .11726 = \bar{1}.88274$. Ans.

Second Method.—Multiplying the characteristic and mantissa separately gives $-1.21 + 1.09274$. Adding characteristic and mantissa algebraically, gives $-.11726$; then, adding $+1$ and -1. log $.8^{1.21} = \bar{1}.88274$. Ans.

Third Method.—Multiplying the characteristic and mantissa separately gives $-1.21 + 1.09274$. Adding the decimal part of the characteristic to the mantissa gives $-1 + (-.21 + 1.09274) = \bar{1}.88274 = \log .8^{1.21}$. The number corresponding to the logarithm $\bar{1}.88274 = .76338$. Ans.

Any one of the above three methods may be used, but we recommend the first or the third. The third is the most elegant and saves figures, but requires the exercise of more caution than the first method does. Below will be found the entire work of multiplication for both $.8^{1.21}$ and $.8^{.21}$.

$$
\begin{array}{r}
\bar{1}.90309 \\
1.21 \\
\hline
90309 \\
180618 \\
90309 \\
\hline
1.0927389 \\
-1.21 \\
\hline
\bar{1}.8827389, \text{ or } \bar{1}.88274
\end{array}
\qquad\qquad
\begin{array}{r}
\bar{1}.90309 \\
.21 \\
\hline
90309 \\
180618 \\
\hline
+1.189649 \\
-1-.21 \\
\hline
\bar{1}.9796489, \text{ or } \bar{1}.97965
\end{array}
$$

In the second case, the negative decimal obtained by multiplying -1 and .21 was greater than the positive decimal obtained by multiplying .90309 and .21; hence, $+1$ and -1 were added, as shown.

EVOLUTION BY LOGARITHMS

If X represents a number whose logarithm is x, we have, from the definition of a logarithm,

$$10^x = X$$

Extracting some root of both members, as the nth, the equation becomes

$$10^{\frac{x}{n}} = \sqrt[n]{X}$$

But $\sqrt[n]{X}$ is the required root of X, and $\frac{x}{n}$ is its logarithm, from which it follows that the logarithm of a number divided by the index of the root to be extracted is equal to the logarithm of the root. Hence, to extract any root of a number by means of logarithms:

Rule.—*Divide the logarithm of the number by the index of the root; the result will be the logarithm of the root.*

Example.—Extract (*a*) the square root of 77,851; (*b*) the cube root of 698,970; (*c*) the 2.4 root of 8 964,300.

Solution.—(*a*) Log 77,851 = 4.89127; the index of the root is 2; hence, log $\sqrt{77{,}851} = 4.89127 \div 2 = 2.44564$; number corresponding to this = 279.02. Hence, $\sqrt{77{,}851} = 279.02$, nearly. Ans.

(*b*) Log $\sqrt[3]{698{,}970} = 5.84446 \div 3 = 1.94815 = \log 88.746$; or $\sqrt[3]{698{,}970} = 88.747$, nearly. Ans.

(*c*) Log $\sqrt[2.4]{8{,}964{,}300} = 6.95251 \div 2.4 = 2.89688 = \log 788.64$; or, $\sqrt[2.4]{8{,}964{,}300} = 788.64$, nearly. Ans.

If it is required to extract a root of any number wholly decimal, and the negative characteristic will not exactly contain the index of the root, without a remainder, proceed as follows:

Separate the two parts of the logarithm; add as many units (or parts of a unit) to the negative characteristic as will make *it exactly contain the index of the root. Add the same number to the mantissa, and divide both parts by the index. The result will be the characteristic and mantissa of the root.*

Example.—Extract the cube root of .0003181.

Solution.—$\text{Log}\sqrt[3]{.0003181} = \frac{\log .0003181}{3} = \frac{\bar{4}.50256}{3}$

$$(\bar{4}+\bar{2}=\bar{6})+(2+.50256=2.50256)$$

$$(\bar{6}\div 3=\bar{2})+(2.50256\div 3=.83419)$$

or, $\log\sqrt[3]{.0003181}=\bar{2}.83419=\log .068263$

Hence, $\sqrt[3]{.0003181}=.068263$. Ans.

Example.—Find the value of $\sqrt[1.41]{.0003181}$.

Solution.—$\text{Log}\sqrt[1.41]{.0003181} = \frac{\log .0003181}{1.41} = \frac{\bar{4}.50256}{1.41}$.

If $-.23$ be added to the characteristic, it will contain 1.41 exactly 3 times. Hence,

$$[-4+(-.23)= -4.23]+(.23+.50256=.73256)$$

$$(-4.23\div 1.41=\bar{3})+(.73256\div 1.41=.51955)$$

or, $\log\sqrt[1.41]{.0003181}=\bar{3}.51955=\log .0033079$

Hence, $\sqrt[1.41]{.0003181}=.0033079$. Ans.

Example.—Solve this expression by logarithms:

$$\frac{497\times .0181\times 762}{3{,}300\times .6517} = ?$$

Solution.—
Log 497	$=2.69636$
Log .0181	$=\bar{2}.25768$
Log 762	$=2.88195$
Log product	$=3.83599$
Log 3,300	$=3.51851$
Log .6517	$=\bar{1}.81405$
Log product	$=3.33256$

$$3.83599-3.33256=.50343=\log 3.1874$$

Hence, $\frac{497\times .0181\times 762}{3{,}300\times .6517} = 3.1874$. Ans.

Example.—Solve $\sqrt[3]{\frac{504{,}203\times 507}{1.75\times 71.4\times 87}}$ by logarithms.

Solution.— Log 504,203 = 5.70260
Log 507 = 2.70501

Log product = 8.40761
Log 1.75 = .24304
Log 71.4 = 1.85370
Log 87 = 1.93952

Log product = 4.03626

$$\frac{8.40761 - 4.03626}{3} = 1.45712 = \log 28.65$$

Hence, $\sqrt[3]{\dfrac{504.203 \times 507}{1.75 \times 71.4 \times 87}} = 28.65$. Ans.

Logarithms can often be applied to the solution of equations.

Example.—Solve the equation $2.43x^5 = \sqrt[6]{.0648}$.

Solution.— $2.43x^5 = \sqrt[6]{.0648}$

Dividing by 2.43, $x^5 = \dfrac{\sqrt[6]{.0648}}{2.43}$

Taking the logarithms of both numbers,

$$5 \times \log x = \frac{\log .0648}{6} - \log 2.43$$

or

$$5 \log x = \frac{\bar{2}.81158}{6} - .38561$$
$$= \bar{1}.80193 - .38561$$
$$= \bar{1}.41632$$

Dividing by 5, $\log x = \bar{1}.88326$;

whence, $x = .7643$

Example.—Solve the equation $4.5^x = 8$.

Solution.—Taking the logarithms of both numbers,

$$x \log 4.5 = \log 8,$$

whence, $x = \dfrac{\log 8}{\log 4.5} = \dfrac{.90309}{.65321}$

Taking logarithms again,

$$\log x = \log .90309 - \log .65321 = \bar{1}.95573 - \bar{1}.81505$$
$$= .14068; \text{ whence, } x = 1.3825$$

Remarks.—Logarithms are particularly useful in those cases when the unknown quantity is an exponent, as in the last example, or when the exponent contains a decimal, as in several instances in the examples given on pages 40–44.

Such examples can be solved without the use of logarithms, but the process is very long and somewhat involved, and the arithmetical work required is enormous. To solve the example last given without using the logarithmic table and obtain the value of x correct to five figures would require, perhaps, 100 times as many figures as were used in the solution given, and the resulting liability to error would be correspondingly increased; indeed, to confine the work to this number of figures would also require a good knowledge of short-cut methods in multiplication and division, and judgment and skill on the part of the calculator that can only be acquired by practice and experience.

Formulas containing quantities affected with decimal exponents are generally of an empirical nature; that is, the constants or exponents or both are given such values as will make the results obtained by the formulas agree with those obtained by experiment. Such formulas occur frequently in works treating on thermodynamics, strength of materials, machine design, etc.

COMMON LOGARITHMS.

N.	L. 0	1	2	3	4	5	6	7	8	9
100	00 000	043	087	130	173	217	260	303	346	389
101	432	475	518	561	604	647	689	732	775	817
102	860	903	945	988	*030	*072	*115	*157	*199	*242
103	01 284	326	368	410	452	494	536	578	620	662
104	703	745	787	828	870	912	953	995	*036	*078
105	02 119	160	202	243	284	325	366	407	449	490
106	531	572	612	653	694	735	776	816	857	898
107	938	979	*019	*060	*100	*141	*181	*222	*262	*302
108	03 342	383	423	463	503	543	583	623	663	703
109	743	782	822	862	902	941	981	*021	*060	*100
110	04 139	179	218	258	297	336	376	415	454	493
111	532	571	610	650	689	727	766	805	844	883
112	922	961	999	*038	*077	*115	*154	*192	*231	*269
113	05 308	346	385	423	461	500	538	576	614	652
114	690	729	767	805	843	881	918	956	994	*032
115	06 070	108	145	183	221	258	296	333	371	408
116	446	483	521	558	595	633	670	707	744	781
117	819	856	893	930	967	*004	*041	*078	*115	*151
118	07 188	225	262	298	335	372	408	445	482	518
119	555	591	628	664	700	737	773	809	846	882
120	918	954	990	*027	*063	*099	*135	*171	*207	*243
121	08 279	314	350	386	422	458	493	529	565	600
122	636	672	707	743	778	814	849	884	920	955
123	991	*026	*061	*096	*132	*167	*202	*237	*272	*307
124	09 342	377	412	447	482	517	552	587	621	656
125	691	726	760	795	830	864	899	934	968	*003
126	10 037	072	106	140	175	209	243	278	312	346
127	380	415	449	483	517	551	585	619	653	687
128	721	755	789	823	857	890	924	958	992	*025
129	11 059	093	126	160	193	227	261	294	327	361
130	394	428	461	494	528	561	594	628	661	694
131	727	760	793	826	860	893	926	959	992	*024
132	12 057	090	123	156	189	222	254	287	320	352
133	385	418	450	483	516	548	581	613	646	678
134	710	743	775	808	840	872	905	937	969	*001
135	13 033	066	098	130	162	194	226	258	290	322
136	354	386	418	450	481	513	545	577	609	640
137	672	704	735	767	799	830	862	893	925	956
138	988	*019	*051	*082	*114	*145	*176	*208	*239	*270
139	14 301	333	364	395	426	457	489	520	551	582
140	613	644	675	706	737	768	799	829	860	891
141	922	953	983	*014	*045	*076	*106	*137	*168	*198
142	15 229	259	290	320	351	381	412	442	473	503
143	534	564	594	625	655	685	715	746	776	806
144	836	866	897	927	957	987	*017	*047	*077	*107
145	16 137	167	197	227	256	286	316	346	376	406
146	435	465	495	524	554	584	613	643	673	702
147	732	761	791	820	850	879	909	938	967	997
148	17 026	056	085	114	143	173	202	231	260	289
149	319	348	377	406	435	464	493	522	551	580
150	609	638	667	696	725	754	782	811	840	869
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.			
	44	**43**	**42**
1	4.4	4.3	4.2
2	8.8	8.6	8.4
3	13.2	12.9	12.6
4	17.6	17.2	16.8
5	22.0	21.5	21.0
6	26.4	25.8	25.2
7	30.8	30.1	29.4
8	35.2	34.4	33.6
9	39.6	38.7	37.8
	41	**40**	**39**
1	4.1	4.0	3.9
2	8.2	8.0	7.8
3	12.3	12.0	11.7
4	16.4	16.0	15.6
5	20.5	20.0	19.5
6	24.6	24.0	23.4
7	28.7	28.0	27.3
8	32.8	32.0	31.2
9	36.9	36.0	35.1
	38	**37**	**36**
1	3.8	3.7	3.6
2	7.6	7.4	7.2
3	11.4	11.1	10.8
4	15.2	14.8	14.4
5	19.0	18.5	18.0
6	22.8	22.2	21.6
7	26.6	25.9	25.2
8	30.4	29.6	28.8
9	34.2	33.3	32.4
	35	**34**	**33**
1	3.5	3.4	3.3
2	7.0	6.8	6.6
3	10.5	10.2	9.9
4	14.0	13.6	13.2
5	17.5	17.0	16.5
6	21.0	20.4	19.8
7	24.5	23.8	23.1
8	28.0	27.2	26.4
9	31.5	30.6	29.7
	32	**31**	**30**
1	3.2	3.1	3.0
2	6.4	6.2	6.0
3	9.6	9.3	9.0
4	12.8	12.4	12.0
5	16.0	15.5	15.0
6	19.2	18.6	18.0
7	22.4	21.7	21.0
8	25.6	24.8	24.0
9	28.8	27.9	27.0
P. P.			

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
150	17 609	638	667	696	725	754	782	811	840	869
151	898	926	955	984	*013	*041	*070	*099	*127	*156
152	18 184	213	241	270	298	327	355	384	412	441
153	469	498	526	554	583	611	639	667	696	724
154	752	780	808	837	865	893	921	949	977	*005
155	19 033	061	089	117	145	173	201	229	257	285
156	312	340	368	396	424	451	479	507	535	562
157	590	618	645	673	700	728	756	783	811	838
158	866	893	921	948	976	*003	*030	*058	*085	*112
159	20 140	167	194	222	249	276	303	330	358	385
160	412	439	466	493	520	548	575	602	629	656
161	683	710	737	763	790	817	844	871	898	925
162	952	978	*005	*032	*059	*085	*112	*139	*165	*192
163	21 219	245	272	299	325	352	378	405	431	458
164	484	511	537	564	590	617	643	669	696	722
165	748	775	801	827	854	880	906	932	958	985
166	22 011	037	063	089	115	141	167	194	220	246
167	272	298	324	350	376	401	427	453	479	505
168	531	557	583	608	634	660	686	712	737	763
169	789	814	840	866	891	917	943	968	994	*019
170	23 045	070	096	121	147	172	198	223	249	274
171	300	325	350	376	401	426	452	477	502	528
172	553	578	603	629	654	679	704	729	754	779
173	805	830	855	880	905	930	955	980	*005	*030
174	24 055	080	105	130	155	180	204	229	254	279
175	304	329	353	378	403	428	452	477	502	527
176	551	576	601	625	650	674	699	724	748	773
177	797	822	846	871	895	920	944	969	993	*018
178	25 042	066	091	115	139	164	188	212	237	261
179	285	310	334	358	382	406	431	455	479	503
180	527	551	575	600	624	648	672	696	720	744
181	768	792	816	840	864	888	912	935	959	983
182	26 007	031	055	079	102	126	150	174	198	221
183	245	269	293	316	340	364	387	411	435	458
184	482	505	529	553	576	600	623	647	670	694
185	717	741	764	788	811	834	858	881	905	928
186	951	975	998	*021	*045	*068	*091	*114	*138	*161
187	27 184	207	231	254	277	300	323	346	370	393
188	416	439	462	485	508	531	554	577	600	623
189	646	669	692	715	738	761	784	807	830	852
190	875	898	921	944	967	989	*012	*035	*058	*081
191	28 103	126	149	171	194	217	240	262	285	307
192	330	353	375	398	421	443	466	488	511	533
193	556	578	601	623	646	668	691	713	735	758
194	780	803	825	847	870	892	914	937	959	981
195	29 003	026	048	070	092	115	137	159	181	203
196	226	248	270	292	314	336	358	380	403	425
197	447	469	491	513	535	557	579	601	623	645
198	667	688	710	732	754	776	798	820	842	863
199	885	907	929	951	973	994	*016	*038	*060	*081
200	30 103	125	146	168	190	211	233	255	276	298
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	29	28
1	2.9	2.8
2	5.8	5.6
3	8.7	8.4
4	11.6	11.2
5	14.5	14.0
6	17.4	16.8
7	20.3	19.6
8	23.2	22.4
9	26.1	25.2

	27	26
1	2.7	2.6
2	5.4	5.2
3	8.1	7.8
4	10.8	10.4
5	13.5	13.0
6	16.2	15.6
7	18.9	18.2
8	21.6	20.8
9	24.3	23.4

	25
1	2.5
2	5.0
4	7.5
4	10.0
5	12.5
6	15.0
7	17.5
8	20.0
9	22.5

	24	23
1	2.4	2.3
2	4.8	4.6
3	7.2	6.9
4	9.6	9.2
5	12.0	11.5
6	14.4	13.8
7	16.8	16.1
8	19.2	18.4
9	21.6	20.7

	22	21
1	2.2	2.1
2	4.4	4.2
3	6.6	6.3
4	8.8	8.4
5	11.0	10.5
6	13.2	12.6
7	15.4	14.7
8	17.6	16.8
9	19.8	18.9

P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
200	30 103	125	146	168	190	211	233	255	276	298
201	320	341	363	384	406	428	449	471	492	514
202	535	557	578	600	621	643	664	685	707	728
203	750	771	792	814	835	856	878	899	920	942
204	963	984	*006	*027	*048	*069	*091	*112	*133	*154
205	31 175	197	218	239	260	281	302	323	345	366
206	387	408	429	450	471	492	513	534	555	576
207	597	618	639	660	681	702	723	744	765	785
208	806	827	848	869	890	911	931	952	973	994
209	32 015	035	056	077	098	118	139	160	181	201
210	222	243	263	284	305	325	346	366	387	408
211	428	449	469	490	510	531	552	572	593	613
212	634	654	675	695	715	736	756	777	797	818
213	838	858	879	899	919	940	960	980	*001	*021
214	33 041	062	082	102	122	143	163	183	203	224
215	244	264	284	304	325	345	365	385	405	425
216	445	465	486	506	526	546	566	586	606	626
217	646	666	686	706	726	746	766	786	806	826
218	846	866	885	905	925	945	965	985	*005	*025
219	34 044	064	084	104	124	143	163	183	203	223
220	242	262	282	301	321	341	361	380	400	420
221	439	459	479	498	518	537	557	577	596	616
222	635	655	674	694	713	733	753	772	792	811
223	830	850	869	889	908	928	947	967	986	*005
224	35 025	044	064	083	102	122	141	160	180	199
225	218	238	257	276	295	315	334	353	372	392
226	411	430	449	468	488	507	526	545	564	583
227	603	622	641	660	679	698	717	736	755	774
228	793	813	832	851	870	889	908	927	946	965
229	984	*003	*021	*040	*059	*078	*097	*116	*135	*154
230	36 173	192	211	229	248	267	286	305	324	342
231	361	380	399	418	436	455	474	493	511	530
232	549	568	586	605	624	642	661	680	698	717
233	736	754	773	791	810	829	847	866	884	903
234	922	940	959	977	996	*014	*033	*051	*070	*088
235	37 107	125	144	162	181	199	218	236	254	273
236	291	310	328	346	365	383	401	420	438	457
237	475	493	511	530	548	566	585	603	621	639
238	658	676	694	712	731	749	767	785	803	822
239	840	858	876	894	912	931	949	967	985	*003
240	38 021	039	057	075	093	112	130	148	166	184
241	202	220	238	256	274	292	310	328	346	364
242	382	399	417	435	453	471	489	507	525	543
243	561	578	596	614	632	650	668	686	703	721
244	739	757	775	792	810	828	846	863	881	899
245	917	934	952	970	987	*005	*023	*041	*058	*076
246	39 094	111	129	146	164	182	199	217	235	252
247	270	287	305	322	340	358	375	393	410	428
248	445	463	480	498	515	533	550	568	585	602
249	620	637	655	672	690	707	724	742	759	777
250	794	811	829	846	863	881	898	915	933	950
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	22	21
1	2.2	2.1
2	4.4	4.2
3	6.6	6.3
4	8.8	8.4
5	11.0	10.5
6	13.2	12.6
7	15.4	14.7
8	17.6	16.8
9	19.8	18.9

	20
1	2.0
2	4.0
3	6.0
4	8.0
5	10.0
6	12.0
7	14.0
8	16.0
9	18.0

	19
1	1.9
2	3.8
3	5.7
4	7.6
5	9.5
6	11.4
7	13.3
8	15.2
9	17.1

	18
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2

	17
1	1.7
2	3.4
3	5.1
4	6.8
5	8.5
6	10.2
7	11.9
8	13.6
9	15.3

P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
250	39 794	811	829	846	863	881	898	915	933	950
251	967	985	*002	*019	*037	*054	*071	*088	*106	*123
252	40 140	157	175	192	209	226	243	261	278	295
253	312	329	346	364	381	398	415	432	449	466
254	483	500	518	535	552	569	586	603	620	637
255	654	671	688	705	722	739	756	773	790	807
256	824	841	858	875	892	909	926	943	960	976
257	993	*010	*027	*044	*061	*078	*095	*111	*128	*145
258	41 162	179	196	212	229	246	263	280	296	313
259	330	347	363	380	397	414	430	447	464	481
260	497	514	531	547	564	581	597	614	631	647
261	664	681	697	714	731	747	764	780	797	814
262	830	847	863	880	896	913	929	946	963	979
263	996	*012	*029	*045	*062	*078	*095	*111	*127	*144
264	42 160	177	193	210	226	243	259	275	292	308
265	325	341	357	374	390	406	423	439	455	472
266	488	504	521	537	553	570	586	602	619	635
267	651	667	684	700	716	732	749	765	781	797
268	813	830	846	862	878	894	911	927	943	959
269	975	991	*008	*024	*040	*056	*072	*088	*104	*120
270	43 136	152	169	185	201	217	233	249	265	281
271	297	313	329	345	361	377	393	409	425	441
272	457	473	489	505	521	537	553	569	584	600
273	616	632	648	664	680	696	712	727	743	759
274	775	791	807	823	838	854	870	886	902	917
275	933	949	965	981	996	*012	*028	*044	*059	*075
276	44 091	107	122	138	154	170	185	201	217	232
277	248	264	279	295	311	326	342	358	373	389
278	404	420	436	451	467	483	498	514	529	545
279	560	576	592	607	623	638	654	669	685	700
280	716	731	747	762	778	793	809	824	840	855
281	871	886	902	917	932	948	963	979	994	*010
282	45 025	040	056	071	086	102	117	133	148	163
283	179	194	209	225	240	255	271	286	301	317
284	332	347	362	378	393	408	423	439	454	469
285	484	500	515	530	545	561	576	591	606	621
286	637	652	667	682	697	712	728	743	758	773
287	788	803	818	834	849	864	879	894	909	924
288	939	954	969	984	*000	*015	*030	*045	*060	*075
289	46 090	105	120	135	150	165	180	195	210	225
290	240	255	270	285	300	315	330	345	359	374
291	389	404	419	434	449	464	479	494	509	523
292	538	553	568	583	598	613	627	642	657	672
293	687	702	716	731	746	761	776	790	805	820
294	835	850	864	879	894	909	923	938	953	967
295	982	997	*012	*026	*041	*056	*070	*085	*100	*114
296	47 129	144	159	173	188	202	217	232	246	261
297	276	290	305	319	334	349	363	378	392	407
298	422	436	451	465	480	494	509	524	538	553
299	567	582	596	611	625	640	654	669	683	698
300	712	727	741	756	770	784	799	813	828	842
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	18	17	16	15	14
1	1.8	1.7	1.6	1.5	1.4
2	3.6	3.4	3.2	3.0	2.8
3	5.4	5.1	4.8	4.5	4.2
4	7.2	6.8	6.4	6.0	5.6
5	9.0	8.5	8.0	7.5	7.0
6	10.8	10.2	9.6	9.0	8.4
7	12.6	11.9	11.2	10.5	9.8
8	14.4	13.6	12.8	12.0	11.2
9	16.2	15.3	14.4	13.5	12.6

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
300	47 712	727	741	756	770	784	799	813	828	842
301	857	871	885	900	914	929	943	958	972	986
302	48 001	015	029	044	058	073	087	101	116	130
303	144	159	173	187	202	216	230	244	259	273
304	287	302	316	330	344	359	373	387	401	416
305	430	444	458	473	487	501	515	530	544	558
306	572	586	601	615	629	643	657	671	686	700
307	714	728	742	756	770	785	799	813	827	841
308	855	869	883	897	911	926	940	954	968	982
309	996	*010	*024	*038	*052	*066	*080	*094	*108	*122
310	49 136	150	164	178	192	206	220	234	248	262
311	276	290	304	318	332	346	360	374	388	402
312	415	429	443	457	471	485	499	513	527	541
313	554	568	582	596	610	624	638	651	665	679
314	693	707	721	734	748	762	776	790	803	817
315	831	845	859	872	886	900	914	927	941	955
316	969	982	996	*010	*024	*037	*051	*065	*079	*092
317	50 106	120	133	147	161	174	188	202	215	229
318	243	256	270	284	297	311	325	338	352	365
319	379	393	406	420	433	447	461	474	488	501
320	515	529	542	556	569	583	596	610	623	637
321	651	664	678	691	705	718	732	745	759	772
322	786	799	813	826	840	853	866	880	893	907
323	920	934	947	961	974	987	*001	*014	*028	*041
324	51 055	068	081	095	108	121	135	148	162	175
325	188	202	215	228	242	255	268	282	295	308
326	322	335	348	362	375	388	402	415	428	441
327	455	468	481	495	508	521	534	548	561	574
328	587	601	614	627	640	654	667	680	693	706
329	720	733	746	759	772	786	799	812	825	838
330	851	865	878	891	904	917	930	943	957	970
331	983	996	*009	*022	*035	*048	*061	*075	*088	*101
332	52 114	127	140	153	166	179	192	205	218	231
333	244	257	270	284	297	310	323	336	349	362
334	375	388	401	414	427	440	453	466	479	492
335	504	517	530	543	556	569	582	595	608	621
336	634	647	660	673	686	699	711	724	737	750
337	763	776	789	802	815	827	840	853	866	879
338	892	905	917	930	943	956	969	982	994	*007
339	53 020	033	046	058	071	084	097	110	122	135
340	148	161	173	186	199	212	224	237	250	263
341	275	288	301	314	326	339	352	364	377	390
342	403	415	428	441	453	466	479	491	504	517
343	529	542	555	567	580	593	605	618	631	643
344	656	668	681	694	706	719	732	744	757	769
345	782	794	807	820	832	845	857	870	882	895
346	908	920	933	945	958	970	983	995	*008	*020
347	54 033	045	058	070	083	095	108	120	133	145
348	158	170	183	195	208	220	233	245	258	270
349	283	295	307	320	332	345	357	370	382	394
350	407	419	432	444	456	469	481	494	506	518
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	15
1	1.5
2	3.0
3	4.5
4	6.0
5	7.5
6	9.0
7	10.5
8	12.0
9	13.5

	14
1	1.4
2	2.8
3	4.2
4	5.6
5	7.0
6	8.4
7	9.8
8	11.2
9	12.6

	13
1	1.3
2	2.6
3	3.9
4	5.2
5	6.5
6	7.8
7	9.1
8	10.4
9	11.7

	12
1	1.2
2	2.4
3	3.6
4	4.8
5	6.0
6	7.2
7	8.4
8	9.6
9	10.8

P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
350	54 407	419	432	444	456	469	481	494	506	518
351	531	543	555	568	580	593	605	617	630	642
352	654	667	679	691	704	716	728	741	753	765
353	777	790	802	814	827	839	851	864	876	888
354	900	913	925	937	949	962	974	986	998	*011
355	55 023	035	047	060	072	084	096	108	121	133
356	145	157	169	182	194	206	218	230	242	255
357	267	279	291	303	315	328	340	352	364	376
358	388	400	413	425	437	449	461	473	485	497
359	509	522	534	546	558	570	582	594	606	618
360	630	642	654	666	678	691	703	715	727	739
361	751	763	775	787	799	811	823	835	847	859
362	871	883	895	907	919	931	943	955	967	979
363	991	*003	*015	*027	*038	*050	*062	*074	*086	*098
364	56 110	122	134	146	158	170	182	194	205	217
365	229	241	253	265	277	289	301	312	324	336
366	348	360	372	384	396	407	419	431	443	455
367	467	478	490	502	514	526	538	549	561	573
368	585	597	608	620	632	644	656	667	679	691
369	703	714	726	738	750	761	773	785	797	808
370	820	832	844	855	867	879	891	902	914	926
371	937	949	961	972	984	996	*008	*019	*031	*043
372	57 054	066	078	089	101	113	124	136	148	159
373	171	183	194	206	217	229	241	252	264	276
374	287	299	310	322	334	345	357	368	380	392
375	403	415	426	438	449	461	473	484	496	507
376	519	530	542	553	565	576	588	600	611	623
377	634	646	657	669	680	692	703	715	726	738
378	749	761	772	784	795	807	818	830	841	852
379	864	875	887	898	910	921	933	944	955	967
380	978	990	*001	*013	*024	*035	*047	*058	*070	*081
381	58 092	104	115	127	138	149	161	172	184	195
382	206	218	229	240	252	263	274	286	297	309
383	320	331	343	354	365	377	388	399	410	422
384	433	444	456	467	478	490	501	512	524	535
385	546	557	569	580	591	602	614	625	636	647
386	659	670	681	692	704	715	726	737	749	760
387	771	782	794	805	816	827	838	850	861	872
388	883	894	906	917	928	939	950	961	973	984
389	995	*006	*017	*028	*040	*051	*062	*073	*084	*095
390	59 106	118	129	140	151	162	173	184	195	207
391	218	229	240	251	262	273	284	295	306	318
392	329	340	351	362	373	384	395	406	417	428
393	439	450	461	472	483	494	506	517	528	539
394	550	561	572	583	594	605	616	627	638	649
395	660	671	682	693	704	715	726	737	748	759
396	770	780	791	802	813	824	835	846	857	868
397	879	890	901	912	923	934	945	956	966	977
398	988	999	*010	*021	*032	*043	*054	*065	*076	*086
399	60 097	108	119	130	141	152	163	173	184	195
400	206	217	228	239	249	260	271	282	293	304
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	13
1	1.3
2	2.6
3	3.9
4	5.2
5	6.5
6	7.8
7	9.1
8	10.4
9	11.7

	12
1	1.2
2	2.4
3	3.6
4	4.8
5	6.0
6	7.2
7	8.4
8	9.6
9	10.8

	11
1	1.1
2	2.2
3	3.3
4	4.4
5	5.5
6	6.6
7	7.7
8	8.8
9	9.9

	10
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0
8	8.0
9	9.0

P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
400	60 206	217	228	239	249	260	271	282	293	304	
401	314	325	336	347	358	369	379	390	401	412	
402	423	433	444	455	466	477	487	498	509	520	
403	531	541	552	563	574	584	595	606	617	627	
404	638	649	660	670	681	692	703	713	724	735	
405	746	756	767	778	788	799	810	821	831	842	
406	853	863	874	885	895	906	917	927	938	949	**11**
407	959	970	981	991	*002	*013	*023	*034	*045	*055	1 1.1
408	61 066	077	087	098	109	119	130	140	151	162	2 2.2
409	172	183	194	204	215	225	236	247	257	268	3 3.3
410	278	289	300	310	321	331	342	352	363	374	4 4.4
411	384	395	405	416	426	437	448	458	469	479	5 5.5
412	490	500	511	521	532	542	553	563	574	584	6 6.6
413	595	606	616	627	637	648	658	669	679	690	7 7.7
414	700	711	721	731	742	752	763	773	784	794	8 8.8
415	805	815	826	836	847	857	868	878	888	899	9 9.9
416	909	920	930	941	951	962	972	982	993	*003	
417	62 014	024	034	045	055	066	076	086	097	107	
418	118	128	138	149	159	170	180	190	201	211	
419	221	232	242	252	263	273	284	294	304	315	
420	325	335	346	356	366	377	387	397	408	418	
421	428	439	449	459	469	480	490	500	511	521	**10**
422	531	542	552	562	572	583	593	603	613	624	1 1.0
423	634	644	655	665	675	685	696	706	716	726	2 2.0
424	737	747	757	767	778	788	798	808	818	829	3 3.0
425	839	849	859	870	880	890	900	910	921	931	4 4.0
426	941	951	961	972	982	992	*002	*012	*022	*033	5 5.0
427	63 043	053	063	073	083	094	104	114	124	134	6 6.0
428	144	155	165	175	185	195	205	215	225	236	7 7.0
429	246	256	266	276	286	296	306	317	327	337	8 8.0
430	347	357	367	377	387	397	407	417	428	438	9 9.0
431	448	458	468	478	488	498	508	518	528	538	
432	548	458	568	579	589	599	609	619	629	639	
433	649	659	669	679	689	699	709	719	729	739	
434	749	759	769	779	789	799	809	819	829	839	
435	849	859	869	879	889	899	909	919	929	939	
436	949	959	969	979	988	998	*008	*018	*028	*038	**9**
437	64 048	058	068	078	088	098	108	118	128	137	1 0.9
438	147	157	167	177	187	197	207	217	227	237	2 1.8
439	246	256	266	276	286	296	306	316	326	335	3 2.7
440	345	355	365	375	385	395	404	414	424	434	4 3.6
441	444	454	464	473	483	493	503	513	523	532	5 4.5
442	542	552	562	572	582	591	601	611	621	631	6 5.4
443	640	650	660	670	680	689	699	709	719	729	7 6.3
444	738	748	758	768	777	787	797	807	816	826	8 7.2
445	836	846	856	865	875	885	895	904	914	924	9 8.1
446	933	943	953	963	972	982	992	*002	*011	*021	
447	65 031	040	050	060	070	079	089	099	108	118	
448	128	137	147	157	167	176	186	196	205	215	
449	225	234	244	254	263	273	283	292	302	312	
450	321	331	341	350	360	369	379	389	398	408	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9
450	65 321	331	341	350	360	369	379	389	398	408
451	418	427	437	447	456	466	475	485	495	504
452	514	523	533	543	552	562	571	581	591	600
453	610	619	629	639	648	658	667	677	686	696
454	706	715	725	734	744	753	763	772	782	792
455	801	811	820	830	839	849	858	868	877	887
456	896	906	916	925	935	944	954	963	973	982
457	992	*001	*011	*020	*030	*039	*049	*058	*068	*077
458	66 087	096	106	115	124	134	143	153	162	172
459	181	191	200	210	219	229	238	247	257	266
460	276	285	295	304	314	323	332	342	351	361
461	370	380	389	398	408	417	427	436	445	455
462	464	474	483	492	502	511	521	530	539	549
463	558	567	577	586	596	605	614	624	633	642
464	652	661	671	680	689	699	708	717	727	736
465	745	755	764	773	783	792	801	811	820	829
466	839	848	857	867	876	885	894	904	913	922
467	932	941	950	960	969	978	987	997	*006	*015
468	67 025	034	043	052	062	071	080	089	099	108
469	117	127	136	145	154	164	173	182	191	201
470	210	219	228	237	247	256	265	274	284	293
471	302	311	321	330	339	348	357	367	376	385
472	394	403	413	422	431	440	449	459	468	477
473	486	495	504	514	523	532	541	550	560	569
474	578	587	596	605	614	624	633	642	651	660
475	669	679	688	697	706	715	724	733	742	752
476	761	770	779	788	797	806	815	825	834	843
477	852	861	870	879	888	897	906	916	925	934
478	943	952	961	970	979	988	997	*006	*015	*024
479	68 034	043	052	061	070	079	088	097	106	115
480	124	133	142	151	160	169	178	187	196	205
481	215	224	233	242	251	260	269	278	287	296
482	305	314	323	332	341	350	359	368	377	386
483	395	404	413	422	431	440	449	458	467	476
484	485	494	502	511	520	529	538	547	556	565
485	574	583	592	601	610	619	628	637	646	655
486	664	673	681	690	699	708	717	726	735	744
487	753	762	771	780	789	797	806	815	824	833
488	842	851	860	869	878	886	895	904	913	922
489	931	940	949	958	966	975	984	993	*002	*011
490	69 020	028	037	046	055	064	073	082	090	099
491	108	117	126	135	144	152	161	170	179	188
492	197	205	214	223	232	241	249	258	267	276
493	285	294	302	311	320	329	338	346	355	364
494	373	381	390	399	408	417	425	434	443	452
495	461	469	478	487	496	504	513	522	531	539
496	548	557	566	574	583	592	601	609	618	627
497	636	644	653	662	671	679	688	697	705	714
498	723	732	740	749	758	767	775	784	793	801
499	810	819	827	836	845	854	862	871	880	888
500	897	906	914	923	932	940	949	958	966	975
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	10
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0
8	8.0
9	9.0

	9
1	0.9
2	1.8
3	2.7
4	3.6
5	4.5
6	5.4
7	6.3
8	7.2
9	8.1

	8
1	0.8
2	1.6
3	2.4
4	3.2
5	4.0
6	4.8
7	5.6
8	6.4
9	7.2

P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
500	69 897	906	914	923	932	940	949	958	966	975	
501	984	992	*001	*010	*018	*027	*036	*044	*053	*062	
502	70 070	079	088	096	105	114	122	131	140	148	
503	157	165	174	183	191	200	209	217	226	234	
504	243	252	260	269	278	286	295	303	312	321	
505	329	338	346	355	364	372	381	389	398	406	
506	415	424	432	441	449	458	467	475	484	492	**9**
507	501	509	518	526	535	544	552	561	569	578	1 | 0.9
508	586	595	603	612	621	629	638	646	655	663	2 | 1.8
509	672	680	689	697	706	714	723	731	740	749	3 | 2.7
510	757	766	774	783	791	800	808	817	825	834	4 | 3.6
511	842	851	859	868	876	885	893	902	910	919	5 | 4.5
512	927	935	944	952	961	969	978	986	995	*003	6 | 5.4
513	71 012	020	029	037	046	054	063	071	079	088	7 | 6.3
514	096	105	113	122	130	139	147	155	164	172	8 | 7.2
515	181	189	198	206	214	223	231	240	248	257	9 | 8.1
516	265	273	282	290	299	307	315	324	332	341	
517	349	357	366	374	383	391	399	408	416	425	
518	433	441	450	458	466	475	483	492	500	508	
519	517	525	533	542	550	559	567	575	584	592	
520	600	609	617	625	634	642	650	659	667	675	
521	684	692	700	709	717	725	734	742	750	759	**8**
522	767	775	784	792	800	809	817	825	834	842	1 | 0.8
523	850	858	867	875	883	892	900	908	917	925	2 | 1.6
524	933	941	950	958	966	975	983	991	999	*008	3 | 2.4
525	72 016	024	032	041	049	057	066	074	082	090	4 | 3.2
526	099	107	115	123	132	140	148	156	165	173	5 | 4.0
527	181	189	198	206	214	222	230	239	247	255	6 | 4.8
528	263	272	280	288	296	304	313	321	329	337	7 | 5.6
529	346	354	362	370	378	387	395	403	411	419	8 | 6.4
530	428	436	444	452	460	469	477	485	493	501	9 | 7.2
531	509	518	526	534	542	550	558	567	575	583	
532	591	599	607	616	624	632	640	648	656	665	
533	673	681	689	697	705	713	722	730	738	746	
534	754	762	770	779	787	795	803	811	819	827	
535	835	843	852	860	868	876	884	892	900	908	
536	916	925	933	941	949	957	965	973	981	989	**7**
537	997	*006	*014	*022	*030	*038	*046	*054	*062	*070	1 | 0.7
538	73 078	086	094	102	111	119	127	135	143	151	2 | 1.4
539	159	167	175	183	191	199	207	215	223	231	3 | 2.1
540	239	247	255	263	272	280	288	296	304	312	4 | 2.8
541	320	328	336	344	352	360	368	376	384	392	5 | 3.5
542	400	408	416	424	432	440	448	456	464	472	6 | 4.2
543	480	488	496	504	512	520	528	536	544	552	7 | 4.9
544	560	568	576	584	592	600	608	616	624	632	8 | 5.6
545	640	648	656	664	672	679	687	695	703	711	9 | 6.3
546	719	727	735	743	751	759	767	775	783	791	
547	799	807	815	823	830	838	846	854	862	870	
548	878	886	894	902	910	918	926	933	941	949	
549	957	965	973	981	989	997	*005	*013	*020	*028	
550	74 036	044	052	060	068	076	084	092	099	107	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
550	74 036	044	052	060	068	076	084	092	099	107	
551	115	123	131	139	147	155	162	170	178	186	
552	194	202	210	218	225	233	241	248	257	265	
553	273	280	288	296	304	312	320	327	335	343	
554	351	359	367	374	382	390	398	406	414	421	
555	429	437	445	453	461	468	476	484	492	500	
556	507	515	523	531	539	547	554	562	570	578	
557	586	593	601	609	617	624	632	640	648	656	
558	663	671	679	687	695	702	710	718	726	733	
559	741	749	757	764	772	780	788	796	803	811	
560	819	827	834	842	850	858	865	873	881	889	**8**
561	896	904	912	920	927	935	943	950	958	966	1 | 0.8
562	974	981	989	997	*005	*012	*020	*028	*035	*043	2 | 1.6
563	75 051	059	066	074	082	089	097	105	113	120	3 | 2.4
564	128	136	143	151	159	166	174	182	189	197	4 | 3.2
565	205	213	220	228	236	243	251	259	266	274	5 | 4.0
566	282	289	297	305	312	320	328	335	343	351	6 | 4.8
567	358	366	374	381	289	397	404	412	420	427	7 | 5.6
568	435	442	450	458	465	473	481	488	496	504	8 | 6.4
569	511	519	526	534	542	549	557	565	572	580	9 | 7.2
570	587	595	603	610	618	626	633	641	648	656	
571	664	671	679	686	694	702	709	717	724	732	
572	740	747	755	762	770	778	785	793	800	808	
573	815	823	831	838	846	853	861	868	876	884	
574	891	899	906	914	921	929	937	944	952	959	
575	967	974	982	989	997	*005	*012	*020	*027	*035	
576	76 042	050	057	065	072	080	087	095	103	110	
577	118	125	133	140	148	155	163	170	178	185	
578	193	200	208	215	223	230	238	245	253	260	
579	268	275	283	290	298	305	313	320	328	335	
580	343	350	358	365	373	380	388	395	403	410	**7**
581	418	425	433	440	448	455	462	470	477	485	1 | 0.7
582	492	500	507	515	522	530	537	545	552	559	2 | 1.4
583	567	574	582	589	597	604	612	619	626	634	3 | 2.1
584	641	649	656	664	671	678	686	693	701	708	4 | 2.8
585	716	723	730	738	745	753	760	768	775	782	5 | 3.5
586	790	797	805	812	819	827	834	842	849	856	6 | 4.2
587	864	871	879	886	893	901	908	916	923	930	7 | 4.9
588	938	945	953	960	967	975	982	989	997	*004	8 | 5.6
589	77 012	019	026	034	041	048	056	063	070	078	9 | 6.3
590	085	093	100	107	115	122	129	137	144	151	
591	159	166	173	181	188	195	203	210	217	225	
592	232	240	247	254	262	269	276	283	291	298	
593	305	313	320	327	335	342	349	357	364	371	
594	379	386	393	401	408	415	422	430	437	444	
595	452	459	466	474	481	488	495	503	510	517	
596	525	532	539	546	554	561	568	576	583	590	
597	597	605	612	619	627	634	641	648	656	663	
598	670	677	685	692	699	706	714	721	728	735	
599	743	750	757	764	772	779	786	793	801	808	
600	815	822	830	837	844	851	859	866	873	880	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
600	77 815	822	830	837	844	851	859	866	873	880	
601	887	895	902	909	916	924	931	938	945	952	
602	960	967	974	981	988	996	*003	*010	*017	*025	
603	78 032	039	046	053	061	068	075	082	089	097	
604	104	111	118	125	132	140	147	154	161	168	
605	176	183	190	197	204	211	219	226	233	240	
606	247	254	262	269	276	283	290	297	305	312	**8**
607	319	326	333	340	347	355	362	369	376	383	1 0.8
608	390	398	405	412	419	426	433	440	447	455	2 1.6
609	462	469	476	483	490	497	504	512	519	526	3 2.4
610	533	540	547	554	561	569	576	583	590	597	4 3.2
611	604	611	618	625	633	640	647	654	661	668	5 4.0
612	675	682	689	696	704	711	718	725	732	739	6 4.8
613	746	753	760	767	774	781	789	796	803	810	7 5.6
614	817	824	831	838	845	852	859	866	873	880	8 6.4
615	888	895	902	909	916	923	930	937	944	951	9 7.2
616	958	965	972	979	986	993	*000	*007	*014	*021	
617	79 029	036	043	050	057	064	071	078	085	092	
618	099	106	113	120	127	134	141	148	155	162	
619	169	176	183	190	197	204	211	218	225	232	
620	239	246	253	260	267	274	281	288	295	302	
621	309	316	323	330	337	344	351	358	365	372	**7**
622	379	386	393	400	407	414	421	428	435	442	1 0.7
623	449	456	463	470	477	484	491	498	505	511	2 1.4
624	518	525	632	539	546	553	560	567	574	581	3 2.1
625	588	595	602	609	616	623	630	637	644	650	4 2.8
626	657	664	671	678	685	692	699	706	713	720	5 3.5
627	727	734	741	748	754	761	768	775	782	789	6 4.2
628	796	803	810	817	824	831	837	844	851	858	7 4.9
629	865	872	879	886	893	900	906	913	920	927	8 5.6
630	934	941	948	955	962	969	975	982	989	996	9 6.8
631	80 003	010	017	024	030	037	044	051	058	065	
632	072	079	085	092	099	106	113	120	127	134	
633	140	147	154	161	168	175	182	188	195	202	
634	209	216	223	229	236	243	250	257	264	271	
635	277	284	291	298	305	312	318	325	332	339	
636	346	353	359	366	373	380	387	393	400	407	**6**
637	414	421	428	434	441	448	455	462	468	475	1 0.6
638	482	489	496	502	509	516	523	530	536	543	2 1.2
639	550	557	564	570	577	584	591	598	604	611	3 1.8
640	618	625	632	638	645	652	659	665	672	679	4 2.4
641	686	693	699	706	713	720	726	733	740	747	5 3.0
642	754	760	767	774	781	787	794	801	808	814	6 3.6
643	821	828	835	841	848	855	862	868	875	882	7 4.2
644	889	895	902	909	916	922	929	936	943	949	8 4.8
645	956	963	969	976	983	990	996	*003	*010	*017	9 5.4
646	81 023	030	037	043	050	057	064	070	077	084	
647	090	097	104	111	117	124	131	137	144	151	
648	158	164	171	178	184	191	198	204	211	218	
649	224	231	238	245	251	258	265	271	278	285	
650	291	298	305	311	318	325	331	338	345	351	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
650	81 291	298	305	311	318	325	331	338	345	351	
651	358	365	371	378	385	391	398	405	411	418	
652	425	431	438	445	451	458	465	471	478	485	
653	491	498	505	511	518	525	531	538	544	551	
654	558	564	571	578	584	591	598	604	611	617	
655	624	631	637	644	651	657	664	671	677	684	
656	690	697	704	710	717	723	730	737	743	750	
657	757	763	770	776	783	790	796	803	809	816	
658	823	829	836	842	849	856	862	869	875	882	
659	889	895	902	908	915	921	928	935	941	948	
660	954	961	968	974	981	987	994	*000	*007	*014	
661	82 020	027	033	040	046	053	060	066	073	079	7
662	086	092	099	105	112	119	125	132	138	145	1 | 0.7
663	151	158	164	171	178	184	191	197	204	210	2 | 1.4
664	217	223	230	236	243	249	256	263	269	276	3 | 2.1
665	282	289	295	302	308	315	321	328	334	341	4 | 2.8
666	347	354	360	367	373	380	387	393	400	406	5 | 3.5
667	413	419	426	432	439	445	452	458	465	471	6 | 4.2
668	478	484	491	497	504	510	517	523	530	536	7 | 4.9
669	543	549	556	562	569	575	582	588	595	601	8 | 5.6
670	607	614	620	627	633	640	646	653	659	666	9 | 6.3
671	672	679	685	692	698	705	711	718	724	730	
672	737	743	750	756	763	769	776	782	789	795	
673	802	808	814	821	827	834	840	847	853	860	
674	866	872	879	885	892	898	905	911	918	924	
675	930	837	943	950	956	963	969	975	982	988	
676	995	*001	*008	*014	*020	*027	*033	*040	*046	*052	
677	83 059	065	072	078	085	091	097	104	110	117	
678	123	129	136	142	149	155	161	168	174	181	
679	187	193	200	206	213	219	225	232	238	245	
680	251	257	264	270	276	283	289	296	302	308	
681	315	321	327	334	340	347	353	359	366	372	6
682	378	385	391	398	404	410	417	423	429	436	1 | 0.6
683	442	448	455	461	467	474	480	487	493	499	2 | 1.2
684	506	512	518	525	531	537	544	550	556	563	3 | 1.8
685	569	575	582	588	594	601	607	613	620	626	4 | 2.4
686	632	639	645	651	658	664	670	677	683	689	5 | 3.0
687	696	702	708	715	721	727	734	740	746	753	6 | 3.6
688	759	765	771	778	784	790	797	803	809	816	7 | 4.2
689	822	828	835	841	847	853	860	866	872	879	8 | 4.8
690	885	891	897	904	910	916	923	929	935	942	9 | 5.4
691	948	954	960	967	973	979	985	992	998	*004	
692	84 011	017	023	029	036	042	048	055	061	067	
693	073	080	086	092	098	105	111	117	123	130	
694	136	142	148	155	161	167	173	180	186	192	
695	198	205	211	217	223	230	236	242	248	255	
696	261	267	273	280	286	292	298	305	311	317	
697	323	330	336	342	348	354	361	367	373	379	
698	386	392	398	404	410	417	423	429	435	442	
699	448	454	460	466	473	479	485	491	497	504	
700	510	516	522	528	535	541	547	553	559	566	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
700	84 510	516	522	528	535	541	547	553	559	566	
701	572	578	584	590	597	603	609	615	621	628	
702	634	640	646	652	658	665	671	677	683	689	
703	696	702	708	714	720	726	733	739	745	751	
704	757	763	770	776	782	788	794	800	807	813	
705	819	825	831	837	844	850	856	862	868	874	
706	880	887	893	899	905	911	917	924	930	936	**7**
707	942	948	954	960	967	973	979	985	991	997	1 0.7
708	85 003	009	016	022	028	034	040	046	052	058	2 1.4
709	065	071	077	083	089	095	101	107	114	120	3 2.1
710	126	132	138	144	150	156	163	169	175	181	4 2.8
711	187	193	199	205	211	217	224	230	236	242	5 3.5
712	248	254	260	266	272	278	285	291	297	303	6 4.2
713	309	315	321	327	333	339	345	352	358	364	7 4.9
714	370	376	382	388	394	400	406	412	418	425	8 5.6
715	431	437	443	449	455	461	467	473	479	485	9 6.3
716	491	497	503	509	516	522	528	534	540	546	
717	552	558	564	570	576	582	588	594	600	606	
718	612	618	625	631	637	643	649	655	661	667	
719	673	679	685	691	697	703	709	715	721	727	
720	733	739	745	751	757	763	769	775	781	788	
721	794	800	806	812	818	824	830	836	842	848	**6**
722	854	860	866	872	878	884	890	896	902	908	1 0.6
723	914	920	926	932	938	944	950	956	962	968	2 1.2
724	974	980	986	992	998	*004	*010	*016	*022	*028	3 1.8
725	86 034	040	046	052	058	064	070	076	082	088	4 2.4
726	094	100	106	112	118	124	130	136	141	147	5 3.0
727	153	159	165	171	177	183	189	195	201	207	6 3.6
728	213	219	225	231	237	243	249	255	261	267	7 4.2
729	273	279	285	291	297	303	308	314	320	326	8 4.8
730	332	338	344	350	356	362	368	374	380	386	9 5.4
731	392	398	404	410	415	421	427	433	439	445	
732	451	457	463	469	475	481	487	493	499	504	
733	510	516	522	528	534	540	546	552	558	564	
734	570	576	581	587	593	599	605	611	617	623	
735	629	635	641	646	652	658	664	670	676	682	
736	688	694	700	705	711	717	723	729	735	741	**5**
737	747	753	759	764	770	776	782	788	794	800	1 0.5
738	806	812	817	823	829	835	841	847	853	859	2 1.0
739	864	870	876	882	888	894	900	906	911	917	3 1.5
740	923	929	935	941	947	953	958	964	970	976	4 2.0
741	982	988	994	999	*005	*011	*017	*023	*029	*035	5 2.5
742	87 040	046	052	058	064	070	075	081	087	093	6 3.0
743	099	105	111	116	122	128	134	140	146	151	7 3.5
744	157	163	169	175	181	186	192	198	204	210	8 4.0
745	216	221	227	233	239	245	251	256	262	268	9 4.5
746	274	280	286	291	297	303	309	315	320	326	
747	332	338	344	349	355	361	367	373	379	384	
748	390	396	402	408	413	419	425	431	437	442	
749	448	454	460	466	371	477	483	489	495	500	
750	506	512	518	523	529	535	541	547	552	558	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
750	87 506	512	518	523	529	535	541	547	552	558	
751	564	570	576	581	587	593	599	604	610	616	
752	622	628	633	639	645	651	656	662	668	674	
753	679	685	691	697	703	708	714	720	726	731	
754	737	743	749	754	760	766	772	777	783	789	
755	795	800	806	812	818	823	829	835	841	846	
756	852	858	864	869	875	881	887	892	898	904	
757	910	915	921	927	933	938	944	950	955	961	
758	967	973	978	984	990	996	*001	*007	*013	*018	
759	88 024	030	036	041	047	053	058	064	070	076	
760	081	087	093	098	104	110	116	121	127	133	
761	138	144	150	156	161	167	173	178	184	190	**6**
762	195	201	207	213	218	224	230	235	241	247	1 | 0.6
763	252	258	264	270	275	281	287	292	298	304	2 | 1.2
764	309	315	321	326	332	338	343	349	355	360	3 | 1.8
765	366	372	377	383	389	395	400	406	412	417	4 | 2.4
766	423	429	434	440	446	451	457	463	468	474	5 | 3.0
767	480	485	491	497	502	508	513	519	525	530	6 | 3.6
768	536	542	547	553	559	564	570	576	581	587	7 | 4.2
769	593	598	604	610	615	621	627	632	638	643	8 | 4.8
770	649	655	660	666	672	677	683	689	694	700	9 | 5.4
771	705	711	717	722	728	734	739	745	750	756	
772	762	767	773	779	784	790	795	801	807	812	
773	818	824	829	835	840	846	852	857	863	868	
774	874	880	885	891	897	902	908	913	919	925	
775	930	936	941	947	953	958	964	969	975	981	
776	986	992	997	*003	*009	*014	*020	*025	*031	*037	
777	89 042	048	053	059	064	070	076	081	087	092	
778	098	104	109	115	120	126	131	137	143	148	
779	154	159	165	170	176	182	187	193	198	204	
780	209	215	221	226	232	237	243	248	254	260	
781	265	271	276	282	287	293	298	304	310	315	**5**
782	321	326	332	337	343	348	354	360	365	371	1 | 0.5
783	376	382	387	393	398	404	409	415	421	426	2 | 1.0
784	432	437	443	448	454	459	465	470	476	481	3 | 1.5
785	487	492	498	504	509	515	520	526	531	537	4 | 2.0
786	542	548	553	559	564	570	575	581	586	592	5 | 2.5
787	597	603	609	614	620	625	631	636	642	647	6 | 3.0
788	653	658	664	669	675	680	686	691	697	702	7 | 3.5
789	708	713	719	724	730	735	741	746	752	757	8 | 4.0
790	763	768	774	779	785	790	796	801	807	812	9 | 4.5
791	818	823	829	834	840	845	851	856	862	867	
792	873	878	883	889	894	900	905	911	916	922	
793	927	933	938	944	949	955	960	966	971	977	
794	982	988	993	998	*004	*009	*015	*020	*026	*031	
795	90 037	042	048	053	059	064	069	075	080	086	
796	091	097	102	108	113	119	124	129	135	140	
797	146	151	157	162	168	173	179	184	189	195	
798	200	206	211	217	222	227	233	238	244	249	
799	255	260	266	271	276	282	287	293	298	304	
800	309	314	320	325	331	336	342	347	352	358	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
800	90 309	314	320	325	331	336	342	347	352	358	
801	363	369	274	380	385	390	396	401	407	412	
802	417	423	428	434	439	445	450	455	461	466	
803	472	477	482	488	493	499	504	509	515	520	
804	526	531	536	542	547	553	558	563	569	574	
805	580	585	590	596	601	607	612	617	623	628	
806	634	639	644	650	655	660	666	671	677	682	
807	687	693	698	703	709	714	720	725	730	736	
808	741	747	752	757	763	768	773	779	784	789	
809	795	800	806	811	816	822	827	832	838	843	
810	849	854	859	865	870	875	881	886	891	897	
811	902	907	913	918	924	929	934	940	945	950	**6**
812	956	961	966	972	977	982	988	993	998	*004	1 0.6
813	91 009	014	020	025	030	036	041	046	052	057	2 1.2
814	062	068	073	078	084	089	094	100	105	110	3 1.8
815	116	121	126	132	137	142	148	153	158	164	4 2.4
816	169	174	180	185	190	196	201	206	212	217	5 3.0
817	222	228	233	238	243	249	254	259	265	270	6 3.6
818	275	281	286	291	297	302	307	312	318	323	7 4.2
819	328	334	339	344	350	355	360	365	371	376	8 4.8
820	381	387	392	397	403	408	413	418	424	429	9 5.4
821	434	440	445	450	455	461	466	471	477	482	
822	487	492	498	503	508	514	519	524	529	535	
823	540	545	551	556	561	566	572	577	582	587	
824	593	598	603	609	614	619	624	630	635	640	
825	645	651	656	661	666	672	677	682	687	693	
826	698	703	709	714	719	724	730	735	740	745	
827	751	756	761	766	772	777	782	787	793	798	
828	803	808	814	819	824	829	834	840	845	850	
829	855	861	866	871	876	882	887	892	897	903	
830	908	913	918	924	929	934	939	944	950	955	
831	960	965	971	976	981	986	991	997	*002	*007	**5**
832	92 012	018	023	028	033	038	044	049	054	059	1 0.5
833	065	070	075	080	085	091	096	101	106	111	2 1.0
834	117	122	127	132	137	143	148	153	158	163	3 1.5
835	169	174	179	184	189	195	200	205	210	215	4 2.0
836	221	226	231	236	241	247	252	257	262	267	5 2.5
837	273	278	283	288	293	298	304	309	314	319	6 3.0
838	324	330	335	340	345	350	355	361	366	371	7 3.5
839	376	381	387	392	397	402	407	412	418	423	8 4.0
840	428	433	438	443	449	454	459	464	469	474	9 4.5
841	480	485	490	495	500	505	511	516	521	526	
842	531	536	542	547	552	557	562	567	572	578	
843	583	588	593	598	603	609	614	619	624	629	
844	634	639	645	650	655	660	665	670	675	681	
845	686	691	696	701	706	711	716	722	727	732	
846	737	742	747	752	758	763	768	773	778	783	
847	788	793	799	804	809	814	819	824	829	834	
848	840	845	850	855	860	865	870	875	881	886	
849	891	996	901	906	911	916	921	927	932	937	
850	942	947	952	957	962	967	973	978	983	988	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

Table—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
850	92 942	947	952	957	962	967	973	978	983	988	
851	993	998	*003	*008	*013	*018	*024	*029	*034	*039	
852	93 044	049	054	059	064	069	075	080	085	090	
853	095	100	105	110	115	120	125	131	136	141	
854	146	151	156	161	166	171	176	181	186	192	
855	197	202	207	212	217	222	227	232	237	242	
856	247	252	258	263	268	273	278	283	288	293	**6**
857	298	303	308	313	318	323	328	334	339	344	1 | 0.6
858	349	354	359	364	369	374	379	384	389	394	2 | 1.2
859	399	404	409	414	420	425	430	435	440	445	3 | 1.8
860	450	455	460	465	470	475	480	485	490	495	4 | 2.4
861	500	505	510	515	520	526	531	536	541	546	5 | 3.0
862	551	556	561	566	571	576	581	586	591	596	6 | 3.6
863	601	606	611	616	621	626	631	636	641	646	7 | 4.2
864	651	656	661	666	671	676	682	687	892	897	8 | 4.8
865	702	707	712	717	722	727	732	737	742	747	9 | 5.4
866	752	757	762	767	772	777	782	787	792	797	
867	802	807	812	817	822	827	832	837	842	847	
868	852	857	862	867	872	877	882	887	892	897	
869	902	907	912	917	922	927	932	937	942	947	
870	952	957	962	967	972	977	982	987	992	997	
871	94 002	007	012	017	022	027	032	037	042	047	**5**
872	052	057	062	067	072	077	082	086	091	096	1 | 0.5
873	101	106	111	116	121	126	131	136	141	146	2 | 1.0
874	151	156	161	166	171	176	181	186	191	196	3 | 1.5
875	201	206	211	216	221	226	231	236	240	245	4 | 2.0
876	250	255	260	265	270	275	280	285	290	295	5 | 2.5
877	300	305	310	315	320	325	330	335	340	345	6 | 3.0
878	349	354	359	364	369	374	379	384	389	394	7 | 3.5
879	399	404	409	414	419	424	429	433	438	443	8 | 4.0
880	448	453	458	463	468	473	478	483	488	493	9 | 4.5
881	498	503	507	512	517	522	527	532	537	542	
882	547	552	557	562	567	571	576	581	586	591	
883	596	601	606	611	616	621	626	630	635	640	
884	645	650	655	660	665	670	675	680	685	689	
885	694	699	704	709	714	719	724	729	734	738	
886	743	748	753	758	763	768	773	778	783	787	**4**
887	792	797	802	807	812	817	822	827	832	836	1 | 0.4
888	841	846	851	856	861	866	871	876	880	885	2 | 0.8
889	890	895	900	905	910	915	919	924	929	934	3 | 1.2
890	939	944	949	954	959	963	968	973	978	983	4 | 1.6
891	988	993	998	*002	*007	*012	*017	*022	*027	*032	5 | 2.0
892	95 036	041	046	051	056	061	066	071	075	080	6 | 2.4
893	085	090	095	100	105	109	114	119	124	129	7 | 2.8
894	134	139	143	148	153	158	163	168	173	177	8 | 3.2
895	182	187	192	197	202	207	211	216	221	226	9 | 3.6
896	231	236	240	245	250	255	260	265	270	274	
897	279	284	289	294	299	303	308	313	318	323	
898	328	332	337	342	347	352	357	361	366	371	
899	376	381	386	390	395	400	405	410	415	419	
900	424	429	434	439	444	448	453	458	463	468	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.	
900	95 424	429	434	439	444	448	453	458	463	468		
901	472	477	482	487	492	497	501	506	511	516		
902	521	525	530	535	540	545	550	554	559	564		
903	569	574	578	583	588	593	598	602	607	612		
904	617	622	626	631	636	641	646	650	655	660		
905	665	670	674	679	684	689	694	698	703	708		
906	713	718	722	727	732	737	742	746	751	756		
907	761	766	770	775	780	785	789	794	799	804		
908	809	813	818	823	828	832	837	842	847	852		
909	856	861	866	871	875	880	885	890	895	899		
910	904	909	914	918	923	928	933	938	942	947		
911	952	957	961	966	971	976	980	985	990	995		**5**
912	999	*004	*009	*014	*019	*023	*028	*033	*038	*042	1	0.5
913	96 047	052	057	061	066	071	076	080	085	090	2	1.0
914	095	099	104	109	114	118	123	128	133	137	3	1.5
915	142	147	152	156	161	166	171	175	180	185	4	2.0
916	190	194	199	204	209	213	218	223	227	232	5	2.5
917	237	242	246	251	256	261	265	270	275	280	6	3.0
918	284	289	294	298	303	308	313	317	322	327	7	3.5
919	332	336	341	346	350	355	360	365	369	374	8	4.0
920	379	384	388	393	398	402	407	412	417	421	9	4.5
921	426	431	435	440	445	450	454	459	464	468		
922	473	478	483	487	492	497	501	506	511	515		
923	520	525	530	534	539	544	548	553	558	562		
924	567	572	577	581	586	591	595	600	605	609		
925	614	619	624	628	633	638	642	647	652	656		
926	661	666	670	675	680	685	689	694	699	703		
927	708	713	717	722	727	731	736	741	745	750		
928	755	759	764	769	774	778	783	788	792	797		
929	802	806	811	816	820	825	830	834	839	844		
930	848	853	858	862	867	872	876	881	886	890		
931	895	900	904	909	914	918	923	928	932	937		**4**
932	942	946	951	956	960	965	970	974	979	984	1	0.4
933	988	993	997	*002	*007	*011	*016	*021	*025	*030	2	0.8
934	97 035	039	044	049	053	058	063	067	072	077	3	1.2
935	081	086	090	095	100	104	109	114	118	123	4	1.6
936	128	132	137	142	146	151	155	160	165	169	5	2.0
937	174	179	183	188	192	197	202	206	211	216	6	2.4
938	220	225	230	234	239	243	248	253	257	262	7	2.8
939	267	271	276	280	285	290	294	299	304	308	8	3.2
940	313	317	322	327	331	336	340	345	350	354	9	3.6
941	359	364	368	373	377	382	387	391	396	400		
942	405	410	414	419	424	428	433	437	442	447		
943	451	456	460	465	470	474	479	483	488	493		
944	497	502	506	511	516	520	525	529	534	539		
945	543	548	552	557	562	566	571	575	580	585		
946	589	594	598	603	607	612	617	621	626	630		
947	635	640	644	649	653	658	663	667	672	676		
948	681	685	690	695	699	704	708	713	717	722		
949	727	731	736	740	745	749	754	759	763	768		
950	772	777	782	786	791	795	800	804	809	813		
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.	

TABLE—(*Continued*).

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
950	97 772	777	782	786	791	795	800	804	809	813	
951	818	823	827	832	836	841	845	850	855	859	
952	864	868	873	877	882	886	891	896	900	905	
953	909	914	918	923	928	932	937	941	946	950	
954	955	959	964	868	973	978	982	987	991	996	
955	98 000	005	009	014	019	023	028	032	037	041	
956	046	050	055	059	064	068	073	078	082	087	
957	091	096	100	105	109	114	118	123	127	132	
958	137	141	146	150	155	159	164	168	173	177	
959	182	186	191	195	200	204	209	214	218	223	
960	227	232	236	241	245	250	254	259	263	268	
961	272	277	281	286	290	295	299	304	308	313	**5**
962	318	322	327	331	336	340	345	349	354	358	1 0.5
963	363	367	372	376	381	385	390	394	399	403	2 1.0
964	408	412	417	421	426	430	435	439	444	448	3 1.5
965	453	457	462	466	471	475	480	484	489	493	4 2.0
966	498	502	507	511	516	520	525	529	534	538	5 2.5
967	543	547	552	556	561	565	570	574	579	583	6 3.0
968	588	592	597	601	605	610	614	619	623	628	7 3.5
969	632	637	641	646	650	655	659	664	668	673	8 4.0
970	677	682	686	691	695	700	704	709	713	717	9 4.5
971	722	726	731	735	740	744	749	753	758	762	
972	767	771	776	780	784	789	793	798	802	807	
973	811	816	820	825	829	834	838	843	847	851	
974	856	860	865	869	874	878	883	887	892	896	
975	900	905	909	914	918	923	927	932	936	941	
976	945	949	954	958	963	967	972	976	981	985	
977	989	994	998	*003	*007	*012	*016	*021	*025	*029	
978	99 034	038	043	047	052	056	061	065	069	074	
979	078	083	087	092	096	100	105	109	114	118	
980	123	127	131	136	140	145	149	154	158	162	
981	167	171	176	180	185	189	193	198	202	207	**4**
982	211	216	220	224	229	233	238	242	247	251	1 0.4
983	255	260	264	269	273	277	282	286	291	295	2 0.8
984	300	304	308	313	317	322	326	330	335	339	3 1.2
985	344	348	352	357	361	366	370	374	379	383	4 1.6
986	388	392	396	401	405	410	414	419	423	427	5 2.0
987	432	436	441	445	449	454	458	463	467	471	6 2.4
988	476	480	484	489	493	498	502	506	511	515	7 2.8
989	520	524	528	533	537	542	546	550	555	559	8 3.2
990	564	568	572	577	581	585	590	594	599	603	9 3.6
991	607	612	616	621	625	629	634	638	642	647	
992	651	656	660	664	669	673	677	682	686	691	
993	695	699	704	708	712	717	721	726	730	734	
994	739	743	747	752	756	760	765	769	774	778	
995	782	787	791	795	800	804	808	813	817	822	
996	826	830	835	839	843	848	852	856	861	865	
997	870	874	878	883	887	891	896	900	904	909	
998	913	917	922	926	930	935	939	944	948	952	
999	957	961	965	970	974	978	983	987	991	996	
1000	00 000	004	009	013	017	022	026	030	035	039	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TRIGONOMETRY

Plane Trigonometry treats of the solution of plane triangles. In every triangle there are six parts—three sides and three angles. These parts are so related that when three of the parts are given, one being a side, the other parts may be found.

An angle is measured by the arc included between its sides, the center of the circumference being at the vertex of the angle. For the purpose of measuring angles, the circumference is divided into 360 equal parts called **degrees**, each degree being divided into 60 equal parts called **minutes.**

The **complement** of an arc is 90° minus the arc.

The **supplement** of an arc is 180° minus the arc.

In trigonometry, instead of comparing the angles of triangles, or the arcs that measure them, we compare the *sine*, *cosine*, *tangent*, *cotangent*, *secant*, and *cosecant*.

The **sine** of the angle *a o c*, Fig. 1, is the line *a b* drawn from *a* perpendicular to *o c*.

The **cosine** of the angle *a o c* is

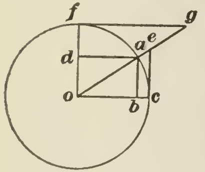


FIG. 1

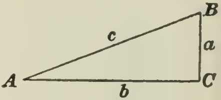


FIG. 2

the sine of its complement; or, it is the distance *o b* (= *d a*) from the foot of the sine to the center of the circle.

The **tangent** of the angle *a o c* is the line *c e* that is perpendicular to the radius *o c* at the extremity *c*, and which is limited by a line passing through the center of the circle and the other extremity *a*.

The **cotangent** of the angle *a o c* is equal to the tangent of its complement; or, it is the line *f g* perpendicular to *f o* and limited by the line *o g* passing through the extremity *a*.

The **secant** of the angle $a\,o\,c$ is a line drawn from the center o through the extremity a and limited by the tangent of the same angle. Thus, $o\,e$ is the secant of the angle $a\,o\,c$.

The **cosecant** of the angle is the secant of the complement of that angle. Thus, $o\,g$ is the cosecant of the angle $a\,o\,c$.

All of these are known as **trigonometric functions**, and are usually denoted by the abbreviations sin, cos, tan, cot, sec, and cosec.

The ratios existing between the trigonometric functions are best explained by means of a right triangle $A\,B\,C$, Fig. 2, where C is the right angle. They are as follows:

$$\sin A = \frac{a}{c} = \text{opposite side} \div \text{hypotenuse}$$

$$\cos A = \frac{b}{c} = \text{adjacent side} \div \text{hypotenuse}$$

$$\tan A = \frac{a}{b} = \text{opposite side} \div \text{adjacent side}$$

$$\cot A = \frac{b}{a} = \text{adjacent side} \div \text{opposite side}$$

$$\sec A = \frac{c}{b} = \text{hypotenuse} \div \text{adjacent side}$$

$$\text{cosec } A = \frac{c}{a} = \text{hypotenuse} \div \text{opposite side}$$

The **hypotenuse** is the side c opposite the right angle. The **adjacent** side b is the side that, with the hypotenuse, includes the angle. The **opposite** side a is the side that joins the adjacent side and the hypotenuse.

From the relations shown, we derive the following simple principles:

1. *The sine of an arc equals the sine of its supplement, and the cosine of an arc equals the cosine of its supplement.*

2. *The tangent of an arc equals the tangent of its supplement, and the cotangent of an arc equals the cotangent of its supplement.*

3. *The secant of an arc equals the secant of its supplement, and the cosecant equals the cosecant of its supplement.*

Thus, the sine of 70° = the sine of 110°
the cosine of 70° = the cosine of 110°
the tangent of 70° = the tangent of 110°
the cotangent of 70° = the cotangent of 110°
the secant of 70° = the secant of 110°
the cosecant of 70° = the cosecant of 110°

Thus, if you want to find the sine of an angle of 120° 30′, look for the sine of 180° − 120° 30′, or 59° 30′, etc.

Functions of the sum and difference of two angles:

$$\sin(A+B) = \sin A \cos B + \cos A \sin B$$
$$\cos(A+B) = \cos A \cos B - \sin A \sin B$$
$$\sin(A-B) = \sin A \cos B - \cos A \sin B$$
$$\cos(A-B) = \cos A \cos B + \sin A \sin B$$

There are two kinds of trigonometrical tables that may be used in the computation of the sides and angles of a triangle, viz.: *natural sines, tangents*, etc., and *logarithmic sines, tangents*, etc. Natural sines, tangents, etc., are calculated for a circle whose radius is unity, and logarithmic sines, tangents, etc., are calculated for a circle whose radius is 10,000,000,000. With natural sines, etc., long and tedious operations in multiplication and division are necessary. With logarithmic sines, etc., these operations, in conjunction with a table of logarithms of numbers, are reduced to simple addition and subtraction.

ILLUSTRATIONS OF TRIGONOMETRY APPLIED IN PRACTICE

Example.—Referring to Fig. 1, suppose that the angle v subtended by the lighthouse is 15° and that the height h of the light is 144 ft.; what is the distance d?

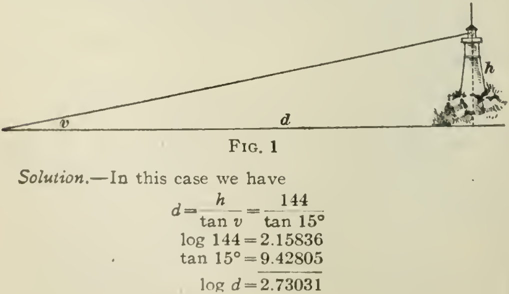


FIG. 1

Solution.—In this case we have

$$d = \frac{h}{\tan v} = \frac{144}{\tan 15°}$$

$$\log 144 = 2.15836$$
$$\tan 15° = 9.42805$$
$$\log d = 2.73031$$
$$d = 537.4 \text{ ft.} \quad \text{Ans.}$$

Example.—Referring to Fig. 2, suppose that a ship from C sails N E by N, or N 33° 45′ E, a distance of 115 mi.; how much northing and how much easting has she made?

Solution.—In this case, $A B$ represents the easting and $C A$ the northing; we have then,

$$AB = BC \times \sin 33° 45'$$
$$CA = BC \times \cos 33° 45'$$

$\log 115 = 2.06070$	$\log 115 = 2.06070$
$\sin 33° 45' = 9.74474$	$\cos 33° 45' = 9.91985$
$\log A B = 1.80544$	$\log C A = 1.98055$
$A B = 63.89$ mi. Ans.	$C A = 95.6$ mi. Ans.

Example.—A ship sails N 69° E for a distance of 80 mi. and is then found to have made good a course due east and

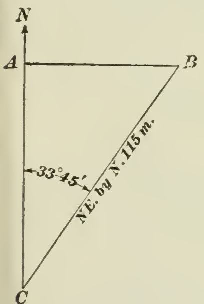


FIG. 2

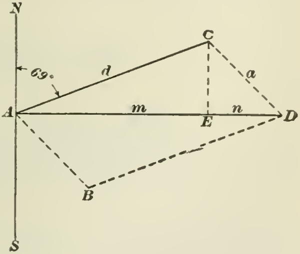


FIG. 3

covered a distance of 103 mi. in that direction; find the direction and distance of the current that has acted on the vessel.

Solution.—If $N S$, Fig. 3, represents the meridian, $A C$ is the course and distance run, and $A D$ the course and distance made good; the line $C D$ ($= A B$) will then represent the direction and distance of the current that has acted on the ship during her run. Using natural functions, we find the required quantities, the angle $E C D$ and the distance

$C\ D$, as follows· From the vertex C draw $C\ E$ perpendicular to $A\ D$, thus forming two right triangles $A\ E\ C$ and $C\ E\ D$. In the triangle $A\ E\ C$, the side d is known, as is also the angle $C\ A\ E$. We then have

$$C\ E = d \sin C\ A\ E = 80 \times \sin 21° = 80 \times .3583 = 28.7$$

and $$m = d \cos C\ A\ E = 80 \times \cos 21° = 80 \times .9336 = 74.7$$

whence, $$n = A\ D - m = 103 - 74.7 = 28.3$$

In the triangle $C\ E\ D$, we have

$$\tan E\ C\ D = \frac{n}{E\ C} = \frac{28.3}{28.7} = 44°\ 36'$$

and $$a = \frac{E\ C}{\cos E\ C\ D} = \frac{28.7}{\cos 44°\ 36'} = \frac{28.7}{.712} = 40.3$$

Therefore, $C\ D$ or the direction of the current is S 44° 36′ E and the drift or distance 40.3 mi. Ans.

NOTE.—For other examples showing the application of Trigonometry in practice, see Navigation by Dead Reckoning.

NAVIGATION

THE COMPASS ERROR

TERMS AND DEFINITIONS RELATING TO THE MAGNETIC NEEDLE

Magnetism is the name given the phenomenon displayed by magnets of attracting small pieces of iron and steel.

Magnets are of two kinds, *natural* and *artificial*. The ore commonly known as *lode stone*, which possesses the property of magnetism, is a **natural magnet.** The chemical composition of this ore is about 72 parts of iron and 28 parts of oxygen. When a bar or needle is rubbed with a piece of lode stone, it acquires magnetic properties similar to those of the lode stone without the latter losing any of its own magnetism. Such bars or needles are called **artificial magnets.**

Magnetic Poles.—When an ordinary bar magnet is plunged into iron filings it does not become uniformly covered but instead the filings arrange themselves around the ends of the bar in feathery tufts that grow smaller as the middle of the bar is approached, leaving that portion bare. The points around which the filings concentrate are called the **poles** of the magnet, while the middle portion of the bar which has no visible magnetic force is called the **neutral zone.**

Magnetic axis is the line connecting the two poles of a magnet.

Magnetic Polarity.—A magnetized needle suspended on its center of gravity will lay itself in a definite direction pointing toward north and south. This tendency, called **polarity,** applies to all magnets. The end pointing northwards is called the north-seeking, or red, pole, and the opposite the south-seeking, or blue, pole. In other words, the north-seeking end of the needle is said to have *red polarity*, while the south-pointing end has *blue polarity.*

Magnetic Attraction and Repulsion.—When two magnetized bars, or needles, are brought close together, the north-seeking, or red, pole of one magnetic needle will repel the north-seeking end of the other needle, while it will attract the south-seeking end. From this, the following law for magnetic attraction and repulsion may be enunciated: Poles of contrary names attract each other, while poles of the same name repel each other; or, the red pole of one magnet will repel the red of another, but attract the blue, and vice versa.

Magnetic Property of the Earth.—The fact that a suspended needle takes up a fixed position has led to the theory that the earth itself is a huge magnet having its red and blue magnetic poles in the neighborhood of the geographical poles, and that the magnetic needle turns to these poles as to the poles of an ordinary magnet, according to the law just given. Since the north-seeking end of a needle has red polarity, it follows that the magnetic pole of the earth situated in the northern hemisphere must be a blue pole and that in the southern a red pole.

Magnetic meridian is the direction that the horizontally suspended magnetic needle assumes when not influenced by local disturbances.

Magnetic Components.—The magnetic force of the earth may be resolved into two components, one horizontal and one vertical; the former represents the directive element of the compass needle; the latter acts only in a vertical direction. A magnetic needle mounted at its center of gravity would be acted upon by both components.

Magnetic dip is the effect of the vertical component of the earth's magnetic force, or the inclination, or downward deflection from the horizontal, of a magnetic needle free to move in the vertical plane. The amount of dip varies from 0° to 90°, being 0° at the magnetic equator and gradually increasing until 90° is reached at the magnetic poles.

Magnetic equator is a narrow belt or zone embracing all points on the earth's surface where the magnetic dip is zero; it encircles the equatorial part of the earth and intersects it, but never recedes more than 16° on either side of the geographical equator.

Magnetic induction is the property of a magnet imparting magnetism to a body of iron or steel in its immediate vicinity. Thus, the earth being a magnet will impart or communicate magnetism to the hull of an iron vessel. The vessel is then said to be *magnetized by induction.*

Magnetic variation is the angle that the magnetic meridian makes with the geographical meridian, or, what is the same, the angle that the direction of the suspended needle makes with the true meridian; it is caused by the magnetic poles of the earth not coinciding with the geographic poles. Variation is not constant, but undergoes a progressive change, the annual amount of which is invariably marked on charts.

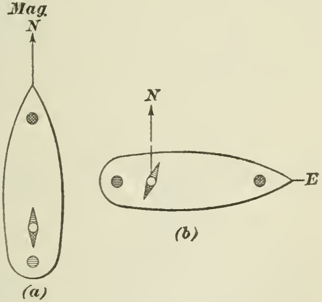
Isogonic lines are curves or lines connecting points of equal variation. Charts on which such lines are plotted are called *isogonic*, or *variation, charts.*

Agonic lines are curves or lines connecting all places on the earth's surface where the variation of the compass is zero.

Isoclinic lines are curves or lines that are drawn intermediate to the poles and equator connecting all places where the dip of the magnetic needle is the same.

Isodynamic lines are curves or lines connecting all places where the intensity of the earth's magnetic force is the same.

Deviation.—A compass placed on board an iron or steel vessel is subjected to various disturbances from the magnetism of the surrounding metal, and the errors thus produced are collectively known as the **deviation** of the compass. Deviation may also be defined as the deflection of the compass needle from the magnetic meridian. At the same time, the needle is acted upon by variation and the combined effect of the two may properly be termed **the total error of the compass.** Deviation and variation must not be confounded with one another; variation, being caused by the magnetic force of the earth, affects the compass alike on all courses, while deviation, being caused by the magnetism of the iron in the hull and fittings of the vessel itself, varies for different headings of the ship. The reason why deviation varies as indicated will be readily understood



by remembering that, through induction of magnetism from the earth, any iron or steel vessel may be considered as a large magnet having red and blue polarity that affects the compass needle in exactly the same manner as an ordinary magnet. Suppose that the vessel has blue polarity in the bow and red polarity in the stern and that no other magnetic disturbances have any effect on the compass needle; then, when heading in the direction of the magnetic meridian, as (*a*) in the appended figure, it is evident there will be no deflection of the needle. But when turning the bow in any other direction, for example to east, as in (*b*), there will necessarily be a deflection due to the influence of the altered position of the ship's magnetic poles. Hence, the cause of the deviation being different for different positions of the ship's head.

Subpermanent magnetism is the magnetic condition of a more or less enduring character possessed by a ship when launched and which was acquired when building, by induction from the earth and rendered permanent, or nearly so, by hammering.

Retentive magnetism is the temporary magnetism communicated to an iron ship when her head is kept in one direction for some time; as, for example, when moored to a pier, or when steering a continuous course for several days. Retentive magnetism frequently remains for days after the cause is removed.

Semicircular deviation is the effect of the combined action of the subpermanent magnetism and the transient magnetism from the vertical soft iron of the ship. It is called *semicircular* because it has the contrary name and maximum value in opposite semicircles.

Quadrantal deviation is the deviation produced by the transient magnetism of horizontal soft iron. It is called quadrantal because it is greatest on the quadrantal points, and because it changes its name in each successive quadrant.

Soft Iron is iron that becomes magnetized as soon as it is exposed to the influence of some magnetic body but which has not power to retain the magnetism thus acquired. Malleable and cast iron belong to this class.

Hard Iron is iron combined with a certain percentage of carbon (steel) and which has the property of retaining its magnetism permanently, or nearly so, when magnetized.

Vertical and **horizontal iron** refer to the structure of a vessel built of iron or steel To the first named, belongs all iron running in a vertical direction, such as frames, stanchions, bulkheads, etc.; to the latter, all iron running horizontally, such as the keel, deck beams, deck plates, etc.

Local attraction is any disturbance, temporary or otherwise, caused by any iron, steel, dynamo, electric wiring, etc., in the immediate vicinity of the compass and which is not included in the stationary metal surrounding the compass. In this expression is included also the magnetic influences due to the locality in which the ship happens to be, for example, when in dock alongside of iron ships, cranes, pillars, etc., or when in close proximity to iron-bearing mountains or volcanic islands. The effect on the compass of cargo containing iron, such as iron ore, machinery, etc., may also be classed as local attraction.

COMPENSATION OF COMPASSES

The general principle of compensating a compass is to counteract the magnetic disturbances by means of magnets and soft iron placed in the immediate neighborhood of the compass and in such position as to cause a disturbance contrary to that caused by the iron of the ship. The magnetic needle will thus be left comparatively free. This may be illustrated as follows: Bearing in mind that the north-seeking end of the compass needle always possesses red polarity and that red polarity repels red and attracts blue, and vice versa, assume a needle to be deflected from magnetic north N to n, Fig. 1. Then, in order to bring the needle back to its proper position N, or, what is the same thing, to counteract the effect of the surrounding iron and steel, magnets may be placed in any of the positions shown at a suitable distance from the needle. It will be noticed in each case, that is, if the magnets are used singly or in pairs, or in any other combination, that the whole operation of compensating is simply an application of the law of magnetic attraction and repulsion.

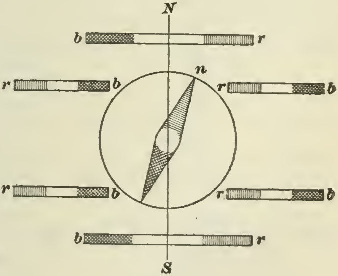


FIG. 1

The two principal errors of a compass to compensate are the semicircular deviation and the quadrantal deviation. The semicircular error is the combined effect of subpermanent magnetism of the ship and the induced magnetism of vertical iron; but, as a whole and for the purpose of compensation, it is convenient to divide this error into two parts and consider each part as a separate force, one acting in a fore-and-aft, and the other in an athwartship direction. The first part of that error, which affects the compass needle when heading on easterly and westerly courses, is usually denoted by the letter *B*; while the second part, which affects the needle when heading on northerly and southerly courses, is denoted by the letter *C*. The quadrantal deviation, resulting from horizontal iron and which attains its maximum value when the ship is heading on any of the quadrantal points, is denoted by *D*. These forces *B*, *C*, and *D* are technically known as **coefficients.**

When compensating a compass, it has been found good practice to correct the quadrantal deviation first and then the two parts of the semicircular error.

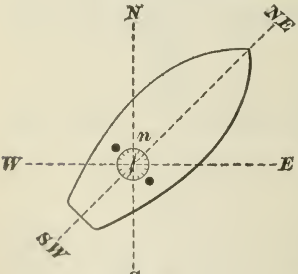


Fig. 2

To Compensate the Quadrantal Deviation. Since this error which is caused by the magnetism of horizontal soft iron, attains its maximum value on the quadrantal points, the ship is swung in the direction of one of these points, for example, N E, as shown in Fig. 2; and since the error is caused by soft iron, it is necessary to compensate it by using hollow soft-iron spheres. These spheres are so placed in the plane of the compass card as to cause an opposite effect to the magnetism of horizontal iron. The error to be corrected being easterly in the N E and S W quadrants and westerly in the N W and S E quadrants in almost every ship, the spheres are placed athwartship on the same horizontal plane and at equal distances from the center of the compass, the distance being determined by trial, moving them to and fro in their respective slits until the compass shows the correct quadrantal point on which the ship is headed. The quadrantal deviation is constant in all latitudes, provided that the surrounding iron remains in the same position, and hence its compensation remains constant everywhere.

To Compensate Coefficient C.—Swing the ship's head toward magnetic north, according to some compass not influenced by the magnetism of the ship (for instance by a compass on shore), or, better still, by permanent marks on land, the bearing between which coincides with the magnetic meridian. If the compass in this position does not show exactly north, but is deflected to the east, as shown in Fig. 3, place a magnet on the fore-and-aft line with its red pole to starboard.

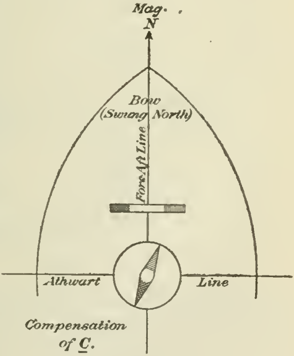


Fig. 3

The distance of the magnet must be determined by trial; begin by placing the magnet at some distance from the compass and gradually approach it until the compass shows correct magnetic north, when the magnet is secured to the deck. If the needle had been deflected to the west, it is evident that the red end, or pole, of the magnet should have been placed to the port side. In case this error is large, the ship is swung toward magnetic south and a similar operation is performed on that heading.

To Compensate Coefficient B.—The ship is swung magnetic east or west. If swung to east and the compass north on that heading is deflected to the west, as in Fig. 4, place a magnet on the athwartship line with its blue pole forwards and at a distance from the compass sufficient to correct the error. The compass north being deflected to the east, the compensating magnet is reversed. A similar operation is then performed, if necessary, with the ship's head swung west.

The foregoing applies to ships not equipped with a compensating binnacle. It becomes necessary then to have fore-and-aft and athwartship lines run out on the deck and

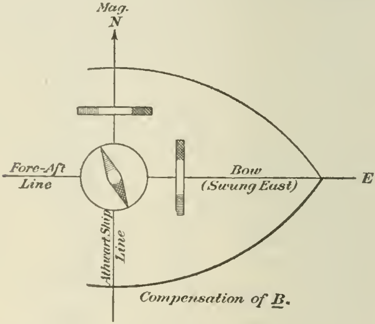


Fig. 4

intersecting at a point vertically below the center of the compass to be compensated. The magnets are then placed perpendicularly with their centers on these lines, as shown in Figs. 3 and 4.

At present, however, and particularly in iron ships, compensating magnets are seldom, if ever, fastened to the deck, but are fitted to slide into horizontal fore-and-aft and athwartship receptacles within the binnacle. In most binnacles, the receptacles are arranged in such a manner as to be moved up or down, nearer to, or farther from, the compass, as may be required, and then secured by means of clamp screws that cannot be touched except by opening the door of the binnacle; in others, the movement of the magnets is controlled from the outside of the binnacle by means of a crank-key, thus enabling the adjuster to watch the compass while he is altering the position of the magnets, and to move them the exact amount required; after the adjustment is completed, the crank-key is removed and the casing locked, making it impossible for any one to tamper with the magnets. The principle of magnets being stored within the binnacle is precisely the same as in securing them to the deck, both the magnets for *B* and *C* being exactly parallel to the ship's deck or to the plane of the compass card when the ship is in an upright position.

As previously stated, the compensation of the quadrantal error is good for all latitudes. Such, however, is not the case with that part of the semicircular error caused by the induced magnetism of vertical iron. Since the amount of this magnetism depends on the magnetic dip, it is evident that the deviation resulting from it will depend on the magnetic dip also. To distinguish this latter error from that produced by subpermanent magnetism and to apply to it a proper compensation is a difficult task, requiring skill, good judgment, and an intimate knowledge of the magnetic condition of the ship. The usual method of correcting or compensating this error is by means of a vertical iron bar, called the **Flinders bar,** which is placed within or outside the binnacle either immediately before or abaft the compass. This bar, which received its name from its inventor, Captain Flinders, of the British Navy, is not a permanent magnet; it is made of soft iron, and consequently receives its magnetism by induction from the earth.

The object, therefore, to be attained by the Flinders bar is to place it in such a position within the binnacle that the gradual change of its magnetism, produced by the change in latitude, will counterbalance the effect of the likewise varying magnetism of the vertical iron of the ship.

Heeling Error.—When, from some cause, the ship has a list to either side, a new error is created, which is generally known as the **heeling error.** The principal cause of this error may be explained as follows: When the ship heels over from the pressure of wind, shifting of cargo, or unequal trimming of coal bunkers, all horizontal iron, such as the deck beams, tends to assume a vertical position, and in doing so will receive magnetism by induction from the earth. Thus, for a ship in the northern hemisphere, the upper ends of the beams, whether heeling to port or starboard, will acquire blue polarity and the lower ends red polarity. In the southern hemisphere, these conditions are reversed. As a consequence, the north end of the compass needle will be attracted by the upper ends of the beams in north magnetic latitudes and repelled in south magnetic latitudes, and the amount of this error will evidently depend on the extent of heeling. As a general rule, the heeling error is greatest on northerly and southerly courses and least on easterly and westerly courses. The simplest method of compensating the heeling error is to place a magnet vertically below the center of the compass bowl. Before compensating, the ship is swung into a north-and-south direction and heeled over at least 5°, for instance, to starboard. If in this position the compass north is deflected toward the uppermost or windward side (as is usually the case), the compensating magnet is placed with its red pole uppermost, and at a distance from the compass bowl that is determined by raising or lowering the magnet until the compass points correctly. In the very exceptional case of the needle being deflected toward the lower or leeward side, the blue pole of the magnet is placed uppermost.

The compensation for heeling error is good only for the latitude in which it is made, and it therefore becomes a necessity to renew it when the ship has changed her latitude considerably, usually for every change of 10° in latitude. At the magnetic equator, the error is at its minimum; and when entering the southern hemisphere, it again increases in amount, although of a different character, in southern magnetic latitudes, therefore, the vertical magnet will have to be reversed.

The foregoing remarks on compensation are general, and while the operations may appear easy of execution, they nevertheless require a certain amount of skill and experience to meet all conditions that may arise; and for this reason it is advisable always to employ a professional compass adjuster, the cost of this being insignificant when compared with the importance of the subject.

SWINGING A SHIP FOR DEVIATION

Preparatory to swinging a ship for finding the amount of deviation remaining after the compass is compensated, a well-defined distant object on land should be selected, the correct magnetic bearing of which is known. If the ship's position is accurately fixed, the magnetic bearing of the selected object may be taken directly from the chart; or, it may be conveniently found by taking the mean of all compass bearings of the object after the ship is swung. Regularly established ranges, such as are found in the principal ports, are, however, to be preferred whenever available.

The magnetic bearing of the object being determined, the ship is gradually swung round so as to bring her head successively upon each of the 32 points of the standard compass, steadying at each. The difference between the correct magnetic bearing of the object and the successive bearings, as observed with the compass on board when the ship's head is on the several points, will show the error on each of these points, or, in other words, the deviation of the standard compass according to the direction in which the ship's head was placed.

When no suitable object by which a range may be established is in sight, the deviation may be found by what is known as **simultaneous reciprocal bearings.** This method consists of a compass being brought on shore and placed on a tripod in a carefully selected spot, where it will be free from the magnetic influence of any iron and where its location can be distinctly seen from the standard compass on board. As the ship is swung around, with her head successively upon each of the 32 points of the standard compass, simultaneous observations, or bearings, are taken by the observer stationed at each compass, according to some prearranged signals.

The bearings should be strictly simultaneous, and in order to guard against any mistake regarding the exact instant at which bearings are taken, both observers should note the time of each observation by watches previously compared. To obtain the deviation resulting from observations by this method, the bearings taken by the shore compass must be reversed and considered as correct magnetic. The rule to be followed in naming the deviation when comparing bearings is:

Rule.—*If the correct magnetic bearing lies to the right of the compass bearing, the deviation is easterly; if to the left, the deviation is westerly.*

Illustration.—Referring to the figure, suppose that when the vessel is heading W by N the shore compass bears E N E and that the bearing of the ship by shore compass (taken at the same time) is W by S. W by S reversed is E by N,

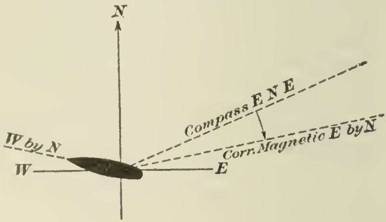


Fig. 5

which is the correct magnetic bearing. The difference between this and the compass bearing is one point. Hence, the deviation for the heading W by N is one point, or 11° 15′ east, because the magnetic bearing falls to the right of the compass bearing, as shown in Fig. 5.

The deviation determined by either method belongs, of course, only to the compass by which the observations are made, and is not applicable to that compass if removed or placed in some other position on the ship.

When deviations are small, as is usually the case in ships where compasses are carefully adjusted, it is sufficient to determine the deviation for the eight principal points only, and then find the deviation for intermediate points by means of the various diagrams in use.

The following forms will be found convenient for tabulating bearings and the resulting deviations.

BEARINGS OF A DISTANT OBJECT

Ship's Head by Standard Compass	Bearing of Distant Object by Standard Compass	Bearing Referred to East Point	Deviation of Standard Compass
N	N 41° E	E 49° N	36° 15′ W
N E	N 30° E	E 60° N	25° 15′ W
E	N 11° E	E 79° N	6° 15′ W
S E	N 12° W	E 102° N	16° 45′ E
S	N 33° W	E 123° N	37° 45′ E
S W	N 27° W	E 117° N	31° 45′ E
W	N	E 90° N	4° 45′ E
N W	N 28° E	E 62° N	23° 15′ W

Sum = 682°

Corr. magnetic bearing $= \frac{682}{8} =$ E 85.25° N = E 85° 15′ N = N 4° 45′ E

When bearings have different names, or do not lie in the same quadrant, it is advisable always to refer them to some convenient cardinal point, as shown. This will prevent any mistake in finding the mean or correct magnetic bearing of the object.

Remarks on Compass Management.—The accuracy of deviation tables should be tested whenever practicable, or whenever there is reason to believe a change of the magnetic condition of the ship has taken place. After coming out of dry dock, after target practice, after considerable alterations in the fittings of the vessel, and after taking in or unloading some cargo of a magnetic character, such as machinery, iron ore, etc., a new deviation table should be made in case the given values do not conform with actual conditions. A navigator should ever be watchful about the proper performance of the compass, and particularly so in modern steamships, where new forms of disturbances are likely to appear at any time. The principal cause of the directive force of a magnetic needle being lessened are vibrations. If the compass is exposed or subjected to vibrations from the propeller or engine room for any length of time, it will begin to act sluggishly, and the needles will have to be recharged or remagnetized.

With the introduction of electricity on board ships, a new form of compass disturbances has been created, inasmuch as the magnetism of the large electromagnets used in the dynamos and the electric currents in general may disturb a compass at a considerable distance. The committee of Lloyd's Register of British and Foreign Shipping has made the following suggestions in reference to protecting compasses from the influence of electricity on shipboard:

RECIPROCAL BEARINGS

Time	Ship's Head by the Standard Compass	Simultaneous Bearings		Deviation of Standard Compass
		By the Standard Compass	By the Shore Compass (Reversed)	
7h 56m	North	S 25.3° E	S 30.8° E	5.5° W
7h 59m	N by E	S 30 9° E	S 32.5° E	1.6° W
8h 3m	N N E	S 35.2° E	S 34.3° E	.9° E
8h 5m	N E by N	S 38.7° E	S 35.4° E	3.3° E
8h 8m	N E	S 40.8° E	S 36.3° E	4.5° E

1. That dynamos and electric motors should be placed as far as possible from all compasses and at a distance of at least 30 ft. from the standard compass.

2. That wires conducting electric currents should not come nearer than 16 ft. to any compass, whereas wires conducting strong currents should be at a still greater distance.

3. That the compensating of compasses should be done when the dynamos are at rest, while the operations for determining the deviation should be performed when the dynamos are running.

CORRECTION OF COURSES

Compass course is the course steered by a ship. It may be affected by variation, deviation, and leeway; and in order to find the corresponding true course proper allowance must be made for any or all of these errors.

True course is equal to the compass course corrected for variation, deviation, and leeway; or, it is the angle that the ship's track over ground makes with the true, or geographical, meridian.

Leeway is the result of the pressure that the sea or wind exerts on the hull and sails of a ship, causing her to drift sideways. The amount of leeway varies with the strength of wind, form of hull under water, etc. It is usually estimated by eye, the observer being guided by the angle between the ship's wake and fore-and-aft line, and is expressed in points and fractions of a point.

To find the true course from a given compass course apply easterly variation and deviation to the right, and westerly variation and deviation to the left. Allow leeway in direction toward which the wind is blowing.

Example.—Compass course is S W by W ¼ W, deviation 14° W, variation 20° E, wind S S E, leeway 2¼ points; find the true course.

Solution.— Comp. course = S W by W ¼ W
Leeway (to the right) = 2¼ points

Course through water = W ½ S
or = S 84° 22′ W
Dev. = 14° 0′ W

Mag. course = S 70° 22′ W
Var. = 20° 0′ E

True course = S 90° 22′ W
or = west. Ans.

Example.—Compass course S E by S, deviation 11° E, variation 25° W, wind S W by S, leeway ¼ point; required the true course.

Solution.—

Comp. course	= S E by S
Leeway (to the left)	= ¼ point
Course through water	= S E ¾ S
	or = S 36° 34′ E
Dev.	= 11° 0′ E
Mag. course	= S 25° 34′ E
Var.	= 25° 0′ W
True course	= S 50° 34′ E
	or = S 51° 0′ E. Ans.

To find the compass course from a given true course apply westerly variation and deviation to the right, and easterly variation and deviation to the left. If leeway, apply against the wind.

Example.—Required the compass course, having given true course N 8° W, variation 17° 10′ W, deviation 3° 20′ E; the wind is easterly and the leeway estimated to ½ point.

Solution.—

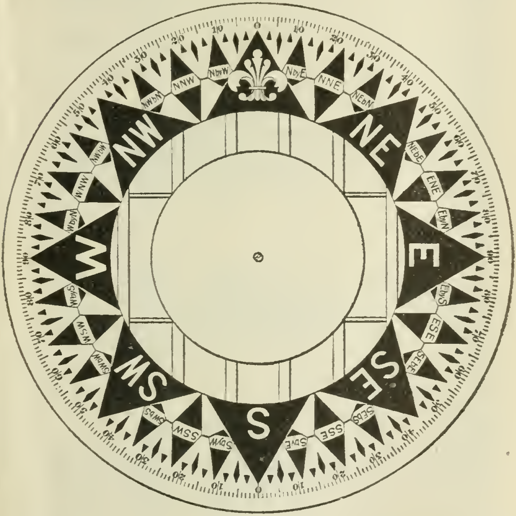
True course	= N 8° 0′ W
Var.	= 17° 10′ W
Mag. course	= N 9° 10′ E
Dev.	= 3° 20′ E
	N 5° 50′ E
Leeway ½ point	= 5° 37′ (against the wind)
Comp. course	= N 11° 27′ E
	or = N by E, nearly. Ans.

Example.—The true course to a certain point is N 30° E, the variation is 28° W, deviation 6° E; find what course to steer by the compass.

Solution.—

True course	= N 30° E
Var.	= 28° W
Mag. course	= N 58° E
Dev.	= 6° E
Comp. course	= N 52° E. Ans.

In correcting courses, it is well to bear in mind that, since the compass card is the representation of the visible horizon, the position of the observer is considered to be at the center of the compass card. Hence, when applying corrections, whether to right or left, always consider yourself



to be stationed at the center of the card and looking in the direction of the course to be corrected.

In the above figure, representing a compass card, quarter-points are indicated by small triangles, and half-points by elongated diamonds; each subdivision is designated by reference to the compass points between which they are situated, as shown in the following tables.

NAMES OF POINTS AND NUMBER OF DEGREES, MINUTES, AND SECONDS CORRESPONDING TO ANY NUMBER OF POINTS AND FRACTIONS THEREOF

North to East	North to West	South to East	South to West	Points	Points in Degrees, Etc.
North	North	South	South		
N ¼ E	N ¼ W	S ¼ E	S ¼ W	¼	2° 48′ 45″
N ½ E	N ½ W	S ½ E	S ½ W	½	5° 37′ 30″
N ¾ E	N ¾ W	S ¾ E	S ¾ W	¾	8° 26′ 15″
N by E	N by W	S by E	S by W	1	11° 15′ 0″
N by E ¼ E	N by W ¼ W	S by E ¼ E	S by W ¼ W	1¼	14° 3′ 45″
N by E ½ E	N by W ½ W	S by E ½ E	S by W ½ W	1½	16° 52′ 30″
N by E ¾ E	N by W ¾ W	S by E ¾ E	S by W ¾ W	1¾	19° 41′ 15″
N N E	N N W	S S E	S S W	2	22° 30′ 0″
N N E ¼ E	N N W ¼ W	S S E ¼ E	S S W ¼ W	2¼	25° 18′ 45″
N N E ½ E	N N W ½ W	S S E ½ E	S S W ½ W	2½	28° 7′ 30″
N N E ¾ E	N N W ¾ W	S S E ¾ E	S S W ¾ W	2¾	30° 56′ 15″
N E by N	N W by N	S E by S	S W by S	3	33° 45′ 0″
N E ¾ N	N W ¾ N	S E ¾ S	S W ¾ S	3¼	36° 33′ 45″
N E ½ N	N W ½ N	S E ½ S	S W ½ S	3½	39° 22′ 30″
N E ¼ N	N W ¼ N	S E ¼ S	S W ¼ S	3¾	42° 11′ 15″
N E	N W	S E	S W	4	45° 0′ 0″

NAMES OF POINTS AND NUMBER OF DEGREES, MINUTES, AND SECONDS CORRESPONDING TO ANY NUMBER OF POINTS AND FRACTIONS THEREOF—(*Continued*)

North to East	North to West	South to East	South to West	Points	Points in Degrees, Etc.
N E $\frac{1}{4}$ E	N W $\frac{1}{4}$ W	S E $\frac{1}{4}$ E	S W $\frac{1}{4}$ W	$4\frac{1}{4}$	47° 48′ 45″
N E $\frac{1}{2}$ E	N W $\frac{1}{2}$ W	S E $\frac{1}{2}$ E	S W $\frac{1}{2}$ W	$4\frac{1}{2}$	50° 37′ 30″
N E $\frac{3}{4}$ E	N W $\frac{3}{4}$ W	S E $\frac{3}{4}$ E	S W $\frac{3}{4}$ W	$4\frac{3}{4}$	53° 26′ 15″
N E by E	N W by W	S E by E	S W by W	5	56° 15′ 0″
N E by E $\frac{1}{4}$ E	N W by W $\frac{1}{4}$ W	S E by E $\frac{1}{4}$ E	S W by W $\frac{1}{4}$ W	$5\frac{1}{4}$	59° 3′ 45″
N E by E $\frac{1}{2}$ E	N W by W $\frac{1}{2}$ W	S E by E $\frac{1}{2}$ E	S W by W $\frac{1}{2}$ W	$5\frac{1}{2}$	61° 52′ 30″
N E by E $\frac{3}{4}$ E	N W by W $\frac{3}{4}$ W	S E by E $\frac{3}{4}$ E	S W by W $\frac{3}{4}$ W	$5\frac{3}{4}$	64° 41′ 15″
E N E	W N W	E S E	W S W	6	67° 30′ 0″
E N E $\frac{1}{4}$ E	W N W $\frac{1}{4}$ W	E S E $\frac{1}{4}$ E	W S W $\frac{1}{4}$ W	$6\frac{1}{4}$	70° 18′ 45″
E N E $\frac{1}{2}$ E	W N W $\frac{1}{2}$ W	E S E $\frac{1}{2}$ E	W S W $\frac{1}{2}$ W	$6\frac{1}{2}$	73° 7′ 30″
E N E $\frac{3}{4}$ E	W N W $\frac{3}{4}$ W	E S E $\frac{3}{4}$ E	W S W $\frac{3}{4}$ W	$6\frac{3}{4}$	75° 56′ 15″
E by N	W by N	E by S	W by S	7	78° 45′ 0″
E $\frac{3}{4}$ N	W $\frac{3}{4}$ N	E $\frac{3}{4}$ S	W $\frac{3}{4}$ S	$7\frac{1}{4}$	81° 33′ 45″
E $\frac{1}{2}$ N	W $\frac{1}{2}$ N	E $\frac{1}{2}$ S	W $\frac{1}{2}$ S	$7\frac{1}{2}$	84° 22′ 30″
E $\frac{1}{4}$ N	W $\frac{1}{4}$ N	E $\frac{1}{4}$ S	W $\frac{1}{4}$ S	$7\frac{3}{4}$	87° 11′ 15″
East	West	East	West	8	90° 0′ 0″

NAMES OF COMPASS POINTS IN VARIOUS LANGUAGES

English	French	German	Spanish	Swedish	Italian
North	Nord.	Nord.	Norte.	Nord.	Tramontana
N by E	N. quart N. E.	N. zu O.	N. cuarto N. E.	N. till O.	T. quarto G.
N N E	N. N. E.	N. N. O.	N. N. E.	N. N. O.	G. T.
N E by N	N. E. quart N.	N. O. zu N.	N. E. cuarto N.	N. O. till N.	G. quarto T.
N E	N. E.	N. O.	N. E.	N. O.	Greco.
N E by E	N. E. quart E.	N. O. zu O.	N. E. cuarto E.	N. O. till O.	G. quarto L.
E N E	E. N. E.	O. N. O.	E. N. E.	O. N. O.	G. L.
E by N	E. quart N. E.	O. zu N.	E. cuarto N. E.	O. till N.	L. quarto G.
East	Est.	Ost.	Este.	Ost.	Levante
E by S	E. quart S. E.	O. zu S.	E. cuarto S. E.	O. till S.	L. quarto S.
E S E	E. S. E.	O. S. O.	E. S. E.	O. S. O.	S. L.
S E by E	S. E. quart E.	S. O. zu O.	S. E. cuarto E.	S. O. till O.	S. quarto L.
S E	S. E.	S. O.	S. E.	S. O.	Scirocco
S E by S	S. E. quart S.	S. O. zu S.	S. E. cuarto S.	S. O. till S.	S. quarto O.
S S E	S. S. E.	S. S. O.	S. S. E.	S. S. O.	O. S.
S by E	S. quart S. E.	S. zu O.	S. cuarto S. E.	S. till O.	O. quarto S.

NAMES OF COMPASS POINTS IN VARIOUS LANGUAGES—(*Continued*)

English	French	German	Spanish	Swedish	Italian
South	Sud.	Sud.	Sur.	Syd.	Ostro.
S by W	S. quart S. O.	S. zu W.	S. cuarto S. O.	S. till W.	O. quarto L.
S S W	S. S. O.	S. S. W.	S. S. O.	S. S. W.	O. L.
S W by S	S. O. quart S.	S. W. zu S.	S. O. cuarto S.	S. W. till S.	L. quarto O.
S W	S. O.	S. W.	S. O.	S. W.	Libeccio
S W by W	S. O. quart O.	S. W. zu W.	S. O. cuarto O.	S. W. till W.	L. quarto P.
W S W	O. S. O.	W. S. W.	O. S. O.	W. S. W.	P. L.
W by S	O. quart S. O.	W. zu S.	O. cuarto S. O.	W. till S.	P. quarto L.
West	Ouest.	West	Oeste.	West	Ponente.
W by N	O. quart N. O.	W. zu N.	O. cuarto N. O.	W. till N.	P. quarto M.
W N W	O. N. O.	W. N. W.	O. N. O.	W. N. W.	P. M.
N W by W	N. O. quart O.	N. W. zu W.	N. O. cuarto O.	N. W. till W.	M. quarto P.
N W	N. O.	N. W.	N. O.	N. W.	Maestro.
N W by N	N. O. quart N.	N. W. zu N.	N. O. cuarto N.	N. W. till N.	M. quarto T.
N N W	N. N. O.	N. N. W.	N. N. O.	N. N. W.	M. T.
N by W	N. quart N. O.	N. zu W.	N. cuarto N. O.	N. till W.	T. quarto M.

THE USE OF PELORUS IN HEADING A SHIP IN ANY DESIRED MAGNETIC DIRECTION

On the date of observation, select, beforehand, a suitable hour of local apparent time, and estimate also, in advance, by dead reckoning, the position of the ship for the hour in which the observation is to be made. With the latitude of the position thus found and the declination, enter the azimuth tables and find the true azimuth or bearing of the sun for the selected hour of apparent time; apply to this true azimuth the variation of the locality taken from the chart; the result will be the magnetic bearing of the sun for the time selected. Shortly before the time selected, and when the ship has reached the position decided on, set that point of the pelorus corresponding with the required magnetic direction to the ship's head and turn the sight vanes of the instrument to correspond with the magnetic bearing of the sun previously found. Then clamp the plate and sight vanes of the instrument. Turn the ship by means of the rudder until the sight vanes are directed toward the sun, and keep them in this position until the exact instant of the local apparent time selected. At that instant the ship's head will correspond with the correct magnetic direction required; any difference shown by the compass at that instant will be the deviation for that heading.

Illustration.—Let it be required, on September 12, 1904, to head the ship correct magnetic North at 2:20 P. M. local apparent time. At the hour selected the ship is estimated to be near Cape Flattery in lat. 44° 30′ N and long. 126° W, the variation for that locality being about 23° E. Proceed as follows: First find the Greenwich apparent time corresponding to the local apparent time selected, and then the declination; thus,

L. App. T., Sept. 12 = $2^h\ 20^m$ P. M.
Long. W. in time = $8^h\ 24^m$
G. App. T., Sept. 12 = $10^h\ 44^m$ P. M.

Sun's Decl. = N 4° 14′ 58″		Change in 1^h = 57″
Corr. for 10.7^h =	−10′ 10″	× 10.7^h
Corr. Decl. = N 4° 4′ 48″		609.9
		Corr. = 10′ 9.9″

The azimuth tables are then entered with the local apparent time, the latitude, and the declination; the corresponding true azimuth is found to be N 132° W. The variation applied to this will give the sun's magnetic azimuth, or bearing; thus,

True azimuth = N 132° W
Variation = 23° E

Sun's Mag. bearing = N 155° W or S 25° W, at 2:20 P. M.

Before reaching the locality decided on, set the north point of the pelorus to correspond with the ship's head, and the sight vanes to S 25° W, clamping both plate and vanes. A few minutes before 2:20 P. M. turn the ship so that the vanes point directly toward the sun; keep them in this direction by means of the helm until the watch set to local apparent time (or its equivalent in mean time) shows 2:20 P. M. At that instant, the ship is heading correct magnetic north. Suppose the steering compass at that time shows N ½ W; the deviation will then be ½ point or 5.5° E, because the compass north falls to the right of the magnetic north.

If it be required at any time to find the true course the ship is heading, the sight vanes of the pelorus are set and clamped at an angle equal to the true azimuth, corresponding to time, declination, and latitude at observation; at the proper time the sight vanes are swung in the direction of the sun, when the lubber line of the pelorus will give the true course on which the ship is heading. By applying to this the variation of the locality the deviation for heading is readily found.

TERRESTRIAL NAVIGATION

TERMS RELATING TO NAVIGATION

A **sphere** is a solid bounded by a surface every point of which is at equal distance from a fixed common point called the *center*. A *radius* of a sphere is a straight line drawn from the center to the surface. A straight line passing through the center and terminated at both ends by the surface is called a *diameter* of the sphere.

A **great circle** is a section of a sphere made by a plane passing through its center. The shortest distance measured on the surface between two points on a sphere is the arc of the great circle joining these two points.

A **small circle** is a section of a sphere made by a plane that does not pass through the center.

Hemisphere.—A great circle divides the sphere into two equal parts, each of which is called a **hemisphere.**

A **spherical angle** is the angle subtended between two great circles.

A **spherical triangle** is a portion of a sphere bounded by three arcs of great circles.

The **axis of the earth** is the diameter around which the earth daily revolves with uniform motion from west to east; the revolution being completed in 24 hr.

The **poles of the earth** are the extremities of its axis, or the points in which the axis meets the surface.

The **equator** is a great circle on the earth's surface equidistant from the poles. It divides the earth into two equal parts—the *northern hemisphere* and the *southern hemisphere.* The poles of the earth are the poles of the equator, every point of the latter being 90° from either pole. The equator of the earth is generally referred to as the *terrestrial* or *geographical equator.*

The **meridians** of the earth are great circles that pass through the poles of the earth, and are therefore perpendicular to the equator.

Prime Meridian.—The first, or prime, meridian is that fixed meridian by reference to which the longitude of places on the earth is measured; as, for example, the meridian of Greenwich.

Parallels of latitude are small circles whose planes are parallel to the plane of the equator.

Latitude.—The latitude of any place is the distance north or south from the equator measured on the meridian that passes through the place; it may be of any value from 0° to 90° N or S.

Longitude.—The longitude of any place is the distance in arc east or west measured on the equator from the first meridian to the meridian passing through that place. Longitude is reckoned from 0° to 180° E or W, but is never considered greater than 180° either way. Longitude is also measured in hours, minutes, and seconds, each hour being equal to 15°.

Difference of latitude is the arc of a meridian contained between the two latitude parallels passing through any two places.

Difference of longitude is the portion of the equator contained between the meridians passing through any two places.

Rhumb.—When a ship is kept on one continuous course, her track crosses the meridians at the same angle. The line representing this track is called the **rhumb** or **loxodromic curve.**

The **distance** between two places, or the distance run by the ship on any course, is the length of the rhumb joining the two places, expressed in miles.

Departure is the distance made good by a ship due east or west, or the distance between any two places measured on one of their parallels; it is expressed in miles.

The **course made good** is equivalent to true course, or the angle between a meridian and the ship's track over ground.

The **bearing** of an object or place is the angle that the direction of the object or place makes with the meridian, and is the same as the course toward it.

Plane sailing is the method of finding the ship's position by assuming the surface sailed over to be a plane. It is used only for short runs.

Middle latitude of two plaçes is the latitude of a parallel midway between the two places; or, it is equal to half the sum of the two latitudes when the places considered are on the same side of the equator.

Parallel sailing is the method of calculating a ship's position when the ship has run a continuous course true east or true west.

Middle-latitude sailing is a combination of plane and parallel sailing, or a method of calculating the position of a ship by assuming that the departure made by the ship is equal to the distance along the middle-latitude parallel.

Mercator's sailing is a method of calculating the position of a ship by using meridional parts.

Meridional parts of a certain latitude give the length, expressed in minutes of the equator, of the line on a Mercator's chart that represents the latitude.

Meridional difference of latitude is the difference between the meridional parts for any two latitudes; or, the length of the line on a Mercator's chart that represents the difference of latitude.

Traverse sailing is the method of reducing to a single course and distance the several courses and distances run by a vessel during a certain period of time.

Traverse tables are a collection, in tabular form, of the lengths of the sides of a right triangle in which one acute angle (course) varies from 1° to 89°, and the hypotenuse (distance) from 1 to 300 mi.; or, they contain the true difference of latitude and departure corresponding to every course from 0° to 90°, and for every distance from 1 to 300 mi.

Great-circle sailing is the various methods of determining, graphically, or by calculation, the compass courses and distances to be run in order to follow the great-circle track from one place to another.

Initial course is the first course run along a great-circle track.

Final course is the last course run along a great-circle track.

Point of maximum separation is the point of a great-circle track that is farthest from the rhumb track. At this point, the courses on both tracks are parallel with each other.

Vertex of a great circle is the point on a great circle having the highest latitude.

Composite sailing is a combination of great-circle and parallel sailing.

NAVIGATION BY DEAD RECKONING

The cases of sailing that most frequently present themselves in the actual navigation of a vessel may consistently be said to be two in number, as follows:

1. When the latitude and longitude of two places are known, to find the course, distance, and departure from one place to the other.

2. When the place left and the course and distance run are known, to find the latitude and longitude of the place arrived at.

Either of these cases may be worked by middle latitude or Mercator's sailing, according to formula given in the accompanying table.

Cases	Middle-Latitude Sailing	Mercator's Sailing
Both latitudes and longitudes given, to find course, distance, and departure	Dep. = D. Long. × cos M. Lat. tan C = cos M. Lat. × D. Long. ÷ D. Lat. tan C = Dep. ÷ D. Lat. Dist. = D. Lat. × sec C Dist. = Dep. × cosec C	tan C = D. Long. ÷ M. D. Lat. Dist. = D. Lat. × sec C Dep. = D. Lat. × tan C Dep. = (D. Lat. × D. Long.) ÷ M. D. Lat.
Place left, course and distance known, to find difference of latitude, departure, and difference of longitude	D. Lat. = Dist. × cos C Dep. = Dist. × sin C D. Long. = Dep. × sec M. Lat. D. Long. = D. Lat. × tan C × sec M. Lat.	Dep. = Dist. × sin C D. Lat. = Dist. × cos C D. Long. = M. D. Lat. × tan C D. Long. = (Dep. × × M. D. Lat.) ÷ D. Lat.

If the distance is less than 300 mi., the middle-latitude method may be used; if greater than 300 mi., Mercator's method should be employed, except in cases where the course is large or very near east or west, when it is preferable to use the former method.

The reason it is preferable to use the middle-latitude method in finding the difference of longitude when the course is large, is that tangents for angles between 80 – 90°

change very rapidly, and hence when using the formula D. Long. = M. D. Lat. × tan C, if there is an error in the course, the resulting D. Long. will be considerably in error. Therefore, when the course is large or nearly 90°, it is better to find the difference of longitude by the middle-latitude formula, D. Long. = Dep. × sec M. Lat., in which the tangent is not used.

Example.—A ship in lat. 37° 3′ N and long. 23° 18′ W is bound for a point, the latitude and longitude of which are, respectively, 32° 38′ N and 31° 13′ W; required the true course and the number of miles to be covered.

Solution By Middle-Latitude Method.—

Lat. left = 37° 3′ N
Lat. in = 32° 38′ N
D. Lat. = 4° 25′ = 265′ S
Sum of Lats. = 69° 41′
½ sum = 34° 50′ = M. Lat.
Long. left = 23° 18′ W
Long. in = 31° 13′ W
D. Long. = 7° 55′ = 475′ W

tan C = cos M. Lat. × D. Long. ÷ D. Lat.
log cos 34° 50′ = 9.91425
log 475 = 2.67669
a. c. log 265 = 7.57675
log tan C = 10.16769
Course = S 55° 48′ W. Ans.

Dist. = D. Lat. × sec C.
log 265 = 2.42325
log sec 55° 48′ = 10.25020
log Dist. = 2.67345
Dist. = 471.5 mi. Ans.

By Traverse Tables.—Enter the Tables with the M. Lat. 34° 50′ (or 35° nearly) as course and the D. Long. 475′ in the distance column, when the departure will be found in the latitude column. Thus,

for 300 we get 245.7
for 175 we get 143.4
Whence, for 475 we get 389.1 mi. as departure

Having found the departure, enter the Tables again with 132.5 (half D. Lat.) and 194.5 (half Dep.) in a latitude and departure column, respectively, and find the corresponding course and distance. The course thus found is nearly 56°, or 5 points and half the distance is 235, which, when doubled, gives the distance as 470 mi. Ans.

Example.—A ship in lat. 32° 15′ N and long. 67° 52′ W is bound for a point in lat. 49° 57′ N and long. 8° 12′ W; find the true course and distance to be run.

Solution.—By Mercator's Sailing.—First find the D. Lat., the M. D. Lat., and the D. Long. as follows, and then calculate the course and distance according to proper formulas taken from the preceding table.

1st Lat. = 32° 15′ N   M. P. = 2,033.9
2d Lat. = 49° 57′ N   M. P. = 3,452.2

D. Lat. = 17° 42′   M. D. Lat. = 1,418.3
or = 1,062′ N.

1st Long. = 67° 52′ W
2d Long. = 8° 12′ W

D. Long. = 59° 40′
or = 3,580′ E

$\tan C = \text{D. Long.} \div \text{M. D. Lat.}$

$\log 3{,}580\ (+10) = 13.55388$

$\log 1{,}418.3 = 3.15168$

$\log \tan C = 10.40220$

Course = N 68° 23′ E. Ans.

$\text{Dist.} = \text{D. Lat.} \times \sec C$

$\log 1{,}062 = 3.02612$

$\log \sec 68° 23' = 10.43369$

$\log \text{Dist.} = 3.45981$

Dist. = 2,883 mi. Ans.

By Traverse Tables.—Enter the Tables with M. D. Lat. in a latitude column and the D. Long. in a departure column, and find the corresponding course. Then, with this course and the D. Lat., find the required distance. In this case, the numbers 1,418 and 3,580 are too large, and we, therefore, divide each by 100 and enter the Tables with 14.1 and

35.8 instead and get a course of 68°. Then, with the corresponding course 68° and the D. Lat. worked by similar artifice, $1,062 \div 10 = 106.2$, the distance found is 2,835. Now, this distance does not agree with that obtained by calculation, but can be made much closer by a simple proportion, if deemed necessary. The correct course is 68° 23′, not 68°, and we therefore must make an allowance for the 23′; thus,

with 68° as course and 1,062 D. Lat., the distance is	2,835 mi.
and with 69° as course and 1,062 D. Lat., the distance is	2,963 mi.
The difference, therefore, for 60′ of the course is	128 mi.

Whence, for 23′ it must be $\frac{23 \times 128}{60} = 49$ mi. This, when added to the distance corresponding to the lesser course, will produce a more correct value of the required distance, or $49 + 2,835 = 2,884$ mi., which very nearly agrees with that derived by computation. Ans.

Example.—From a place in lat. 52° 6′ N and long. 38° 27′ W, a vessel runs N 56° W, 229 mi.; find her latitude and longitude in.

Solution.—By the Middle-Latitude Method.—

D. Lat. = Dist. × cos C	Lat. left = 52° 6′ N
log 229 = 2.35984	D. Lat. = 2° 8.1′ N
log cos 56° = 9.74756	Lat. in = 54° 14.1′ N. **Ans.**
log D. Lat. = 2.10740	Sum of Lats. = 106° 20.1′
D. Lat. = 128.1′ N	½ sum = 53° 10′ = M. **Lat.**

D. Long. = D. Lat. × tan C × sec M. Lat.

log 128.1 = 2.10740
log tan 56° = 10.17101
log sec 53° 10′ = 10.22222
log D. Long. = 2.50063
D. Long. = 316.7′ W

Long. left = 38° 27′ W
D. Long. = 316.7′ = 5° 16.7′ W
Long. in = 43° 43.7′ W. Ans.

By Traverse Tables.—Enter Tables with course 56° and distance 229 and find the corresponding D. Lat. 128.1 and Dep. 189.8 in their respective columns. Then, with the M. Lat. as course and the Dep. just found, enter the Tables again with Dep. in a latitude column when the required D. Long. is found in the distance column. Thus,

for 144.4 we get 240′ D. Long.
for 45.4 we get 76′ D. Long.

Whence, for 189.8 we get 316′ D. Long.

This applied to the longitude left will give the longitude in as 43° 43′ W. Ans.

Example.—From a point situated in lat. 49° 52′ S and long. 27° 15′ W, a ship steams 513.5 mi., steering a true course N 26° 36′ E; find the latitude and longitude in.

Solution.—*By Mercator's Sailing.*—

$$\text{D. Lat.} = \text{Dist.} \times \cos C$$
$$\log 513.5 = 2.71054$$
$$\log \cos 26° \, 36' = 9.95141$$
$$\log \text{D. Lat.} = 2.66195$$
$$\text{D. Lat.} = 459.1' \text{ N}$$

Lat. left = 49° 52′ S
D. Lat. = 7° 39′ N
Lat. in = 42° 13′ S

M. P. = 3444.5
M. P. = 2783.8
M. D. Lat. = 660.7

$$\text{D. Long.} = \text{M. D. Lat.} \times \tan C$$
$$\log 660.7 = 2.82000$$
$$\log \tan 26° \, 36' = 9.69963$$
$$\log \text{D. Long.} = 2.51963$$
$$\text{D. Long.} = 330.8' \text{ E}$$

Long. left = 27° 15′ W
D. Long. = 5° 31′ E
Long. in = 21° 44′ W. Ans.

By Traverse Tables.—Entering the Tables with N 26° 36′ E and the distance 513.5, the corresponding D. Lat. is found to be 459.4′. This value is obtained by taking the mean of the D. Lat. for 26° and 27°, respectively, the corresponding course being 26½°, nearly. To find the D. Long., the Tables are entered again in a similar manner with course and the M. D. Lat., 660.7, in a latitude column when the required D. Long. is found in the departure column. Ans.

THE DAY'S WORK

The operation of calculating at each noon the course and distance made good during the past 24 hr. is commonly known as the **day's work.** Each compass course run during the day is converted to true and, together with its distance, entered in a traverse, whence the course and distance made good and the latitude and longitude in are found from the total D. Lat. and Dep., either by calculation or by inspection of the Traverse Tables, as shown in the following example. Strictly speaking, the day's work includes the finding of the ship's position both by dead reckoning and astronomical observations. In the example that follows only the former method is considered.

The official *log book* of a ship should contain a carefully prepared record of the day's work, and, in fact, all important happenings that may occur on board ship. In it should be entered courses and distances run, with amount of leeway, variation, and deviation applicable to each. This is usually done at the end of each watch by the officer in charge of the deck, who inserts them in a scrap log; from the scrap log they are subsequently transferred to the official log book.

Example.—On June 16, 1904, at noon, a point in lat. 51° 53′ N and long. 55° 22′ W bore N N W by compass, the estimated distance being 48 mi. When bearing was taken the ship headed S E by S, the deviation for that point being recorded in the appended log account. From the place where bearing was taken the following compass courses and distances were run; find course and distance made good and the latitude and longitude of the ship at noon June 17, assuming a current setting correct magnetic east, 1½ mi. per hr., to have uniformly affected the ship during the entire run from noon to noon.

Log-Book Account

Hours	Knots	Tenths	Courses	Wind	Leeway	Dev.	Remarks
June 16							
1	12	0	South	E S E	¼	0	P. M.
2	11	5					
3	13	0					
4	13	5					
5	13	5	S S E	East	0	11° W	
6	13	5					
7	12	5					Var.36° W
8	12	5					
9	12	5	S E by S	E by N	¼	18° W	
10	12	5					
11	13	0					
12	12	0					Midnight
June 17							
1	12	0	E S E ¼ E	N E	1	27° W	A. M.
2	12	0					
3	12	0					
4	12	0					
5	12	0	E ½ N	N N E	½	29° W	
6	11	5					
7	12	0					Var.36° W
8	10	5					
9	10	5	S by E ¼ E	East	½	8° W	
10	10	0					
11	11	5					
12	12	0					Noon

Solution.—Correct each compass course for variation, deviation, and leeway; take the sum of distances run on each course. Correct current for variation and consider it as a separate course run. Reverse bearing, apply the necessary corrections, and enter it with the estimated distance in the Traverse as the first course and distance run. Thus,

1st Comp. C. =	South	2d Comp. C. =	S 22° 30′ E
Leeway =	2° 49′	Dev. =	11° 0′ W
	S 2° 49′ W		S 33° 30′ E
Var. =	36° 0′ W	Var. =	36° 0′ W
True C =	S 33° 11′ E	True C =	S 69° 30′ E
Dist. 50 mi.		Dist. 52 mi.	

3d Comp. C. =	S 33° 45′ E	4th Comp. C. =	S 70° 19′ E
Leeway =	2° 49′	Leeway =	11° 15′
	S 30° 56′ E		S 59° 4′ E
Dev. =	18° 0′ W	Dev. =	27° 0′ W
	S 48° 56′ E		S 86° 4′ E
Var. =	36° 0′ W	Var. =	36° 0′ W
True C. =	S 84° 56′ E	True C. =	S 122° 4′ E
Dist. 50 mi.		or =	N 57° 56′ E
		Dist. 48 mi.	

5th Comp. C. =	N 84° 22′ E	6th Comp. C. =	S 14° 4′ E
Leeway =	5° 38	Leeway =	5° 38′
	N 90° 0′ E		S 8° 26′ E
Dev. =	29° 0′ W	Dev. =	8° 0′ W
	N 61° 0′ E		S 16° 26′ E
Var. =	36° 0′ W	Var. =	36° 0′ W
True C. =	N 25° 0′ E	True C. =	S 52° 26′ E
Dist. 46 mi.		Dist. 44 mi.	

Bearing rev'd. =	S 22° 30′ E	Current (mag.) =	N 90° E
Dev. for SE by S =	18° 0′ W	Var. =	36° W
	S 40° 30′ E	True set =	N 54° E
Var. =	36° 0′ W	Rate or distance	
True rev'd. bear. =	S 76° 30′ E	for 24^h =	36 mi.
Dist. 48 mi.			

Enter the true courses thus found in a Traverse arranged in the form shown, and find from Traverse Tables the D. Lat. and Dep. corresponding to each course and distance. The total D. Lat. and Dep. made by the ship is found, respectively, by taking the algebraic sum of northerly and southerly differences of latitudes and easterly and westerly departures.

TRAVERSE

True Courses	Dist.	D. Lat.		Dep.	
		N	S	E	W
S 77° E	48		10.8	46.8	
S 33° E	50		41.9	27.2	
S 70° E	52		17.8	48.9	
S 85° E	50		4.4	49.8	
N 58° E	48	25.4		40.7	
N 25° E	46	41.7		19.4	
S 52° E	44		27.1	34.7	
N 54° E	36	21.2		29.1	
		88.3	102.0	296.6	E = Dep.
			88.3		

D. Lat. = 13.7′ S
Lat. left = 51° 53′ N
Lat. in = 51° 39.3′ N. Ans.
M. Lat. = 51° 46′

For Course

tan C = Dep. ÷ D. Lat
log 296.6 = 2.47217
log 13.7 = 1.13672
log tan C = 11.33545
Course = S 87° 21′ E. Ans.

For Distance

Dist. = D. Lat. × sec C
log 13.7 = 1.13672
log sec C = 1.33503
log Dist. = 2.47175
Dist. = 296.3 mi. Ans.

For Diff. Longitude

D. Long. = Dep. × sec M. Lat.
log 296.6 = 2.47217
log sec M. Lat. = .20840
log D. Long. = 2.68057
D. Long. = 479.3′ E

For Longitude In

Long. left = 55° 22′ W
D. Long. = 7° 59.3′ E
Long. in = 47° 22.7′ W. Ans.

The required data are found also by inspection of Traverse Tables in the usual manner. Thus, the nearest whole degree course corresponding to the D. Lat. 13.7 and Dep. 296.6 is S 87° E, the distance by tables being 297 mi.; with M. Lat. 52° as course and 29.6 in a latitude column, the corresponding number found in distance column is 48, which multiplied by 10 gives the D. Long. as 480′.

LENGTHS, IN NAUTICAL MILES, OF A DEGREE OF LONGITUDE FOR EACH DEGREE OF LATITUDE FROM 0° TO 90°

Lat. Degrees	Miles	Lat. Degrees	Miles	Lat. Degrees	Miles
1	59.99	31	51.43	61	29.09
2	59.96	32	50.88	62	28.17
3	59.92	33	50.32	63	27.74
4	59.85	34	49.74	64	26.30
5	59.77	35	49.15	65	25.36
6	59.67	36	48.54	66	24.40
7	59.55	37	47.92	67	23.44
8	59.42	38	47.28	68	22.48
9	59.26	39	46.63	69	21.50
10	59.09	40	45.96	70	20.52
11	58.89	41	45.28	71	19.53
12	58.69	42	44.59	72	18.54
13	58.46	43	43.88	73	17.54
14	58.22	44	43.16	74	16.54
15	57.95	45	42.43	75	15.53
16	57.67	46	41.68	76	14.52
17	57.38	47	40.92	77	13.50
18	57.06	48	40.15	78	12.48
19	56.73	49	39.36	79	11.45
20	56.38	50	38.57	80	10.42
21	56.01	51	37.76	81	9.38
22	55.63	52	36.94	82	8.35
23	55.23	53	36.11	83	7.31
24	54.81	54	35.27	84	6.27
25	54.38	55	34.41	85	5.23
26	53.93	56	33.45	86	4.18
27	53.46	57	32.68	87	3.14
28	52.97	58	31.79	88	2.00
29	52.48	59	30.09	89	1.05
30	51.96	60	30.00	90	.00

CONSTRUCTING A MERCATORIAL CHART

First, determine the limits of the proposed chart—in other words, the number of degrees and minutes it is to contain, both of latitude and of longitude. Then draw a straight line near the lower margin of the paper, if the chart is to represent north latitude; near the upper margin, if it is to represent south latitude; or at a suitable position in the center, if both north and south latitudes are to be represented. Divide this base line into as many equal parts as the number of degrees of longitude required; for instance, if the chart is to contain 15° of longitude, divide the line into 15 equal parts; if it is to contain 4° of longitude, divide it into 4 equal parts. At each extremity of the base line, erect lines perpendicular to it. Take from the Tables of Meridional Parts (I. C. S. Nautical Tables, or Bowditch) the meridional parts for each degree of latitude, for the limits between which the chart is to be drawn, and take the difference between each successive pair, thus obtaining the meridional differences of latitude. Reduce these meridional differences to degrees by dividing them by 60; the result will be the lengths, measured on the longitude scale, between the chosen degrees of latitude. Lay off these lengths successively on the perpendicular lines, and through the points thus obtained draw straight lines parallel to the base line, to represent latitude parallels. At convenient intervals, or through each division on the base line, draw lines parallel to the perpendiculars to represent meridians.

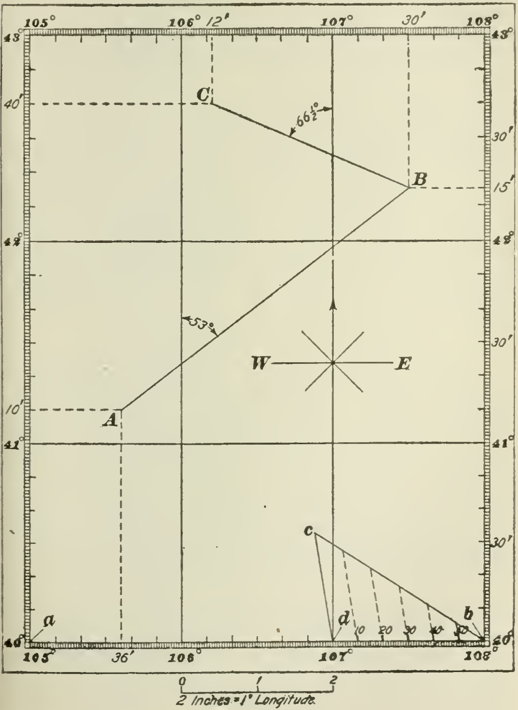
The accuracy of the frame of the chart thus completed should be tested by measuring the two diagonals of the rectangle formed; if they are of the same length, the frame is perfect. Then graduate the scale into suitable divisions of 5′ or 10′ each, or if deemed necessary divide each degree into 60 divisions, which will then represent minutes. The principal points in the chart are now laid down according to their respective latitudes and longitudes, and whatever formations and contours of water or land are required, together with other useful items, are drawn in freehand. Compass diagrams may also be inserted at convenient places, remembering that the direction of the meridians indicates true north and south.

Example.—Construct a Mercator's chart extending from lat. 40° to 43° N and from long. 105° to 108° E, on a scale of 2 in. to a degree of longitude. On this chart, plot the following positions: *A* lat. 41° 10′ N, long. 105° 36′ E; *B* lat. 42° 15′ N, long. 107° 30′ E; and *C* lat. 42° 40′ N, long. 106° 12′ E. Find the true course from *A* to *B*, then from *B* to *C*.

Solution.—Referring to the chart, draw a line *a b* at the bottom margin of the paper to represent the 40th parallel. On this base line, lay off three lengths of .2 in. each and divide each length into 60 equal parts, representing minutes or nautical miles. This is conveniently done by the method shown in the lower right-hand corner of the chart, which consists in drawing a pencil line *b c* at an angle of about 45° from the extremity of a degree and dividing it into a desired number of equal divisions directly from the rule used; the last division of this line is then connected with the other extremity *d* of the degree, and lines parallel to this line are drawn from each division: the lines thus drawn will divide the degree into the desired number of equal parts, as shown. Proceed similarly in graduating the other degrees. Next, consult the Table of Meridional Parts and take out the values corresponding to each degree of latitude and obtain the meridional differences of latitude as indicated below.

Lat.	*M. P.*	*M. D. Lat.*
40°	2,607.9	78.6 ÷ 60 = 1° 18.6′ (40°–41°)
41°	2,686.5	79.8 ÷ 60 = 1° 19.8′ (41°–42°)
42°	2,766.3	81.1 ÷ 60 = 1° 21.1′ (42°–43°)
43°	2,847.4	

This being complied with, take, with a pair of dividers, 1° 18.6′ from the longitude scale and lay it off on each perpendicular from the base line; and through the points thus obtained, draw the parallel of 41°. In like manner, from the parallel 41°, lay off the next length 1° 19.8′ taken from the longitude scale, and draw the parallel of 42°. Proceed similarly and get the parallel of 43°. Divide this last parallel into degrees and minutes the same as the parallel



of 40°, at the bottom of the chart, and draw the meridians of 106° and 107° east longitude. The frame of the chart is then completed and the positions *A*, *B*, and *C* may now be plotted in the usual manner.

Joining *A* and *B* with a straight line, we find the course between the two points to be N 53° E. In like manner, we find the course from *B* to *C* to be N 66½° W, nearly. Ans.

It is very useful to a navigator, in case charts are lost or destroyed, to be able to construct a substitute for temporary use.

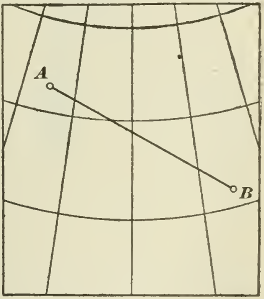
In connection with the use of charts, especially old charts, care should be taken that all changes in the position or character of lights, the establishment of new or discontinuation of existing lights, buoys, landmarks, etc., are properly noted on the chart before it is used, also the exact location of sunken wrecks and other obstructions as given in **Notice to Mariners.** This work of correcting charts is, as a rule, performed free of cost by officers in charge of Branch Hydrographic Offices located in the principal ports along the seaboard.

PLOTTING A GREAT-CIRCLE TRACK

Let the appended diagram represent a **gnomonic,** or **great-circle chart,** the straight line *A B* being the great-circle track between the two places *A* and *B*. In order to transfer this track to a Mercator's chart, select a few points along the line and find, by inspection, the latitude and longitude of each. Plot these points carefully on the Mercatorial chart and draw a uniform curve passing through all points thus established. This curve will be the great-circle track and the courses and distance to be run, in order to follow this track, may be conveniently found as follows: Get the difference between the initial course and the course at the point of maximum separation (equal to the rhumb course) and find how many quarter points are contained in it. Divide the distance between the first place and the point of maximum separation by this number of quarter points; the result will be the number of miles to be sailed on each quarter-point course.

For instance, assume the initial course to be N W, the course at the point of maximum separation W N W, and the distance between these points 800 mi. Now, the difference between N W and W N W is 2 points, or 8 quarter points; hence, dividing 800 mi. by 8 will give 100 mi. for each quarter-point course. In other words, the course will have to be changed one-quarter of a point to the west for every 100 mi. run.

Proceed, similarly, to find the course and distance from the point of maximum separation to the point of destination. It is evident that the difference between the courses can be divided into still smaller divisions if required; for instance, in the case just mentioned, it may be divided into eighths of a point; the course will then have to be changed one-eighth of a point for each 50 mi. run. For ordinary practice, however, quarter points will suffice.



The courses thus found are true and must be corrected for variation, deviation, and leeway, if any.

On great-circle charts published by the United States Hydrographic Office will be found a Great-Circle Course Diagram, by which courses and distances along the track are conveniently found by inspection. Directions how to use this diagram are printed on the chart under the head of Explanation.

USEFUL METHODS IN COAST NAVIGATION

Cross-Bearings.—When the bearings of two selected objects are corrected for deviation, due to the direction of the ship's head at the time of observing them, place the parallel ruler on the nearest magnetic compass rose on the chart so that the edge passes through the center and the requisite degree or point on the circumference. Then move the ruler, step by step, until the edge passes through the object when a light pencil line drawn along the edge will represent one of the bearings. The ship will then be somewhere on the line. Proceed similarly with the other bearing. Now, the ship will be somewhere on this line also, and since the only common point of two lines intersecting each other is at their point of intersection, the position of the ship on the chart must necessarily be at the point where the two bearings intersect.

It is evident that the objects selected for cross-bearings should be so situated that the lines of bearing do not intersect at a very acute angle, since the point of intersection in such cases is somewhat doubtful. To obtain accurate results, the angle between the bearings should be as near as possible to 90°, or 8 points.

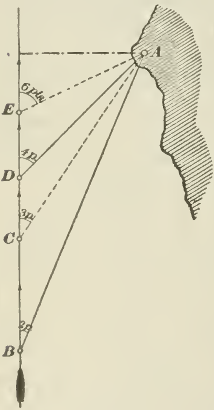


Fig. 1

Bow-Bearings.—A compass bearing is taken of a light or other prominent known object when it is 2, 3, or 4 points off the bow, and the time and log noted. When the bearing has doubled, the log and time are again noted. (If a patent log is used, it is not necessary to note the time, but simply the indicator of the log at both bearings.) The distance of the ship from the object is then equal to the distance run in the interval between the first and second bearing, or, the difference of readings of the patent log at the two bearings.

By using this method when the object bears 2 or 3 points off the bow, the distance of vessel from *A* is known before the object is abeam, as shown in the figure.

Illustration.—Referring to the figure, suppose that the reading of the patent log when at *B* is 69.6 mi., and when at *D*, or when bearing is doubled, it is 74.2 mi. The distance of ship from A is then $74.2-69.6=4.6$ mi. In other words, $BD=DA$; also, in case C and E are considered, $CE=EA$. This method is frequently used when the ship is at D, or when object bears 4 points off the bow, and is then known as **4-point bearing.** Doubling this angle, the ship is exactly abeam of object.

Bearings of Same Object and Distance Run.—A compass bearing is taken of some known object at any instant and the number of points, or degrees, contained between its direction and the ship's head, or course, are noted. A straight continuous course is then kept until the bearing of the object has altered at least 3 points, when another bearing is taken and the number of points between it and the ship's head are again noted.

These angles, if expressed in points, are then entered in the table found on page 112, or, if expressed in degrees, in the table on the following page, and the distance is found as follows: With the first number of points, or degrees, at the top and the second angle at the side column, find the corresponding number; multiply this by the number of miles run in the interval between bearings. The product is the distance, in miles, at the time the second bearing was taken.

Example.—A certain lighthouse bore N N W; 2 hr. later, after the ship had run true west 12 mi., the bearing of the same light was N E by N; required, the distance of the ship from the light at the second bearing.

Solution.—The number of points included between the first bearing and the ship's head is 6; between the second bearing and the ship's head there are 11 points. Entering the proper Table with 6 points at the top and with 11 points in the side column, we find, below the former and opposite the latter, the number 1.11; multiplying this by 12, the number of miles run in the interval between bearings, the product, $1.11\times12=13.3$ mi., which will be the distance of the ship from the light at the time of taking the second bearing. Ans.

TABLE FOR FINDING DISTANCE FROM AN OBJECT BY TWO BEARINGS AND DISTANCE RUN BETWEEN THEM

Difference Between Course and Second Bearing	Difference Between Course and First Bearing, in Points																	
Points	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½
4	1.00																	
4½	.81	1.23																
5	.69	1.00	1.45															
5½	.60	.85	1.18	1.66														
6	.54	.74	1.00	1.35	1.85													
6½	.50	.67	.88	1.14	1.50	2.02												
7	.46	.61	.79	1.00	1.27	1.64	2.17											
7½	.43	.57	.72	.90	1.11	1.39	1.76	2.30										
8	.41	.53	.67	.82	1.00	1.22	1.50	1.87	2.41									
8½	.40	.51	.63	.76	.91	1.09	1.31	1.59	1.96	2.50								
9	.39	.49	.60	.72	.85	1.00	1.18	1.39	1.66	2.03	2.56							
9½	.38	.48	.58	.69	.80	.93	1.08	1.25	1.46	1.72	2.08	2.60						
10	.38	.47	.57	.66	.77	.88	1.00	1.14	1.31	1.51	1.77	2.11	2.61					
10½	.38	.47	.56	.65	.74	.84	.94	1.06	1.20	1.35	1.55	1.79	2.12	2.60				
11	.39	.47	.56	.64	.72	.81	.90	1.00	1.11	1.24	1.39	1.57	1.80	2.11	2.56			
11½	.40	.48	.56	.63	.71	.79	.87	.95	1.05	1.15	1.27	1.41	1.58	1.79	2.08	2.50		
12	.41	.49	.57	.64	.71	.78	.85	.92	1.00	1.09	1.18	1.29	1.41	1.57	1.77	2.03	2.41	
12½	.43	.51	.58	.65	.71	.77	.84	.90	.97	1.04	1.11	1.20	1.29	1.41	1.55	1.72	1.96	2.30

TABLE FOR FINDING DISTANCE FROM AN OBJECT BY TWO BEARINGS AND DISTANCE RUN BETWEEN THEM

Difference Between Course and Second Bearing	Difference Between Course and First Bearing, in Degrees																	
Degrees	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
40	1.00																	
45	.81	1.24																
50	.68	1.00	1.46															
55	.59	.84	1.18	1.68														
60	.53	.74	1.00	1.36	1.88													
65	.48	.66	.87	1.15	1.52	2.07												
70	.44	.60	.78	1.00	1.28	1.67	2.24											
75	.42	.55	.71	.89	1.12	1.41	1.81	2.40										
80	.39	.51	.65	.81	1.00	1.23	1.53	1.94	2.53									
85	.38	.49	.61	.75	.91	1.10	1.33	1.64	2.05	2.65								
90	.36	.47	.58	.70	.84	1.00	1.19	1.43	1.73	2.14	2.75							
95	.35	.45	.55	.66	.78	.92	1.08	1.27	1.51	1.81	2.22	2.82						
100	.35	.44	.53	.63	.74	.86	1.00	1.16	1.35	1.58	1.88	2.28	2.88					
105	.34	.43	.52	.61	.71	.82	.93	1.07	1.22	1.41	1.64	1.93	2.33	2.91				
110	.34	.42	.51	.59	.68	.78	.88	1.00	1.13	1.28	1.46	1.68	1.97	2.36	2.92			
115	.34	.42	.50	.58	.66	.75	.84	.94	1.06	1.18	1.33	1.50	1.72	1.99	2.37	2.91		
120	.35	.42	.50	.58	.65	.73	.81	.90	1.00	1.11	1.23	1.37	1.53	1.74	2.00	2.36	2.88	
125	.35	.43	.50	.57	.64	.72	.79	.87	.95	1.05	1.15	1.26	1.39	1.55	1.74	1.99	2.33	2.82
130	.36	.44	.51	.58	.64	.71	.78	.85	.92	1.00	1.08	1.18	1.28	1.41	1.56	1.74	1.97	2.28

NOTE.—In using these tables, due allowance must be made for the effect of any current.

DISTANCES OF OBJECTS AT SEA, IN NAUTICAL MILES

The maximum distance at which an object is visible at sea according to its elevation and that of the observer, the weather being clear and the refraction normal, is shown by the following table:

Height Feet	Distance Nautical Miles	Height Feet	Distance Nautical Miles
5	2.56	110	12.07
10	3.63	120	12.60
15	4.44	130	13.12
20	5.15	140	13.62
25	5.75	150	14.08
30	6.30	200	16.26
35	6.81	250	18.18
40	7.27	300	19.92
45	7.71	350	21.51
50	8.13	400	23.00
55	8.53	450	24.39
60	8.91	500	25.71
65	9.27	550	26.97
70	9.62	600	28.17
75	9.96	650	29.32
80	10.28	700	30.43
85	10.60	800	32.53
90	10.91	900	34.50
95	11.21	1,000	36.36
100	11.50		

The distances of visibility given in the above table are those from which an object may be seen by an observer whose eye is at the sea level; in practice, therefore, it is necessary to add to these a distance of visibility corresponding to the height of the observer's eye above sea level.

Example.—A light 90 ft. high is seen just at the horizon; height of observer is 15 ft. What, under ordinary conditions of the atmosphere, is its distance from the observer?

Solution.—Distance corresponding to 90 ft. is.................... 10.91

Add distance corresponding to height of observer's eye above sea level, 15 ft...... .... 4.44

Distance of light is................ 15.35 naut. mi. Ans.

Example.—A vessel is running for a certain port. At the time the lighthouse at the entrance of the harbor is expected to become visible, a man is sent aloft; his height above the water-line is 60 ft. After a while he discovers the light, the height of which is 75 ft.; what is the distance of the ship from the light, in nautical miles?

Solution.—Entering table, we find that
distance corresponding to 60 ft. is 8.91
distance corresponding to 75 ft. is 9.96

Hence, distance from light is 18.87 naut. mi. Ans.

Distances corresponding to heights not included in the above table may be found by the formula,

$$D = \frac{8}{7}\sqrt{H}$$

in which H = elevation, or height, in feet, of the object above sea level;

D = corresponding distance of visibility, in nautical miles.

The formula is based on the mean curvature of the earth and is corrected for ordinary atmospheric refraction. The distance of visibility of a light may be augmented by abnormal atmospheric refraction, which usually increases with the height of the barometer and a falling temperature.

Distance by the Velocity of Sound.—A convenient method, whenever available, is to determine the distance by noting the number of seconds elapsed between seeing the flash and hearing the report of a gun fired. The velocity of sound is 1 naut. mi. in 5.6 sec. or .18′ (=1,092 ft.) in 1 sec. Hence, the following rule:

Rule.—*Divide the number of seconds elapsed by* 5.6, *or, multiply them by* .18; *the result is the required distance expressed in miles.*

Thus, if the number of seconds counted in the interval of time between the flash and report of a gun is 14, the required distance is $\frac{14}{5.6} = 2.5$; or, $= 14 \times .18 = 2.52$ mi.

Danger Angles.—The danger angle, which may be either vertical or horizontal, is the name given to a method that is used when coasting to avoid hidden dangers, such as rocks, shoals, sunken derelicts, and other obstructions situated immediately at or below the water level. By its use, any such dangerous obstacle may be passed or rounded at any desired distance.

The vertical danger angle is based on the principle that the distance to an object will remain the same as long as the angle subtended by the height of the object remains the same. Tables containing angles corresponding to different heights and distances expressed in miles and fractions of a mile have accordingly been prepared for the use of navigators. Thus, if an object is 190 ft. high and it is required to round it at a distance of, for example, 2 mi., the angle that the object should subtend is 53.7′; the sextant is then set and clamped at that angle and the vessel's course altered so that the angle will remain the same. If the angle referred to becomes larger, the ship is inside the 2-mi. limit; if smaller it is outside, or the distance of the ship from the object is greater than 2 mi.

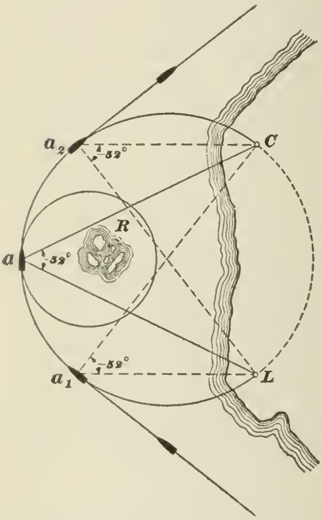


Fig. 2

The horizontal danger angle is an application of the geometrical properties of the circle, namely, that angles inscribed in the same segment are equal. The following example will serve to explain this method: Suppose that when steaming along a coast it is necessary to avoid some hidden rocks R, Fig. 2, by passing ½ mi. outside of them. On the shore, there are two known objects in sight, a lighthouse L and a church C, both being marked on the chart. Then, to find the danger angle corresponding to a distance of ½ mi. from the rocks, proceed as follows: With the outermost rock as a center and a radius equal to ½ mi., describe a circle on the chart. Then, through the most seaward point a of this circle and the points C and L, describe another circle; connect a with C and L; measure, with a protractor, the angle $C\,a\,L$ formed by the lines $a\,C$ and $a\,L$. Assume it to be 52°, as in the figure. This is the required horizontal danger angle. Now, set that angle on the sextant (neglecting the index error if it is small) and watch the two selected objects C and L, holding the instrument in a horizontal position. When the two objects appear in the horizon glass, the ship is close to the circle of safety $a_1\,a\,a_2$, and when they come in contact, the ship is on that circle; once on the circle, change the course of the ship so that the two images will remain in contact until the danger is passed. As long as this is being done, the ship will be on the circle of safety $a_1\,a\,a_2$, since the angles $C\,a_1\,L$, $C\,a\,L$, and $C\,a_2\,L$ are all equal, being angles in the same segment. If the angle increases, the ship is on the inside of the circle of safety and consequently nearer the danger than is desirable. if it becomes smaller, the ship is outside of the ½-mi. limit.

When circumstances permit the selection of a vertical and a horizontal danger angle the latter should always be preferred as being more reliable, because much larger, than the former.

NOTES RELATING TO THE USE OF FOREIGN CHARTS

Meridians Used on Foreign Charts.—On English, Dutch, Scandinavian, Russian, Austrian, and American charts, Greenwich meridian is used as the first, or prime, meridian. On French charts, the meridian passing through Paris is used; its long. is 2° 20′ 15″ or, $0^h\,9^m\,21^s$ east of the Greenwich meridian. The meridian of San Fernando, used on Spanish charts, is in long. 6° 12′ 24″, or $0^h\,24^m\,49.6^s$ west of the

Greenwich meridian. On Portuguese charts, the meridian passing through the Marine Observatory, Lisbon, is used; its long. is 9° 11′ 10″, or $0^h\ 36^m\ 44.7^s$ west of Greenwich. The meridian of Pulkowa Observatory, St. Petersburg, which is sometimes used on Russian charts, lies in long. 30° 19′ 40″, or $2^h\ 1^m\ 18.7^s$ east of Greenwich. The observatory of Naples, the meridian of which is sometimes used on Italian charts, is in long. 14° 15′ 7.3″ or, $0^h\ 57^m\ 0.5^s$ east of Greenwich.

NAMES OF LIGHTS USED ON CHARTS IN DIFFERENT LANGUAGES

English	German	French	Italian
Fixed light	Festes feuer	Feu fixe	Luçe fissa
Fixed and flashing light	Festes feuer mit Blinken	Feu fixe à éclats	Luçe bianca a splendori
Revolving light	Blinkfeuer	Feu tournant et feu à éclipses	Luçe a splendori
Quick flashing light	Funkelfeuer	Feu scintillant	Luçe scintillante
Group flashing light	Gruppen-blinkfeuer	Feu à éclats	Luçe a gruppi di splendori
Flashing light	Blitzfeuer	Feu cliquotant	Luçe scintillante
Intermittent or occulting light	Unter-brochenes feuer	Feu intermittent	Luçe intermittente
Alternating light	Wechselfeuer	Feu alternatif	Luçe alternate

For symbols and abbreviations in use on the official charts of the principal maritime nations, the reader should consult U. S. Hydrographic Office Publication No. 121.

Soundings on Foreign Charts.—In order to facilitate the reduction of measurements of depth given on foreign charts to English standards, the following may prove useful.

		Feet	Fathoms
Danish and Norwegian	*Fawn*	= 6.175	= 1.029
Dutch (old)	*Vadem*	= 5.575	= .929
Dutch (recent)	*Elle*	= 3.281	= .547
French	*Metre*	= 3.281	= .547
Portuguese	*Braca*	= 6.004	= 1.000
Prussian	*Faden*	= 5.906	= .984
Spanish	*Metro*	= 3.281	= .547
Swedish	*Famn*	= 5.843	= .974

Russian, equal to English feet and fathoms.

The Spanish, Portuguese, and Italian *Metro*, and the Dutch *Elle* and French *Metre* are identical.

CELESTIAL NAVIGATION

ASTRONOMICAL TERMS AND DEFINITIONS

Angular distance is the arc contained between lines drawn from two objects toward an observer; it must not be confounded with the actual linear distance between the objects; it is expressed in angular measure and must necessarily be the same at any points along the lines at equal distance from the observer.

Celestial sphere is the apparent spherical surface, called the sky, that surrounds the earth on every side and to which all the heavenly bodies seem to be attached. The center of the celestial sphere is regarded to be at the center of the earth.

Celestial Poles.—The position of the **celestial poles** is indicated by the prolongation of the axis of the earth.

Celestial equator is the great circle formed by the plane of the earth's equator extended toward the celestial sphere, it is also known as the **equinoctial.**

Ecliptic is the great circle that the sun's apparent path describes on the celestial sphere. It is inclined to the equator at an angle that may be assumed to be 23° 27′, crossing it in two opposite points called the **equinoctial points.** The point at which the sun passes from south to north of the equinoctial is called the **first point of Aries**, or **vernal equinox,** while the opposite point is called the **autumnal equinox.**

Solstitial points are those points of the ecliptic that are farthest north or south from the equator and situated therefore midway between the equinoctial points.

Obliquity of the ecliptic is the angle between the ecliptic and the celestial equator.

Celestial meridians are great circles passing through the celestial poles and intersecting the celestial equator at right angles. They are identical to meridians of the earth extended toward the celestial sphere. The celestial meridian most frequently in use by navigators passes through the zenith, and consequently through the north and south point of the horizon, as shown in Fig. 1. It is known as the *meridian*. Celestial meridians are also called **hour circles,** because the arcs of the equator intercepted between them are used as measures of time.

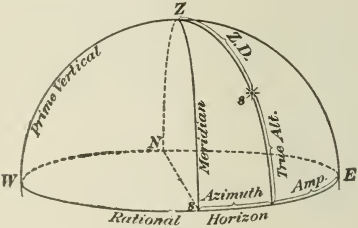


FIG. 1

Diurnal motion is the apparent daily motion of the heavenly bodies from east to west caused by the rotation of the earth on its axis.

Zenith is the point Z, Fig. 1, of the celestial sphere that is vertically above the head of an observer. The zenith of any point on the surface of the earth is indicated by the direction of the plumb-line at that point.

Rational horizon is the great circle whose plane is perpendicular to the zenith and passes through the center of the earth.

Sensible, or **true, horizon** is the plane passing through the point where the observer stands; it is perpendicular to the observer's zenith and consequently parallel with the rational horizon, as shown in Fig. 2.

Sea horizon is the apparent boundary between the sky and the sea, forming a circle at the center of which the observer stands.

Verticals.—Circles of altitude, or **verticals**, are great circles that pass through the zenith intersecting the rational horizon at right angles.

Prime vertical is the vertical at right angles to the meridian; it passes through the east and west point of the horizon, as shown in Fig. 1.

True altitude is the angular distance of a celestial body from the rational horizon; it is measured along the vertical passing through the body, as shown in Fig. 1.

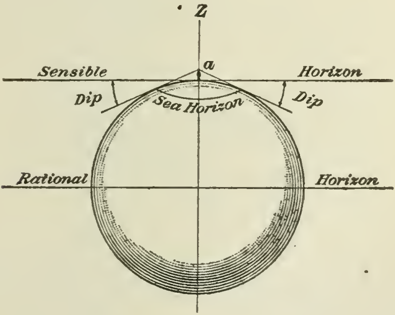


FIG. 2

Observed altitude is the distance of a celestial body above the sea horizon, expressed in angular measure.

Zenith distance is the distance of the observed body from the observer's zenith; it is the complement of the altitude.

True azimuth is the arc of the horizon intercepted between the true north or south and the vertical passing through the body; it is measured from north or south toward east or west and may be of any value from 0° to 180°.

Compass azimuth is the azimuth measured by the ship's compass; the difference between the true and compass azimuths is the total error of the compass.

True amplitude is the complement of the true azimuth; it is measured along the horizon from the prime vertical toward north or south.

Compass amplitude is the amplitude measured by the ship's compass; it is affected by variation and deviation.

Hour angle is the angle at the pole subtended between the meridian and the hour circle passing through a celestial body. It is measured from the meridian westwards and may be of any magnitude from 0^h to 24^h.

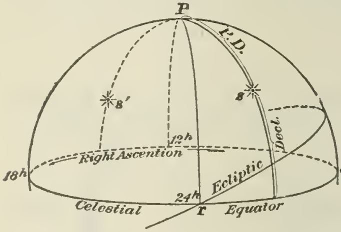


FIG. 3

Declination is the angular distance of a body north or south from the celestial equator; it is measured by the arc of the hour circle passing through the object and intercepted between it and the equator.

Polar distance is the distance of a celestial body from the nearer pole; it is measured by the arc of the hour circle intercepted between the pole and the body. The polar distance is, therefore, the complement of the declination, as shown in Fig. 3.

Parallels of declination are small circles parallel to the celestial equator.

Right ascension is the arc of the celestial equator measured eastwards from the vernal equinox to the hour circle passing through a celestial body. It is reckoned from 0^h to 24^h. Thus, in Fig. 3, the right ascension of the star *s* is about 3^h, while that of the star *s'* is about 15^h. The approximate position of the vernal equinox in the sky is easily fixed any clear night by following an imaginary line from Polaris that passes through or very near the stars Alpha, Andromeda, and Algenib. At a distance of 90° from Polaris, along that line, is the vernal equinox. Hence, the right ascension of all stars to the left of that line is small, while that of stars to the right is large.

Annual parallax is the greatest angle subtended at a star by the radius of the earth's orbit. The parallax of only a few stars has, as yet, been determined, and in no case does it amount to as much as 1 sec.

Parallax in altitude is the angle subtended by a line joining a celestial body with the point of observation and a line joining the same body with a certain point of reference, such as the center of the earth. A correction for parallax is used when correcting observed altitudes, and is always additive. This correction is maximum when the body is near the horizon and vanishes on approaching the zenith.

Dip is the angular distance between the sensible horizon and a line drawn from the observer's eye to the sea horizon, as shown in Fig. 2. The amount of dip depends on the height above the surface of the sea, increasing as the height of the eye increases. The correction for dip is always subtractive.

Refraction is the downward deflection of a ray of light on entering the atmosphere of the earth, causing a celestial body to appear higher than it actually is. It is least in high altitudes, and increases toward the horizon. The correction for refraction is subtractive.

Transit, or transition, is the passage of a celestial body, such as a star, across the meridian of a certain place, either above or below the pole; it is identical to meridian passage and culmination. Thus, when the sun reaches its highest altitude on any day, it is said to be in culmination or transition.

Circles of celestial longitude are great circles perpendicular to the ecliptic and passing through the poles of the ecliptic.

Celestial latitude is the angular distance of a star or planet from the ecliptic measured along the circle of longitude that passes through the object.

Celestial longitude is the arc of the ecliptic measured eastwards from the vernal equinox to the circle of longitude passing through a celestial object.

The Solar System.—A body, like the earth, that performs a circuit about the sun, is called a **planet.** A smaller body, like the moon, that revolves about a planet, is called a **satellite** of that planet. The sun, planets, and satellites constitute what is called the **solar system.** Including the earth, there are eight known planets, which are divided into two classes—interior and exterior planets. **Interior planets** are those whose orbits lie within that of the earth; viz., Mercury and Venus; **exterior planets** are those whose orbits are greater than that of the earth and, consequently, lie outside of it; they are, Mars, Jupiter, Saturn, Uranus, and Neptune. The principal elements of the solar system are given in the table.

Between the orbits of Mars and Jupiter, there are a number of small planets, called **asteroids,** of which at present about 384 are known; they are supposed to be the fragments of a burst planet. A number of these small planets have not been observed since their discovery and are practically lost. Hence, it is sometimes a matter of doubt, until certain elements have been computed, whether a supposed new planet is really new or only an old one rediscovered. All the exterior planets are attended by moons, similar to ours, that move around them in the same direction that the planets themselves revolve around the sun. The only exceptions are the satellites of Uranus and Neptune, which revolve in the opposite direction.

Conjunction.—A planet is said to be in **conjunction** with another body when both lie on the same line, or is seen in the same direction in the heavens. In the case of interior planets this conjunction is of two kinds: the one when the planet is between the earth and the sun, called **inferior conjunction**; and the other when at the opposite point of its orbit, with the sun between the planet and the earth, called **superior conjunction.**

PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM

Name	Mean Distance From Sun Expressed in Millions of Miles	Number of Days in Year	Mean Diameter Miles	Mass Earth = 1	Volume Earth = 1	Density Earth = 1	Gravity at Surface Earth = 1
Sun..........			866,400	331,100	1,310,000	.25	27.65
Mercury.....	36.0	87.96	3,030	.12	.05	2.23	.85
Venus.......	67.2	224.70	7,700	.78	.92	.86	.83
Earth.......	92.8	365.25	7,910	1.00	1.00	1.00	1.00
Mars.........	141.5	686.95	4,230	.11	.15	.72	.38
Jupiter......	484.3	4,332.58	86,500	316.00	1,309.00	.24	2.65
Saturn.......	886.0	10,759.22	71,000	94.90	721.00	.13	1.18
Uranus......	1,781.9	30,686.82	31.900	14.70	65.00	.22	.91
Neptune.....	2,791.6	60,181.11	34,800	17.10	85.00	.20	.88

Opposition.—A planet is said to be in **opposition** when the earth is directly between it and the sun, at which time it is most brilliant.

Elongation is the angle formed by lines connecting the earth with a planet and sun, respectively.

Quadrature.—Two heavenly bodies are said to be in quadrature when they are half way between conjunction and opposition.

Occultation.—The moon, in her orbital motion, often passes before, and hides from a spectator on the earth, certain of the fixed stars, and occasionally one of the planets; these occurrences are called **occultations.**

EXPLANATIONS OF TERMS RELATING TO TIME

Apparent solar day is the interval of time between two successive transits of the sun over the same meridian; apparent time is measured by the hour angle of the true sun.

Mean Sun.—The intervals between the successive returns of the sun to the same meridian are not exactly equal, owing to the varying motion of the earth around the sun, and to the obliquity of the ecliptic, and for this reason the length of the apparent solar day is not the same at all times of the year and cannot be measured by a clock whose rate is uniform. To avoid the irregularity that would arise from using the true sun as the measure of time, a fictitious sun, called the **mean sun** has been devised, which is supposed to move along the celestial equator with a uniform velocity. This mean sun is supposed to keep, on the average, as near the real sun as is consistent with perfect uniformity of motion; it is sometimes in advance of it, and sometimes behind it, the greatest deviation being about 16 min. of time.

Mean time, which is perfectly equable in its increase, is measured by the motion of the mean sun. The clocks in ordinary use and chronometers are regulated to mean time.

Mean solar day is the average, or mean, of all the apparent solar days in a year; or, the interval of time between two successive mean noons.

Equation of time is the difference between apparent and mean time; its value for every day of the year is recorded in the Nautical Almanac. By means of the equation of time, we change apparent to mean time, or the reverse, by adding or subtracting it acording to directions in the Almanac.

Sidereal time is the time measured by the daily motion of the stars; or for astronomical purposes, by the daily motion of that point in the equator from which the true right ascension of the stars is counted. This point is the vernal equinox, and its hour angle is called sidereal time. Astronomical clocks, regulated to sidereal time, are called sidereal clocks.

Sidereal day is the interval between two successive upper transits of the vernal equinoctial point, and begins when the vernal equinoctial point is on the meridian. It is about 3 min. and 56 sec. shorter than the mean solar day; and is divided into 24 sid. hr.

Astronomical Day.—When mean time is used in astronomical work, the day begins at mean noon and is called the **astronomical day**; astronomical mean time is reckoned continuously up to 24 hr.

Civil Day.—When mean time is used in the ordinary affairs of life it is called **civil time** and the civil day begins at midnight, 12 hr. earlier than the astronomical day. Thus, Jan. 9, 2 o'clock A. M., civil time, is Jan. 8, 14 hr., astronomical time; and Jan. 9, 2 o'clock P. M., civil time, is also Jan. 9, 2 hr., astronomical time. The rule for converting civil time into astronomical time is this: If the civil time is marked A. M., take 1 from the date and add 12 to the hours, and the result is the astronomical time wanted; if the civil time is marked P. M., take away the designation P. M., and the astronomical time is had without further change.

To change astronomical to civil time, we simply write P. M. after it if it is less than 12 hr. If greater than 12 hr., we subtract 12 hr. from it, increase the date by 1, and write A. M. For example, Jan. 3, 23 hr., astronomical time, is Jan. 4, 11 o clock A. M., civil time.

Local mean time (L. M. T.) is the mean time at a certain place or locality, as, for example, the mean time at ship; at no time can the mean time be the same at two places unless they are situated on the same meridian.

Greenwich date (G. D.) is the local mean time at Greenwich shown by the chronometer and with proper date appended; the Greenwich date should be expressed astronomically. Chronometer being marked up to 12 hr. only, it cannot always be decided, especially where longitude is large, whether the Greenwich mean time (G. M. T.) is more or less than 12 hr. In such cases, it is advisable to get an approximate value of the G. D. by applying to the local time the hours and minutes of the ship's longitude, adding if in west, subtracting if in east, longitude. In case the difference between this approximation and the time by the chronometer is nearly 12 hr., add 12 hr. to the latter and put the day back 1, if necessary.

Example.—The local time at a ship in longitude 150° 30′ W is $5^h\ 40^m$ P. M., Dec. 16. The chronometer indicates $3^h\ 22^m\ 10^s$, its error on G. M. T. being $10^m\ 50^s$ slow. Find G. D.

Solution.—Ship's time, Dec. 16 =	$5^h\ 40^m$
Long. (W) in time =	$+10^h\ 2^m$
Approx. G. D., Dec. 16 =	$15^h\ 42^m$
Chron. =	$3^h\ 22^m\ 10^s$
Error =	$+10^m\ 50^s$
G. M. T., Dec. 16 =	$3^h\ 33^m$
Add =	12^h
G. M. T. or G. D., Dec. 16 =	$15^h\ 33^m$

In this case 12^h must be added to the time indicated by the chronometer. This gives the G. D., corresponding to ship time, as Dec. 16, $15^h\ 33^m$. Ans.

Notes on the Correction of Altitudes.—The altitude of a celestial object, as measured with a sextant, is called the observed altitude; but in order to obtain the true altitude some or all of the following corrections must be applied: (1) Index error of the sextant, (2) dip of the horizon, (3) refraction, (4) parallax, (5) semi-diameter. The correction for dip and refraction are taken from nautical tables; parallax of the sun is also found in tables, while that of the moon is tabulated in the Nautical Almanac. The semi-diameter of the sun that is taken from the Nautical Almanac is applied according to what limb is brought in contact with the horizon; if lower limb is observed, it is additive; if upper limb, subtractive.

In correcting altitudes, it should be remembered that the observed altitude is that read off the sextant. When this has been corrected for index error, dip, and semi-diameter, the result is the apparent altitude of the center, and the application to this of the corrections for refraction and parallax produces the true altitude of the center of the observed body, as if the observation had been made at the center of the earth and the altitude had been measured from the rational horizon.

The observed altitude of a star has to be corrected only for index error, dip, and refraction. When an artificial horizon is used, apply index error to the double altitude read off the sextant, divide by 2, and apply the other corrections as usual, except that for dip. When correcting altitudes of the sun, use refraction and parallax corresponding to the apparent altitude of the upper or lower limb; for altitude of the moon, use the apparent altitude of the moon's center.

Since the value of dip depends on the height of the eye above surface of the sea, it is advisable always to ascertain beforehand the exact vertical distance from water-line to the bridge, or other place usually occupied by observer, when measuring altitudes. And due allowance should be made for any reduction or increase in this vertical distance when ship is loaded, or light, or when having a considerable list to either side.

LATITUDE DETERMINATIONS

Meridian Altitude of the Sun.—The measurement should begin a short time before noon, say 10 or 15 min. The altitude will increase gradually until apparent noon, when it will stop and begin to decrease. The highest altitude attained is the desired meridian altitude. Apply to this observed altitude the necessary corrections, and subtract the true altitude thus found from 90°. The result is the zenith distance, which is named opposite to the direction the observer is facing when measuring the altitude. Find, from the Nautical Almanac, the sun's declination and correct it for the G. D. Take the algebraic sum of the declination and zenith distance, and name it the same as the larger quantity. The result is the required latitude.

Example.—On Sept. 23, 1904, in longitude 11° 45′ W, by dead reckoning, the observed meridian altitude of the sun's lower limb was 33° 37′ 40″, the observer facing south; index error = +1′ 40″; height of eye = 23 ft. Find the latitude.

Solution.—L. App. T. Sept. 23 = 0^h 0^m 0^s
Long. (W) in time = 0^h 47^m 0^s
G. D. Sept. 23 = 0^h 47^m 0^s

Decl. = S 0° 0′ 11.6″ — Change in 1^h = 58.4″
Corr. for 47^m = +46.7″ — × $.8^h$
Corr. Decl. = S 0° 0′ 58.3″ — Corr. = 46.72″

Obs. Mer. Alt. = 33° 37′ 40″
I. E. = +1′ 40″
33° 39′ 20″
Dip = −4′ 42″
33° 34′ 38″
S. D. = +15′ 59″
App. Alt. = 33° 50′ 37″
Ref. = −1′ 26″
33° 49′ 11″
Parallax = +0′ 7″
True Mer. Alt. = 33° 49′ 18″
90° 0′ 0″
Z. D. = 56° 10′ 42″ N
Decl. = 0° 0′ 58″ S
Latitude = 56° 9′ 44″ N Ans.

In this case, the bearing of the sun being south, the zenith distance is north; the declination being south, the latitude is therefore equal to the difference between the two, having the same name as the larger quantity.

Meridian Altitude of a Star.—Select a bright star that is near and about to cross your meridian. Be sure that the star selected is identified without doubt. Find to the nearest minute the local apparent time of its meridian passage, by subtracting from the star's right ascension the right ascension of the sun, and thence the corresponding mean time. Be ready with the sextant a few minutes before that time and proceed exactly as in the case of observing the sun.

Example.—On Oct. 19, 1904, an opportunity presented itself to observe the meridian altitude of the star Sirius (α Canis Majoris); the altitude when measured was 45° 34 20″, the observer facing south; index error = −2′ 20″; height of eye = 23 ft. Find the latitude.

Solution.—For approximate time of meridian passage.

$$\begin{aligned} \text{R. A. } (+24^h) &= 30^h\ 41^m \\ \text{R. A. Sun} &= \underline{13^h\ 35^m} \\ \text{L. App. T.} &= 17^h\ \ 6^m \\ \text{Eq. of T.} &= \underline{\ \ -15^m} \\ \text{L. M. T.} &= 16^h\ 51^m \text{ P. M.} \\ \text{Approx. L. M. T. of passage} &= 4^h\ 51^m \text{ A. M.} \end{aligned}$$

$$\begin{aligned} \text{Obs. Mer. Alt.} &= 45°\ 34'\ 20'' \\ \text{I. E.} &= \underline{\quad -2'\ 20''} \\ & \quad 45°\ 32'\ \ 0'' \\ \text{Dip} &= \underline{\quad -4'\ 42''} \\ & \quad 45°\ 27'\ 18'' \\ \text{Ref.} &= \underline{\quad -0'\ 56''} \\ \text{True Alt.} &= 45°\ 26'\ 22'' \\ & \quad \underline{90°\ \ 0'\ \ 0''} \\ \text{Z. D.} &= 44°\ 33'\ 38''\text{ N} \\ \text{Decl.} &= \underline{16°\ 35'\ \ 5''\text{ S}} \\ \text{Latitude} &= 27°\ 58'\ 33''\text{ N} \quad \text{Ans.} \end{aligned}$$

The star's declination, which is practically constant, is taken directly from the catalog of fixed stars in the Nautical Almanac.

Meridian Altitude of the Moon.—Find, from the Nautical Almanac, the mean time of the moon's meridian passage at Greenwich. If your local time is P. M., take it out for the given date; if A. M., for the day preceding. Apply to it a correction equal to the hourly difference multiplied by the longitude in time, adding this correction when longitude is west, but subtracting it when east; the result is the local time of transition. Then find the corresponding G. M. T. by applying the longitude in time. For the G. D. thus found, correct the moon's semi-diameter declination and parallax as shown in the example that follows: Measure the altitude at the proper time and reduce it to true, whence the latitude is found as usual.

Example.—On Aug. 22, 1904, in the evening, a meridian altitude of the moon's lower limb measured in an artificial horizon was 61° 46′ 30″, the observer facing south; index error of sextant = + 1′ 30″; long. = 75° 45′ W. Find the latitude.

Solution.—Find, first, the local time of meridian passage and the requisite elements of the moon in the Nautical Almanac.

Mer. pass. Aug. 22 =	$9^h\ 40.5^m$	Change in $1^h = 2^m$	
Corr. for long. =	$+\ 10^m$	$\times 5^h$	
L. M. T. of pass. =	$9^h\ 50.5^m$ P. M.	Corr. = 10^m	
Long. in time =	$+5^h\ 3^m$		
G. M. T. Aug. 22 =	$14^h\ 53.5^m$		

Moon's S.D. at midnight = 14′ 56″ (nearly)
Corr. for Alt. = +7″
Corr. S. D. = 15′ 3″

Hor. Par. at midnight = 54′ 42″

Decl. at 14^h Aug. 22 =	S 16° 43′ 28″	Change $1^h = 4''$
Cor. for 53.5^m =	−3′ 34″	$\times 53.5^m$
Corr. Decl. =	S 16° 39′ 54″	214.0″
		Corr. = 3′ 34″

Obs. double Alt. = 61° 46′ 30″
I. E. = +1′ 30″
2)61° 48′ 0″
Obs. Mer. Alt. = 30° 54′ 0″
S. D. = + 15′ 3″
App. Alt. center = 31° 9′ 3″
Par. Ref. = +45′ 13″
True Mer. Alt. = 31° 54′ 16″

$$\begin{array}{rl} \text{True Mer. Alt.} = & 31° \ 54' \ 16'' \\ & \underline{90° \ \ 0' \ \ 0''} \\ \text{Z. D.} = & 58° \ \ 5' \ 44'' \text{ N} \\ \text{Decl.} = & \underline{16° \ 39' \ 54'' \text{ S}} \\ \text{Latitude} = & 41° \ 25' \ 50'' \text{ N} \quad \text{Ans.} \end{array}$$

The correction for parallax and refraction is taken from I. C. S. Nautical Tables, page 170, or from Table 24, Bowditch.

Ex-Meridian of the Sun.—Measure an altitude within 1 hr. of noon (either P. M. or A. M.), and note the chronometer time at instant of observation. From the time thus noted, find the hour angle, H. A., which is equal to local apparent time, and express it in degrees, minutes, and seconds. Reduce the observed altitude to true, and correct the declination for G. M. T. From the data now at hand, calculate two quantities that we will designate M and N. Find the value of M by formula:

$$\text{Tan } M = \text{sec H. A.} \times \text{tan Decl.}$$

and that of N by formula:

$$\text{Cos } N = \text{sin } M \times \text{sin Alt.} \times \text{cosec Decl.}$$

Name M the same as declination and N the same as zenith distance. If they have the same name, take their sum; if of different names, subtract the smaller from the larger. The result is the latitude, which is named the same as the larger quantity.

Example.—On June 8, 1904, in long. 60° 15′ W, the sun being obscured by clouds at noon, an altitude of the lower limb, observed at about 12.40 P. M., was found to be 78° 33′ 40″, the observer facing south. At the instant of measuring the altitude, the chronometer indicated $4^h \ 46^m \ 25^s$, its error on G. M. T. being $1^m \ 55^s$ fast; index error = −3′ 40″; height of eye = 20 ft. Required the latitude.

Solution.—

$$\begin{array}{rr} \text{Chron.} = & 4^h \ 46^m \ 25^s \\ \text{Error (fast)} = & \underline{-1^m \ 55^s} \\ \text{G. D., June 8} = & 4^h \ 44^m \ 30^s \end{array}$$

$$
\begin{aligned}
\text{G. D., June 8} &= 4^h\ 44^m\ 30^s \\
\text{Long. (W) in time} &= \underline{4^h\ \ 1^m\ \ 0^s} \\
\text{L. M. T.} &= 0^h\ 43^m\ 30^s \\
\text{Eq. of T.} &= \underline{+1^m\ 13^s} \\
\text{L. App. T.} &= 0^h\ 44^m\ 43^s \\
\text{Or, hour angle} &= 11°\ 10'\ 45''
\end{aligned}
$$

Eq. of T. $= 1^m\ 15.5^s$	Change in $1^h = 0.47^s$
Corr. for $4.7^h = -\ 2.2^s$	4.7^h
Eq. of T. $= 1^m\ 13.3^s\ (+)$	2.209^s

Decl. = N 22° 50′ 8.5″	Change in $1^h = 13.68''$
Corr. for 4.7^h = +1′ 4.3″	4.7^h
Decl. = N 22° 51′ 12.8″	9576
	5472
	64.296″

$$
\begin{aligned}
\text{Obs. Alt.} &= 78°\ 33'\ 40'' \\
\text{I. E.} &= \underline{-3'\ 40''} \\
& \quad 78°\ 30'\ \ 0'' \\
\text{Dip} &= \underline{-4'\ 23''} \\
& \quad 78°\ 25'\ 37'' \\
\text{S. D.} &= \underline{+15'\ 47''} \\
& \quad 78°\ 41'\ 24'' \\
\text{Ref. and Par.} &= \underline{-0'\ 10''} \\
\text{True Alt.} &= 78°\ 41'\ 14''
\end{aligned}
$$

The true altitude being found, calculate the quantity M and N according to formulas given; thus,

Tan M = Sec H. A. × tan Decl.	Cos N = sin M × sin Alt. × cosec Decl.
sec 11° 10′ 45″ = .00832	sin 23° 15′ = 9.59632
tan 22° 51′ 12″ = 9.62475	sin 78° 41′ 14″ = 9.99147
tan M = 9.63307	cosec 22° 51′ 12″ = .41075
M = 23° 15′	Cos N = 9.99854
	N = 4° 42′

Lat. = $M + N$ = 23° 15′ + 4° 42′ = 27° 57′ N. Ans.

LONGITUDE DETERMINATIONS

Time Sight of the Sun.—Measure an altitude of the sun in the forenoon or afternoon when it bears nearly east or west, and note the corresponding time, either directly on the chronometer or by a watch previously compared with the chronometer. The altitude should not be less than 15°.

Correct the chronometer time for error and accumulated rate; the result will be the G. M. T., or G. D., at the instant of observation. Reduce the observed altitude to true by applying the usual corrections. Compute the latitude of the ship by dead reckoning from the last observation up to the time of taking the sight. Take out the equation of time and correct it for the G. D. Similarly, correct the sun's declination for the G. D., and find the polar distance (p) as follows: If latitude and declination have the same name, $p = 90° - \text{decl.}$; if of different name, $p = 90° + \text{decl.}$ Then calculate the hour angle by the formula

$$\text{Sin } \tfrac{1}{2} \text{ H. A.} = \sqrt{\text{cosec } p \text{ sec } l \text{ cos } S \text{ sin } (S-a)}$$

in which p = polar distance;
l = latitude;
a = true altitude;
S = half sum of a, p, and l.

In other words, calculate the hour angle by the given formula, adding the log cosec p, log sec l, log cos S, and log sin $(S-a)$. The sum divided by 2 is the log sine for ½-hour angle. If the observation is made in the forenoon, take out the corresponding local apparent time from A. M. column in the tables; if made in the afternoon, from the P. M. column.

The local apparent time having been determined, the corresponding local mean time is found by applying the equation of time according to its sign. The difference between L. M. T. and the G. M. T., reduced to degrees, minutes, and seconds, will be the required longitude. If G. M. T. is greater than L. M. T., the longitude is west; if the L. M. T. is greater than G. M. T., the longitude is east.

Example.—On Jan. 17, 1904, at about 3.50 in the afternoon an altitude of the sun's lower limb measured 37° 7′ 40″; index error = −2′ 30″; height of eye = 16 ft.; at instant of observation the chronometer indicated $7^h\ 26^m\ 47^s$, its error on G. M. T. being $2^m\ 43^s$ slow; lat., by dead reckoning, is 46° 30′ S. Find the longitude.

Solution.—Chron., Jan. 17 = $7^h\ 26^m\ 47^s$
Error (slow) = $+2^m\ 43^s$
G. M. T. Jan. 17 = $7^h\ 29^m\ 30^s$ P. M.

Decl. =	S 20° 57′ 42.9″	Change in 1^h = 28.51″
Corr. =	− 3′ 33.8″	$\times 7.5^h$
Decl. =	S 20° 54′ 9.1″	213.825
	90° 0′ 0″	3′ 33.8″
P. D. =	69° 5′ 51″	

Eq. of T. =	$9^m\ 53.64^s$	Change in 1^h = $.86^s$
Corr. =	$+6.45^s$	$\times 7.5^h$
Eq. of T. =	$10^m\ 0.09^s$ +	6.450^s

Obs. Alt. =	37° 7′ 40
I. E. =	− 2′ 30″
	37° 5′ 10″
Dip =	− 3′ 55″
	37° 1′ 15″
S. D. =	+ 16′ 17″
	37° 17′ 32″
Ref. and Par. =	− 1′ 9″

a = 37° 16′ 23″		
p = 69° 5′ 51″	cosec =	.02956
l = 46° 30′ 0″	sec =	.16219
2)152° 52′ 15″		
S = 76° 26′ 7″	cos =	9.37028
$S-a$ = 39° 9′ 44″	sin =	9.80039
		2)19.36242

Sin ½ H. A. = 9.68121
L. App. T. = $3^h\ 49^m\ 28^s$
$+10^m\ 0^s$
L. M. T. Jan. 17 = $3^h\ 59^m\ 28^s$ P. M.
G. M. T. Jan. 17 = $7^h\ 29^m\ 30^s$ P. M.
Diff. = $3^h\ 30^m\ 2^s$
Long. = 52° 30′ 30″ W. Ans.

Time Sight of a Star.—Select a bright star bearing nearly east or west; measure its altitude and note the chronometer time at instant of observation. Reduce the G. M. T. into G. S. T. by adding the right ascension of the mean sun to G. M. T., as shown in the example that follows: Correct the altitude as usual and find, from the Nautical Almanac, the star's right ascension and declination. Calculate the hour angle in exactly the same way as for the sun, but use only the P. M. column of the tables in finding the hour angle.

If the hour angle is east (or when the observed star is to the east of the observer's meridian), subtract it from the star's right ascension; if the hour angle is west (or the star is west of the meridian), add it to the star's right ascension. The result will be the right ascension of the observer's meridian, or the L. Sid. T. The difference between this time and G. Sid. T., reduced to degrees, minutes, etc. is the required longitude.

Example.—On Oct. 18, 1904, at about $2^h\ 30^m$ A. M., the observed altitude of the star Sirius (α Canis Majoris) when east of the meridian was 53° 52′ 40″; index error = +2′ 43″; height of eye = 22 ft. The time indicated by chronometer was $11^h\ 7^m\ 21^s$, its error on G. M. T. being $3^m\ 22^s$ fast; long. estimated at 50° E; lat. = 15° 14′ S. Find the longitude.

Solution.—First, find the approximate G. D.; thus,

Approx. L. M. T. Oct. 17 = $14^h\ 30^m$
Long. (E) in time = $-3^h\ 20^m$
Approx. G. D. Oct. 17 = $11^h\ 10^m$

Then, from reading of chronometer get the G. M. T., or G. D. and the corresponding sidereal time at Greenwich; thus,

Chron. = $11^h\ 7^m\ 21^s$	S. T. G. M. N. = $13^h\ 42^m\ 13.9^s$
Error (fast) = $-3^m\ 22^s$	Corr. { for 11^h $1^m\ 48.4^s$
	for 4^m $.7^s$
G. M. T. Oct. 17 = $11^h\ 3^m\ 59^s$	
R. A. M. S. = $13^h\ 44^m\ 3^s$	R. A. M. S. = $13^h\ 44^m\ 3^s$
G. S. T. Oct. 18 = $0^h\ 48^m\ 2^s$	

* Decl. = S 16° 35′ 5″
90° 0′ 0″
* P. D. = 73° 24′ 55″

*R. A. = $6^h\ 40^m\ 55^s$

Obs. Alt. =	53° 52′ 40″		
I. E. =	+2′ 43″		
	53° 55′ 23″		
Dip =	−4′ 36″		
	53° 50′ 47″		
Refraction =	−0 42″		
True Alt. or a =	53° 50′ 5″		
p =	73° 24′ 55″	cosec =	.01845
l =	15° 14′ 0″	sec =	.01553
	2)142° 29′ 0″		
S =	71° 14′ 30″	cos =	9.50729
$S-a$ =	17° 24′ 25″	sin =	9.47593
			2)19.01720
		sin ½ H. A. =	9.50860

*H. A. = $2^h\ 30^m\ 32^s$ E (Column P. M.)
*R. A. = $6^h\ 40^m\ 55^s$
L. Sid. T. Oct. 18 = $4^h\ 10^m\ 23^s$
G. Sid. T. Oct. 18 = $0^h\ 48^m\ 2^s$
Diff. = $3^h\ 22^m\ 21^s$
Long. = 50° 35′ 15″ E. Ans.

Equal Altitudes Near Noon.—Observe an altitude of the sun shortly before noon (usually as many minutes as there are degrees in the latitude in), clamp the sextant, and note carefully the reading of the chronometer at instant of observing. After the sun has crossed the meridian and begins to descend, watch by means of the clamped sextant the moment when it attains the same altitude, and note the chronometer at that instant. Find the mean of the two times by dividing their sum by 2. Correct this time for whatever error the chronometer may have. The result will be the G. M. T. at apparent noon. Find, from the Nautical Almanac, the equation of time; correct it for the G. M. T. and apply it to the apparent time at noon ($=0^h\ 0^m\ 0^s$). The result will be the L. M. T. at apparent noon. The difference between the local and Greenwich time, converted into degrees, etc., will be the approximate longitude of the ship at instant of apparent noon.

If the vessel has sailed toward the sun, in the interval between observations, the second altitude should be increased by resetting the sextant as many minutes as there are miles in the difference of latitude; if the vessel has sailed from the sun, the second altitude should be decreased in the same proportion. Thus, if the first altitude is 62° 24′, and the ship in the interval of time has changed her latitude 5′ toward the sun, the sextant, when taking the second observation, should be set to 62° 29′; if she has sailed from the sun, the instrument should be set to 62° 19′, before measuring the second altitude.

Example.—On Aug. 16, 1904, in lat. 12° N, the sun was observed to have equal altitudes when near the meridian at the following times by the chronometer: Before noon, $4^h\ 10^m\ 25^s$; after noon, $4^h\ 30^m\ 23^s$. Find the longitude of the ship, the error of the chronometer on Greenwich mean time being $2^m\ 10^s$ fast.

Solution.—Chron. before noon $= 4^h\ 10^m\ 25^s$
Chron. after noon $= 4^h\ 30^m\ 23^s$
$2)\overline{8^h\ 40^m\ 48^s}$
Mid. time $= 4^h\ 20^m\ 24^s$
Error (fast) $-2^m\ 10^s$
G. M. T. at noon $= 4^h\ 18^m\ 14^s$

Eq. of T. Aug. 16 $= 4^m\ 11^s$ — Change in $1^h = 0.5^s$
Corr. $= -2.15^s$ — $\times 4.3^h$
Corr. Eq. of T. $= 4^m\ 8.85^s\ (+)$ — Corr. $= 2.15^s$

L. App. T. at noon $= 0^h\ 0^m\ 0^s$
Eq. of T. $= +4^m\ 8.9^s$
L. M. T. at noon $= 0^h\ 4^m\ 8.9^s$
G. M. T. at noon $= 4^h\ 18^m\ 14$
Diff. $= 4^h\ 14^m\ 5.1^s$
Long. $= 63°\ 31.3'$ W. Ans.

Sunrise and Sunset Sights.—When the sun's upper or lower limb is exactly in contact with the sea horizon, either at sunrise or sunset, note the chronometer and correct its time for any error it may have. For the G. D. thus found, find, from the Nautical Almanac, the equation of time, the declination, and thence the polar distance. To the polar distance, add the latitude at observation, and from the sum subtract 21′ if lower limb was observed, or 53′ if upper limb was used. Half the sum thus obtained is the quantity S in the formula for hour angles. By adding to S the 21′ or 53′ previously subtracted, the quantity $(S-a)$ is had, whence the longitude is computed in the usual way, as shown in the example that follows:

Example.—On Sept. 10, 1904, at sunset, the chronometer indicated $8^h\ 37^m\ 26^s$ when the sun's lower edge, or limb, came into contact with the horizon; the chronometer s error on G. M. T. was $5^m\ 56^s$ fast; lat. in, by dead reckoning, was 48° 10′ N. Find the longitude.

Solution.— Chron. =	$8^h\ 37^m\ 26^s$		
Error (fast) =	$-\ 5^h\ 56^s$		
G. M. T. Sept. 10 =	$8^h\ 31^m\ 30^s$		
Eq. of T. =	$2^m\ 59.6^s$	Change in 1^h =	0.86^s
Corr. =	$+7.3^s$		$\times 8.5^h$
Corr. Eq. of T. =	$3^m\ 6.9^s$ (−)	Corr. =	7.310^s
Decl. =	N 5° 0′ 34″	Change in 1^h =	56.8″
Corr. =	8′ 3″		$\times 8.5^h$
Corr. Decl. =	4° 52′ 31″	Corr. =	482.8″ = 8′ 3″
	90° 0′ 0″		
P. D. =	85° 7′ 29″	cosec =	0.00158
Lat. =	48° 10′ 0″	sec =	0.17590
	133° 17′ 29″		
Constant =	−21′ 0″		
	2)132° 56′ 29″		
S =	66° 28′ 15″	cos =	9.60121
Constant =	+21′ 0″		
$(S-a)$ =	66° 49′ 15″	sin =	9.96345
			2)19.74214
		sin ½ H. A. =	9.87107

L. App. T. =	$6^h\ 24^m\ \ 0^s$
Eq. of T. =	$-3^m\ \ 7^s$
L. M. T. Sept. 10 =	$6^h\ 20^m\ 53^s$ P. M.
G. M. T. Sept. 10 =	$8^h\ 31^m\ 30^s$ P. M.
Diff. =	$2^h\ 10^m\ 37^s$
Long. =	32° 39.2′ W. Ans.

The longitude thus found is approximate only. It is evident that an abnormal refraction caused by unusual atmospheric conditions at setting or rising often renders this method unreliable. Its value lies in the fact that the observation can be made without the sextant, and hence, if that instrument for some reason is rendered useless, the longitude may be found simply by using a smoked glass to note the contact of the sun's limb with the horizon.

SUMNER'S METHOD

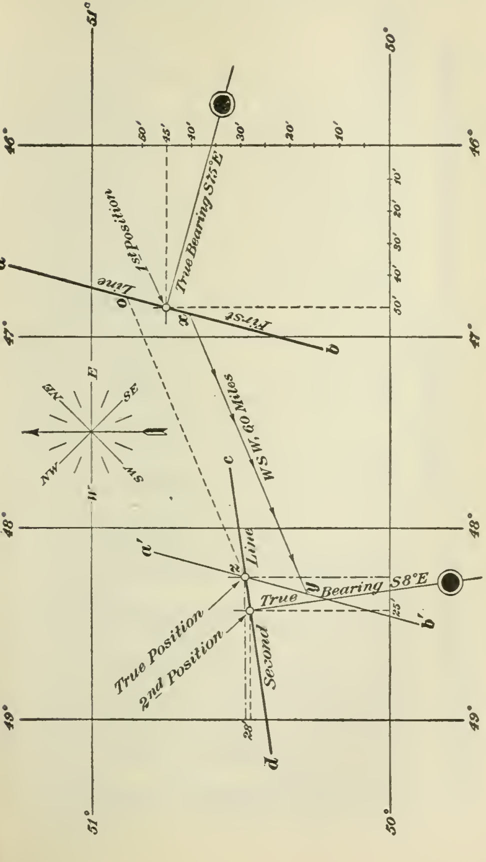
Sumner's method consists in fixing the position of a ship at sea by means of astronomical cross-bearings or by the intersection of lines of position. A line of position, also called a *Sumner line*, is a line drawn through a calculated position at right angles to the observed body. Thus, a Sumner line can be obtained whenever a sight of the sun or any other celestial body is taken. For instance. in the morning, when measuring the sun's altitude for a time sight, the observer calculates the longitude, and uses the same data for calculating the true azimuth (or finds the azimuth directly from tables). The azimuth is, of course, the sun's true bearing at the moment that the altitude is measured. He then plots the position on the chart, and through the longitude thus found, and the latitude used in the computation, he draws a line perpendicular to the sun's true bearing or azimuth. This line is his Sumner line; he is somewhere on this line, provided that his chronometer is not wrong and no errors have been made in measuring the altitude or in the computations. His exact position on that line will depend on the exactness of the latitude used; but, whatever the error in the latitude, whether it is 10′ or 20′, the navigator will have the great satisfaction of knowing that his vessel is on that line. Now, having one line established, a second line may be had by a similar observation, when the sun has changed its azimuth enough to insure a defined point of intersection between the two lines. Since the position of the ship must be on each and both of these lines, it is evident that its exact position must be at their point of intersection. If, therefore, one observation for time sight is made early in the morning and another some time later, when the bearing of the sun has changed at least two points, two Sumner lines are obtained whose point of intersection will be the position of the ship, unless the ship has not moved in the interval between the observations. But in case the ship has changed its position in the interval, which is more likely, the first Sumner line is carried forwards, parallel to itself, according to the course and distance run, when its intersection with the second Sumner line will be the position of the ship at the time the second observation is made.

This, in brief, is the whole theory of Sumner's method. The various forms of its utility in navigation is practically unlimited, especially in approaching or navigating along a coast line, when a Sumner line in combination with, for instance, a chain of sounding or a single bearing of a distant light, or other known object, will accurately fix the position of a ship. (See *Nautical Astronomy*, Part 4, I. C. S. Ocean Navigation Course.) It should be remembered that a Sumner line may be had from any kind of observation, whether it be for latitude or for longitude, provided that the true bearing of the observed object is noted at instance of measuring the altitude. Thus the Sumner line resulting from a meridian altitude of the sun will run true east or west, and may be combined with a second line obtained by a time sight taken 2 or 3 hr. later, or 2 or 3 hr. before noon. Probably the most valuable Sumner line obtainable is that from a star or planet at morning twilight crossed by a subsequent line obtained from the sun; or one from the sun in the latter part of the afternoon crossed by a subsequent line from a star or planet at evening twilight. The star or planet selected should, in each case, be situated so that the resulting line will cross the line obtained from the sun at right angles, or nearly so, in order to establish a good point of intersection.

It is evident that if the bearing of the object is taken by compass in order to get the true bearing, allowance must be made for variation and deviation due to the direction of the ship's head when observing.

In connection with the plotting of Sumner lines be careful not to soil or deface the chart. If a regular chart is used, draw very light pencil lines and avoid the common practice of using the dividers in such manner as to punch holes at every step. A good idea is not to use the chart for this purpose at all. Simply construct a chart on a suitable sheet of paper and on a sufficiently large scale according to directions given on page 105. This will give more satisfaction and will save the regular chart from being worn out too soon. In fact, it is not always possible to plot lines on a chart of small scale, and, moreover, a navigator may not always have at his command sufficient table space to spread out a good-sized chart.

Illustration.—Suppose that a time sight of the sun is taken in the morning and that the resulting long. is 46° 50′ W; the lat., by dead reckoning is somewhat uncertain, but is assumed to be 50° 45 N, and this value is therefore used in computing the hour angle. At instance of observation, the sun's true bearing was S 75° E, and hence the resulting Sumner line runs N 15° E and S 15° W. This line *a b*, in the appended diagram, is now laid down on the chart through the position found and at right angles to the true bearing of the sun. The ship's position is now somewhere on this line, but on account of the uncertainty of the latitude used, we cannot tell exactly where until a second line is established. After making a run W S W 60 mi. another sight is taken, and the position thus found is in lat. 50° 28′ N and long. 48° 25′ W. The true bearing of the sun at the second sight is S 8° E, and hence the resulting Sumner line *c d* runs S 82° W and N 82° E. In order to find the true position, we proceed as follows: From any point *x* on the first Sumner line, lay off the course and distance run in the interval between sights, in this case W S W 60 mi., and at the extremity *y* of this line draw *a b′* parallel to the first Sumner line, so that it will intersect *c d*, the second Sumner line. The point *z* where *a b′* crosses *c d* will be the true position of the ship at time of taking the second sight, its lat. and long. being, respectively, 50° 29′ N and 48° 15′ W. To find the true position of the ship at time of the first sight, we draw a line from *z*, toward *a b* parallel to *x y*, the course run; the point *o* where this line intersects *a b* was the position of the ship at first observation. By inspection of the chart, it will be noticed that the latitude assumed and used in the first sight was nearly 8 miles in error



51°
50°
46°
47°
48°
49°
50'
45'
40'
30'
20'
10'
1st Position
True Bearing S75°E
First Line
a
b
x
o
WSW, 60 Miles
E
NE
SE
W
NW
SW
c
d
a'
b'
z
y
Second Line
True Bearing S8°E
True Position
2nd Position
25'
28

SAILING DISTANCES, IN NAUTICAL MILES, BETWEEN THE PRINCIPAL PORTS IN NORTH AMERICA

Halifax																		
383	Boston																	
365	103	Nantucket Light																
572	338	257	Sandy Hook															
590	356	275	18	New York														
641	407	326	150	168	Cape Henlopen													
735	501	420	244	262	94	Philadelphia												
740	511	430	257	275	152	246	Cape Henry											
906	677	596	423	441	318	412	166	Baltimore										
926	697	616	443	461	338	432	186	183	Washington									
773	544	463	290	308	185	279	33	158	190	Norfolk								
869	640	559	386	404	281	375	129	223	275	101	Richmond							
796	570	489	330	348	222	316	124	290	310	157	253	Cape Hatteras						
1,066	842	761	605	623	503	597	398	564	584	431	527	265	Charleston					
1,142	918	837	681	699	579	673	474	640	660	507	603	341	98	Savannah				
1,552	1,341	1,260	1,104	1,122	1,002	1,096	897	1,063	1,083	930	1,026	764	594	564	Key West			
1,597	1,386	1,305	1,149	1,227	1,047	1,141	942	1,108	1,128	975	1,071	809	639	609	71	Havana		
2,125	1,914	1,833	1,677	1,693	1,575	1,669	1,470	1,636	1,656	1,503	1,599	1,337	1,167	1,137	573	597	New Orleans	
2,401	2,190	2,109	1,953	1,971	1,851	1,945	1,746	1,912	1,932	1,779	1,875	1,613	1,443	1,413	859	877	782	Vera Cruz

SAILING DISTANCES, IN NAUTICAL MILES, BETWEEN THE PRINCIPAL PORTS OF THE WORLD

Cape Good Hope	Cape Horn	Constantinople	Copenhagen	Gibraltar	Hamburg	Havre	Lisbon	Liverpool	London	Marseilles	New Orleans	New York	
3,610													
7,040	8,400												
6,900	8,150	3,673											
5,123	6,470	1,920	1,953										
6,560	7,810	3,577	492	1,657									
6,130	7,460	3,109	830	1,189	492								
4,700	6,020	2,213	1,835	293	1,498	1,040							
6,080	7,400	3,224	1,329	1,312	992	550	1,010						
6,260	7,510	3,278	682	1,358	417	190	1,196	689					
5,800	7,150	1,470	2,676	680	2,336	1,896	973	1,846	2,036				
7,260	7,600	6,400	5,370	4,485	5,030	4,570	4,370	4,480	4,730	5,165			
6,790	7,232	5,100	3,873	3,204	3,540	3,245	3,148	3,166	3,303	3,850	1,699		
5,990	5,663	13,020*	12,890*	11,110*	12,550*	12,120*	10,690*	12,100	12,250*	11,800*	13,260†	12,900†	Sidney
7,630	8,880	4,573	730	2,653	1,222	1,560	2,565	2,060	1,412	3,400	6,100	4,100	St. Peters'g
9,990†	6,380	14,770†	14,520†	12,850†	14,200†	13,840†	12,400†	13,800†	13,880†	13,500†	13,980	13,610†	San Fran.

* By way of Cape Good Hope.
† By way of Cape Horn.

ADDITIONAL SAILING DISTANCES, IN NAUTICAL MILES, BETWEEN THE MOST FREQUENTED PORTS OF THE WORLD

	Miles
Bermudas to Nassau	804
Boston to Halifax	383
Boston to Liverpool (via Halifax)	2,856
Cape Bonavista to Cape Spear	76
Cape Spear to Cape Race	55
Cape Race to Liverpool	1,992
Cape Race to Halifax	457
Cape Race to Boston	835
Cape Race to New York	1,004
Cape Race to Philadelphia	1,155
Cape Race to Cape Pine	19
Colon to St. Thomas	1,014
Halifax to Liverpool	2,459
Honolulu to Apia	2,240
Honolulu to Dutch Harbor	2,016
Honolulu to Hong Kong	4,917* 4,961
Honolulu to Numed	3,551
Honolulu to Panama	4,665
Honolulu to San Diego	2,280
Honolulu to San Francisco	2,089
Honolulu to Tahiti	2,389
Honolulu to Valparaiso	5,916
Honolulu to Vancouver	2,372
Honolulu to Wellington	4,163
Manila to Hong Kong	628
New Orleans to Colon	1,380
New Orleans to Havana	597
New Orleans to Minatitlan	818
New York to Barbados	1,829
New York to Colon	1,981
New York to Gibraltar	3,204
New York to Havre	3,245
New York to Bremerhaven	3,600
New York to Liverpool	3,166
New York to London	3,303
New York to Havana	1,227
New York to Panama (via Cape Horn)	11,329
New York to Pernambuco	3,696
New York to San Juan, Porto Rico	1,381
New York to Minatitlan	1,962
New York to St. Thomas	1,428
New York to St. Vincent	2,919

* Indicates distance along the great-circle track.

ADDITIONAL SAILING DISTANCES, IN NAUTICAL MILES, BETWEEN THE MOST FREQUENTED PORTS OF THE WORLD—(*Continued*)

	Miles
Panama to Acapulco	1,416
Panama to David Chiriqui	276
Panama to Gulf of Fonseca	739
Panama to Manzanilla	1,724
Panama to Monterey	3,198
Panama to Punta Arenas	3,932
Panama to San Diego	2,897
Panama to Wellington	6,581
Quebec to Liverpool	2,600
Quebec to Plymouth	2,620
San Francisco to Apia	4,160
San Francisco to Acapulco	1,830
San Francisco to Columbia River Bar	530
San Francisco to Dutch Harbor	2,035
San Francisco to Honolulu	2,089
San Francisco to Humboldt	200
San Francisco to Manzanilla	1,543
San Francisco to Panama	3,277
San Francisco to Portland	650
San Francisco to Port Townsend	732
San Francisco to San Diego	474
San Francisco to San Juan del Sud	2,685
San Francisco to Tahiti	3,658
San Francisco to Vancouver	638
San Francisco to Valparaiso	5,140
San Francisco to Yokohama	4,536* 4,791
San Francisco to Victoria	715
St. Johns, N. F., to Quebec	891
St. Johns, N. F., to Boston	890
St. Johns, N. F., to Bristol	1,936
St. Johns, N. F., to Cape Bonavista	72
St. Johns, N. F., to Cape Spear	5
St. Johns, N. F., to Cape Race	60
St. Johns, N. F., to Galway	1,677
St. Johns, N. F., to Greenock	1,848
St. Johns, N. F., to Liverpool	1,956
St. Johns, N. F., to St. Peter's Light	183
Yokohama to Apia	4,072
Yokohama to Honolulu	3,399
Yokohama to Sydney	4,390
Yokohama to Vancouver	4,259* 4,632

* Indicates distance along the great-circle track.

UNITED STATES NAVY

ORGANIZATION OF THE NAVY

Administrative Bureaus.—By the Constitution of the United States, the President is Commander-in-Chief of the Navy, but in practice most of the administrative details are left to the Secretary of the Navy, who is assisted by an Assistant Secretary and by the chiefs of eight **Bureaus,** between which the work of the Navy Department is divided. These Bureaus are: The Bureau of Yards and Docks, the Bureau of Equipment, the Bureau of Navigation, the Bureau of Ordnance, the Bureau of Construction and Repair, the Bureau of Steam Engineering, the Bureau of Supplies and Accounts, the Bureau of Medicine and Surgery.

In a general way, the above titles are descriptive of the duties of the Bureaus, except in the case of the Bureau of Navigation, which would be more accurately described as the *Bureau of Personnel,* since it has nothing whatever to do with navigation and has everything to do with the enlistment and training of men, the assignment of officers and crew to stations afloat and ashore, and, broadly speaking, with all matters of organization. drill, and discipline.

A **Chief of Bureau,** while serving in that capacity, has the rank and pay of a rear-admiral, no matter what his actual rank may be on the Navy List.

Navy Yards.—Each navy yard is under the command of a *Commandant,* who is either a rear-admiral or a captain; but each of the Navy Department Bureaus has its representative in charge of its own work at the yard, and maintains an intimate oversight and control of all such work.

The present navy yards are at Portsmouth, N. H.; Boston, Mass.; Brooklyn, N. Y.; Philadelphia, Pa.; Norfolk, Va.; Pensacola Fla.; Mare Island, Cal.; and Bremerton, Wash. There are, also, naval stations at Newport, R. I.; New London, Conn.; Washington, D. C.; Port Royal and Charleston, S. C.; Key West, Fla.; Algiers, La.; San Francisco and San Diego, Cal.

Training stations for enlisted men are maintained at Newport, R. I., Norfolk, Va., and San Francisco, Cal., and an appropriation has been made for establishing one in the Great Lakes.

Officers.—The officers of the Navy are divided into **Line officers** and **Staff officers**; the **Staff corps** including medical officers, pay officers, and chaplains, as sea-going officers; and naval constructots, civil engineers, and professors of mathematics for service on shore only.

The grades in the Line, with the grades to which they correspond in the Army, are as follows:

Admiral	General
Vice-Admiral	Lieutenant-General
Rear-Admiral	Major-General Brigadier-General
Captain	Colonel
Commander	Lieutenant-Colonel
Lieutenant-Commander	Major
Lieutenant	Captain
Lieutenant, junior grade	First Lieutenant
Ensign	Second Lieutenant
Midshipman	Cadet
Chief Boatswain	Second Lieutenant
Chief Gunners	Second Lieutenant
Chief Carpenters (are staff officers)	Second Lieutenant
Chief Sailmakers (are staff officers)	Second Lieutenant

The grades in the staff corps, with corresponding rank in the Line, are as follows:

Medical Corps

Medical Directors	With rank of Captain
Medical Inspectors	With rank of Commander
Surgeons	With rank of Lieutenant-Commander
Passed Assistant Surgeons	With rank of Lieutenant
Assistant Surgeon	With rank of Lieutenant junior grade

Pay Corps

Pay Directors..........	With rank of Captain
Pay Inspectors.........	With rank of Commander
Paymasters.............	With rank of Lieutenant-Commander and Lieutenant
Passed Assistant Paymasters	With rank of Lieutenant, junior grade
Assistant Paymaster.....	With rank of Ensign
Chaplain	With rank of Captain, Commander, or Lieutenant
Professors of Mathematics	With rank of Captain, Commander, or Lieutenant
Naval Constructors and Assistant Naval Constructors............	With rank of Captain, Commander, Lieutenant, or Lieutenant, junior grade
Civil Engineers and Assistant Civil Engineers...............	With rank of Captain, Commander, Lieutenant, or Lieutenant, junior grade

The *Warrant officers* are the following: Boatswains, gunners, carpenters, sailmakers, pharmacists, warrant machinists.

Mates are officers, but have neither commissions nor warrants.

The numbers of Line officers allowed by law in the different grades are as follows: Admiral, 1; vice-admiral, —; rear-admirals, 18; captains, 70; commanders, 112; lieutenant-commanders, 186; lieutenants, 324. In the grades below lieutenant, the number is not at present limited by law.

Titles of Officers.—In conversation, admirals and captains are addressed by their titles. A commander may be properly addressed by his title, or as *Captain*. And any officer who is actually in command of a ship is by courtesy addressed as captain. All other Line officers are addressed as *Mister*. Medical officers are commonly addressed as *Doctor*, but it is not unusual to address a medical director, medical inspector, or surgeon by his ranking title. Similarly, pay officers of high rank are commonly addressed by their ranking titles, but those below the actual rank of paymaster are called *Paymaster*.

Insignia of Naval Officers.—The insignia of the various grades are of two kinds, the first consisting of a device worn on the collar, the shoulder strap, or the epaulet; the second, of an arrangement of stripes on the sleeve.

The device for the collar or shoulder consists of two parts, one indicating the branch of the service to which the wearer belongs, the other, his rank in that branch.

Line officers wear a silver foul anchor.

Medical officers wear a gold oak leaf on which is embroidered a silver acorn.

Pay officers wear a silver oak sprig.

Naval constructors wear a gold sprig of two live oak leaves and a silver acorn.

Professors wear a silver oak leaf and an acorn.

Civil engineers wear the letters C. E. in silver.

Chaplains wear a silver cross.

The insignia of rank in the Line and the various Staff corps are as follows. These are worn in connection with the preceding Corps marks.

Admiral.................Four silver stars
Rear-Admiral............Two silver stars
Captain..................A silver spread eagle
Commander..............A silver oak leaf
Lieutenant-Commander....A gold oak leaf
Lieutenant...............Two silver bars
Lieutenant, junior grade...One silver bar
Ensign..................A silver foul anchor
Midshipman..............A gold foul anchor
Chief Boatswain..........Two silver foul anchors crossed
Chief Gunners............A flaming spherical shell in silver
Chief Carpenter...........A charm of silver
Chief Sailmaker...........A diamond in silver

The rank and corps are further indicated by stripes on the sleeves, as follows:

Admiral................Two stripes of 2-in. gold lace with one stripe of 1-in. lace between
Rear-Admiral...........One stripe of 2-in. gold lace with one stripe of ½-in. lace above
Captain.................Four stripes of ½-in. gold lace

Commander	Three stripes of ½-in. gold lace
Lieutenant-Commander	Two stripes of ½-in. gold lace with one stripe of ¼-in. lace between
Lieutenant	Two stripes of ½-in. gold lace
Lieutenant, junior grade	One stripe of ½-in. gold lace with one stripe of ¼-in. lace above
Ensign	One stripe of ½-in. gold lace
Midshipman	One stripe of ¼-in. gold lace

All Line officers wear a gold star on the sleeve above the stripes.

For Staff officers the stripes are the same as for Line officers of corresponding grades, except that: first, staff officers do not wear a star; and, second, each staff corps is distinguished by colored cloth worn between the gold stripes: thus, medical officers wear dark maroon; pay officers, white; naval constructors, dark violet; professors, olive green; civil engineers, light blue. In the case of chaplains, the gold stripes on the sleeves are replaced by black.

Chief boatswains, chief gunners, chief carpenters, and chief sailmakers wear one stripe of gold lace interrupted at intervals of 2 in. by a break of ½ in. filled in with blue silk.

ENLISTMENT, CLASSIFICATION, AND PAY OF ENLISTED MEN IN THE UNITED STATES NAVY

Recruiting Stations.—Men are enlisted at the following recruiting stations and receiving ships: United States Recruiting Station, 87 South Street, New York, N. Y.; United States Recruiting Station, 22 Hanover Street, Boston, Mass.; United States Recruiting Station, 1319 Market Street, Philadelphia, Pa.; United States Recruiting Station, 207 North Calvert Street, Baltimore, Md.; Seamen's Quarters, U. S. Navy Yard, Washington, D. C.; United States Recruiting Station, Masonic Temple, Chicago, Ill.; Receiving ship *Wabash*, Navy Yard, Boston, Mass.; Receiving ship *Hancock*, Navy Yard, New York, N. Y.; Receiving ship *Lancaster*, Navy Yard, League Island, Pa.; Receiving ship *Franklin*, Navy Yard, Norfolk, Va.; Receiving ship *Independence*, Navy Yard, Mare Island, Cal.; U. S. Navy Yard, Bremerton, Wash.; U. S. Naval Recruiting Station, San Francisco, Cal.;

U. S. Navy Yard, Pensacola, Fla.; U. S. Navy Yard, Portsmouth, N. H.; U. S. Naval Station, Port Royal, S. C.; U. S. Naval Recruiting Station, Prudential Building, Buffalo, N. Y.; also at any traveling recruiting station, information regarding which will be furnished on application to the Bureau of Navigation, Navy Department, Washington, D. C.

Applicants for enlistment in the United States Navy must be over 18 years of age, of American citizenship and capable of reading and writing English. The term of enlistment is 4 years, but no person will be accepted until he has passed the medical examination prescribed by the regulations.

No minor under the age of 18 years will be accepted without the consent of parent or guardian, and any such minor claiming to be more than 18 years of age, in order to secure enlistment, is liable to punishment.

Caution.—Applicants residing at a distance should, in all cases, communicate with the nearest recruiting station for a list of qualifications before reporting for examination, and on receipt of same should consult a physician and ascertain the probabilities of their being able to conform to the requirements. If favorably advised, the recruiting office should be immediately informed, and request made that the applicant's name be entered on the list to be notified, after which complete instructions will be given as to the proper time to report for examination. This course is suggested, as no allowance is made for traveling expenses of applicants, and they should be as certain as possible of their ability to pass the examination before incurring any expense.

Transportation is furnished only to accepted applicants from the recruiting station to the point of assignment.

Age Limits.—First enlistment may be made in the following ratings of men within the limits of age indicated in Table following.

Rating	Years of Age
Seamen	21 to 35
Ordinary seamen	18 to 30
Landsmen	18 to 25
Shipwrights	21 to 35
Blacksmiths	21 to 35
Plumbers and fitters	21 to 35
Machinists, first class	21 to 35
Machinists, second class	21 to 35
Sailmakers' mates	21 to 35
Electricians, third class	21 to 35
Boilermakers	21 to 35
Coppersmiths	21 to 35
Firemen, first class	21 to 35
Firemen, second class	21 to 35
Landsmen, for yeomen	18 to 25
Coal passers	21 to 35
Hospital stewards	21 to 30
Hospital apprentices, first class	21 to 28
Hospital apprentices	18 to 25
Officers' stewards	21 to 35
Officers' cooks	21 to 35
Mess attendants	18 to 30
Ships' cooks, fourth class	18 to 30
Musicians, first class	21 to 35
Musicians, second class	21 to 35
Buglers	21 to 35
Painters	21 to 35
Bakers, second class	21 to 35
Shipfitters, first class	21 to 35
Shipfitters, second class	21 to 35

Ratings and Monthly Pay.—In the following table are given the monthly pay for the various ratings in the Navy:

SEAMEN BRANCH

Chief Petty Officers:	
Chief masters at arms	$65
Chief boatswains' mates	50
Chief gunners' mates	50
Chief gun captains	50
Chief turret captains	60
Chief quartermasters	50
Petty Officers, First Class:	
Masters at arms, first class	$40
Boatswains' mates, first class	40
Gunners' mates, first class	40

Gun captains, first class	$40
Turret captains, first class	50
Quartermasters, first class	40
PETTY OFFICERS, SECOND CLASS:	
Masters at arms, second class	$35
Boatswains' mates, second class	35
Gunners' mates, second class	35
Gun captains, second class	35
Quartermasters, second class	35
PETTY OFFICERS, THIRD CLASS:	
Masters at arms, third class	$30
Coxswains	30
Gunners' mates, third class	30
Quartermasters, third class	30
SEAMEN, FIRST CLASS:	
Seamen gunners	$26
Seamen	24
Apprentices, first class	21
SEAMEN, SECOND CLASS:	
Ordinary seamen	$19
Apprentices, second class	15
SEAMEN, THIRD CLASS:	
Landsmen	$16
Apprentices, third class	9

ARTIFICER BRANCH

CHIEF PETTY OFFICERS:	
Chief machinists	$70
Chief electricians	60
Chief carpenters' mates	50
Chief water tenders	50
PETTY OFFICERS, FIRST CLASS:	
Boilermakers	$65
Machinists, first class	55
Coppersmiths	55
Shipfitters, first class	55
Electricians, first class	50
Blacksmiths	50
Plumbers and fitters	45
Sailmakers' mates	40
Carpenters' mates, first class	40
Water tenders	40
Painters, first class	40
PETTY OFFICERS, SECOND CLASS:	
Machinists, second class	$40
Electricians, second class	40
Shipfitters, second class	40
Oilers	37
Carpenter's mates, second class	35
Printers	35
Painters, second class	35

PETTY OFFICERS, THIRD CLASS:	
Electricians, third class	$30
Carpenters' mates, third class	30
Painters, third class	30
SEAMEN, FIRST CLASS:	
Firemen, first class	$35
SEAMEN, SECOND CLASS:	
Firemen, second class	$30
Shipwrights	25
SEAMEN, THIRD CLASS:	
Coal passers	$22

SPECIAL BRANCH

CHIEF PETTY OFFICERS:	
Chief commissary steward	$70
Chief yeoman	60
Hospital stewards	60
Bandmasters	52
Commissary steward	60
PETTY OFFICERS, FIRST CLASS:	
Yeoman, first class	$40
First musicians	36
PETTY OFFICERS, SECOND CLASS:	
Yeoman, second class	$35
PETTY OFFICERS, THIRD CLASS:	
Yeomen, third class	$30
Hospital apprentices, first class	30
SEAMEN, FIRST CLASS:	
Musicians first class	$32
SEAMEN, SECOND CLASS:	
Musicians, second class	$30
Buglers	30
Hospital apprentices	20

MESSMEN BRANCH

Stewards to commanders in chief	$60
Cooks to commanders in chief	50
Stewards to commandants	60
Cooks to commandants	50
Cabin stewards	50
Cabin cooks	45
Wardroom stewards	50
Wardroom cooks	45
Steerage stewards	35
Steerage cooks	30
Warrant officers' stewards	35
Warrant officers' cooks	30
Ship's cooks, first class	55
Ship's cooks, second class	40
Ship's cooks, third class	30
Ship's cooks, fourth class	25

Bakers, first class	$45
Bakers, second class	35
Mess attendants, first class	24
Mess attendants, second class	20
Mess attendants, third class	16

Special Pay and Privileges.—Every enlisted man and apprentice who has been rated a seaman gunner, or holds a gun captain's certificate, or a certificate of graduation from one or more classes of the Petty Officers' School of Instruction, receives $2 a mo. in addition to the pay of his rating for each such certificate.

Each enlisted man of the Navy receives 75 ct. per mo. in addition to the pay of his rating for each rating, for each good-conduct medal, pin, or bar which he may be awarded.

Coxswains detailed as coxwains of boats propelled by machinery, or as coxswains to commanders in chief, receive $5 per mo. in addition to their pay.

All enlisted men of the Navy receive $5 per mo. in addition to their pay while serving on board of submarine vessels of the Navy.

Seamen in charge of holds receive $5 per mo. in addition to their pay.

Landsmen assigned to duty as jacks-of-the-dust, or as lamplighters, receive $5 per mo. in addition to their pay.

Enlisted men detailed as crew messmen while so acting, except when assigned as reliefs during the temporary absence of the regular crew messmen, receive extra compensation at the rate of $5 per mo.

Enlisted men of the naval service regularly detailed as signalmen receive the following extra compensation in addition to the monthly pay of their rating: Signalmen, first class, $3; signalmen, second class, $2; signalmen, third class, $1.

All enlisted men of the navy, after having qualified as gun pointers, and who are regularly detailed as gun pointers by the commanding officer of the vessel, receive monthly, in addition to the pay of their respective ratings, extra pay as follows: Heavy gun pointers of the first class, $10; heavy gun pointers of the second class $6; intermediate gun pointers of the first class, $8; intermediate gun pointers of the second class, $4; secondary gun pointers of the first class, $4; secondary gun pointers of the second class, $2.

Enlisted men of the Navy regularly detailed by the commanding officer of a vessel as gun captains, except of secondary battery guns, receive, in addition to the pay of their respective ratings, $5 per mo., which in the case of men holding certificates as gun captains, or of graduation from the gun captain class, Petty Officers' School, shall include the $2 per mo. to which such certificate entitles them.

Additional Rewards.—The pay of the various grades may not seem large, but it must be remembered that it is nearly all clear. The ship constitutes a comfortable home and the government supplies an excellent ration. An outfit of clothing is issued free at the beginning of an enlistment. Medical and hospital attendance are free. Thus, the only real demand on the pay is for keeping up the outfit of clothing. Men can and do save very large sums of money, and these sums they have the privilege of depositing with the government, which allows interest at the rate of 4% compounded. There are, moreover, many additions to the pay for special details of duty and special excellencies of various kinds. A man distinguished in marksmanship and serving as pointer of a turret gun receives $10 per mo. in addition to his regular pay. An expert signalman gets $5 additional; and so with many other cases, as indicated in the pages that follow.

A man having served one term of enlistment and having been honorably discharged, if he reenlists within 4 mo., receives a bonus of 4 mo. pay. This amounts in the higher ratings to as much as $280. Moreover, for each reenlistment his monthly pay is slightly increased.

In case of disability from illness or accident, not only is a man fully cared for without charge but his full pay goes on, no matter how long the disability may continue; and in the case of permanent disability resulting from causes incident to the service, he receives a pension for life, provided that he has served 10 yr. Even though he may be in perfect health, he has the privilege on reaching 50 yr.

of age, provided that he has served for 30 yr., of being placed on the retired list for the remainder of his life with three-quarters of the full pay of his grade. If he is a chief petty officer, and any reasonably deserving man would surely be this after 30 yr. service, this retired pay is $52.50 per mo., and for this he is not called upon to make any return whatever.

Although, in general, a man must expect in the Navy, as elsewhere, to begin at the bottom and work his way up, there are many well-paid positions for which competent men are enlisted directly. Thus, a man who is already a competent seaman is gladly taken in as such, and, owing to the great demand for coxswains, quartermasters, etc., he may reasonably expect almost immediate advancement to one of these ratings. So, in the artificer branch, a man who is qualified for machinist, water tender, fireman, boilermaker, electrician, plumber, painter, etc. is enlisted directly as such.

Naval Apprentices.—Boys between the age of 17 and 18 yr. may, with the consent of their parents or guardians, be enlisted to serve as apprentices in the Navy until they reach the age of 21 yr. They are trained to fill the positions of seamen, petty officers, and warrant officers, and from these positions they can be advanced to be commissioned officers in the Navy. Their pay as apprentices begins at $9 per mo and increases to $21.

BRIEF OUTLINE OF DUTIES

Master at Arms.—The chief master at arms is the chief of police of the ship. He has from one to three or four assistants, according to the size of the ship. It is the duty of these men to suppress disorder, to arrest offenders where physical restraint is needed, and to confine any one if ordered to do so by proper authority. They have charge of the cleanliness of the ship on the lower decks and are responsible for the eating arrangements of the men, so far as regards the condition of the tables and the table service. The actual preparation of the food is in charge of the ship's cooks, under the supervision of the *commissary steward;* but the food is served by the berth-deck cooks, or crew messmen, and these messmen are subject to the direction of the master at arms.

Boatswain's Mates.—The boatswain's mates are the assistants to the officer of the deck in carrying on the work of the ship. All orders given are repeated by them, and they are expected to make sure, not only that the orders are heard in all parts of the ship, but that they are obeyed. If a boat is to be hoisted, they "pass the word" and then make sure that the boat is properly hooked on, that the deck force "man the falls," and that the boat is safely hoisted and secured. They bear much the same relation to affairs on the upper deck that the masters at arms bear to those on the lower decks, except that, while they are expected to maintain order, they have none of the police functions that belong to the masters at arms. They call attention by blowing a silver whistle, or *boatswain's call.*

Coxswains.—Coxswains have charge of boats, their outfits and their crews. When a boat is absent from the ship without an officer, the authority of the coxswain is absolute.

Machinists.—Machinists, when on duty, have charge of the engine room and fire-room, have full authority there and full responsibility for work and discipline. Thus, the masters at arms, boatswain's mates, coxswains, and machinists are directly charged with responsibility for the maintenance of discipline, and their orders are entitled to the same weight as those of commissioned officers. Other petty officers have no such general authority as this, though many of them may be placed in positions of authority by reason of special detail. An oiler or a fireman, for example, may do a machinist's duty in the engine room; a gunner's mate may be sent in charge of a party to bring off ammunition, etc.

Quartermasters.—The quartermasters have charge of the steering of the ship and everything connected with it, of the making and reading of signals, and of the hourly record of weather, etc. as entered in the ship's log. In port, they stand watch on the bridge and are responsible for the "lookout," reporting to the officer of the deck everything of importance that goes on within sight of the ship.

Yeomen.—Yeomen are writers or accountants; their duties are purely clerical. One yeoman is usually allowed for the commanding officers, two for the executive officer, one for the engineer's department, one for the navigator, and two or more for the pay department.

Commissary Steward.—The commissary steward has charge of the purchase and preparation of provisions for the men's messes.

The duties of other petty officers and rated men are indicated with sufficient exactness by their titles.

PROMOTION OF ENLISTED MEN TO OFFICERS

Mates.—These are officers, although not commissioned, their salary being $900 a yr.

"As a reward for long and faithful service in the navy, the Department will in the future appoint ten mates annually from the enlisted men of the service, appointments to be made on or about July 1 of each year. No man will be appointed who is not recommended for appointment by his commanding officer and who does not come within the following provisions: He must be a chief petty officer of the seaman branch, at least 35 yr. of age, serving under continuous service, who has had 15 yr. service in a seagoing ship, with an average of 85% taken from all his enlistment records, and there must be on file in the Bureau of Navigation letters of recommendation from his commanding officers."

Warrant Officers.—Warrant officers rank next below commissioned officers in the service; they are officers in every sense of the word. Enlisted men who serve continuously and reach the grade of chief petty officer or first-class petty officer are eligible for appointment as warrant officers. The warrant officers are boatswains, gunners, carpenters, sailmakers, warrant machinists, and pharmacists. The pay of a warrant officer is from $1,200 to $1,800 a yr., and he may retire at 62 yr. of age on three-quarter pay.

Commissioned Officers.—Warrant officers after 10 yr. service are given a commission and rank with ensigns of the Line. A warrant officer who can pass the requisite examination may be regularly commissioned as an ensign in the Line of the Navy and advance through all the grades of the service up to admiral, exactly as if he had graduated at the Naval Academy. A number of such appointments have already been made, the majority of appointees being I. C. S. nautical students.

Educational Facilities in the Navy.—The earnestness with which the Navy endeavors to help those who wish to fit themselves for advancement in the service is evidenced by the following statement of facilities provided for the purpose:

Elaborately equipped training stations for apprentices are maintained at Newport, R. I., and San Francisco, Cal., where from 1,000 to 2,000 young men are kept under instruction.

Similar stations for the training of recruits other than apprentices are maintained at Brooklyn, N. Y., and at Norfolk, Va., and a third will shortly be established at some point on the Great Lakes.

Nine large and comfortable vessels are kept in cruising commission for the training afloat of recruits of all branches. The cruises of these ships are varied as much as possible with a view to making the duty interesting as well as instructive.

The following special schools of instruction are maintained, and any man whose abilities and conduct justify the privilege can take a course in one or more of them: A school for the training of petty officers, at Newport; a school for the training of torpedo specialists, at Newport; a school for the training of electricians, at Brooklyn; a school for the training of wireless telegraphers, at Brooklyn; a school for the training of yeomen, at Brooklyn; a school for the training of gunners, at Washington; a school for the training of gunners, at Newport; a school for the training of cooks, at Brooklyn.

It should be explained that the cooks for whom the cooking school exists are those who cook for the enlisted men, not for the officers. The attention that is given to the question of food for the men is further illustrated by the fact that a board of officers recently spent several months in studying the most desirable articles to be provided for the rations of the men, and that the recommendations of these officers have resulted in the adoption on board

United States men of war of what is unquestionably the most liberal and most appetizing ration allowed by any military or naval service in the world. On the large ships of the Navy, cold-storage rooms are fitted which admit of carrying considerable quantities of fresh meat and vegetables and of furnishing cool drinking water in the tropics. Moreover, the Navy Department has, within the last few years, adopted the policy of keeping refrigerating ships in company with all large squadrons serving on tropical waters, and these ships carry abundant supplies of fresh meats and vegetables, which are distributed daily to all ships within reach.

THE ORGANIZATION OF A MAN OF WAR

OFFICERS AND THEIR DUTIES

The commanding officer, whatever his actual rank and title on the Navy List, is the **captain** of the ship, and as such is responsible for her safety, discipline, and efficiency. He is assisted by a number of subordinate officers, each of whom is charged with special duties, but this does not lessen his responsibility, which extends to every detail throughout the ship. Even when a pilot is taken for entering and leaving port, the captain cannot, as in the case of a merchant vessel, relinquish his responsibility for the navigation of the ship, but must regard the pilot as merely an adviser.

The discipline of the ship is, subject to the captain, in the hands of a certain number of **Line officers,** associated with whom are the **Staff officers** of various corps; the **medical officers** in charge of the health, hygiene, and sanitation of the ship; the **pay officer,** in charge of accounts, money, stores, and purchases; and, on large ships, **chaplains.**

The line officer next in rank to the captain is the **executive,** who may be a lieutenant-commander, a lieutenant, or on a small ship even an ensign. He attends to the details of all matters of organization and discipline, directs the drills, keeps the ship in good condition, transmits the orders of the captain, and sees that they are executed—hence his title.

In immediate charge of the ship at any given time, and responsible for the execution of the orders of the captain and executive, is the **officer of the deck.** There are usually three or four officers who take this duty in turn, "standing watch," as it is called, for 4 hr. at a time. As these officers also have charge of the *divisions* into which the crew is divided for drills and for battle, they are called **watch and division officers.** At sea, the officer of the deck is always on the bridge to see that the proper course is steered, to look out for and avoid dangers, and to carry on the routine of work. In port, he is on the alert to maintain order, supervise all work that may be in progress, receive visiting officials, etc. In his capacity as division officer, he has command of a division of men to whom he stands in the relation of the captain of a company in a military organization. The watch and division officers are always Line officers, usually lieutenants or ensigns. They are assisted in all of their duties by such junior officers as may be assigned to the ships.

The **navigator** is usually the Line officer next in rank to the executive. He assists the captain in the navigation, determines the position of the ship as often as may be necessary, and has charge of all the instruments used for this purpose.

The **engineer officers** were formerly a corps of specialists, but the Personnel Bill of 1899 merged them in the Line, and under the present system a certain number of Line officers are detailed for duty in charge of the engineering department of the ship, the actual standing of watches in charge of the engines and boilers being entrusted to **machinists.**

ORGANIZATION OF THE CREW

The crew of a ship is first of all divided into two parts, or watches, the *starboard* and the *port*. Each watch is subdivided into two parts, the first and the second. Thus, a man's position on board is fixed in one way by the statement that he belongs to the first part of the starboard watch, to the second part of the port watch, etc.

A more important assignment is that to a **division,** as this not only fixes his station in battle, but indicates the part of the ship that he assists to keep in order, and in which his most important duties are localized. The arrangement of divisions is determined largely by the arrangement of the battery. The *first division*, for example, is usually composed of the men stationed at the guns on or near the forecastle; or, in a turret ship, of those stationed in the forward turret. The ship is divided into parts corresponding with the guns, so that each division keeps that part of the ship in the order in which its guns are situated.

In addition to the *gun divisions* which are designated by numbers, there is the *powder division* which supplies ammunition, passing it from the magazines to the guns. This is usually the largest division in the ship, and is made up chiefly of men whose regular duties keep them below decks, such as cooks, stewards, mess-attendants, waiters, etc. With these men, however, are associated many of the leading men of the ship: gunners, mates, masters-at-arms, etc., charged with the safety of the magazines and with an oversight of the rapid and uninterrupted supply of ammunition.

The **engineers' force** constitutes a division by itself, but sends a detail of firemen and coal passers to assist the powder division in action.

In addition to his station for routine ship's work and for battle, every man of the deck force is assigned to a boat in which he takes his place when that particular boat is engaged either in the ordinary boating that is incident to necessary communication with other ships and with the shore, or in the cases where the boats take part in operations against an enemy. Every officer and man on the ship, moreover, has his station in a boat for abandoning ship, in the event of collision or wreck.

In every ship, there is an organization of the crew as a military force of infantry and field artillery for operations on shore in case the occasion arises for landing such a force. Hardly a year passes without the necessity for operations of this kind in some part of the world.

Drilling.—Each division on the ship has its specified duties in the case of fire, and each man in the division knows his station, whether this be to lead out a hose, to flood a magazine with water, to close certain water-tight doors so that the fire shall not spread, or to close air ports or hatches to prevent a draft from fanning the flames; and all these duties become so familiar by frequent drills that an actual fire on board a man of war is rarely accompanied by any indication of excitement, even though it may be near the magazine. Similarly in case of collision; every man knows his station, whether it be to get the collision mat over the side in hope of stopping a leak, to close the water-tight doors, to start the wrecking pump, or only to fall in ranks with his division and keep silence while awaiting instructions. Naturally, the most important drill of all is the *battle drill*, or, as it is called, *general quarters;* and when the call for this is sounded, whether at the regular morning hour for drill or unexpectedly in the middle of the night, every man makes his way quickly and silently to his station, the magazines are opened and ammunition rushed to the guns; the guns are loaded and swung until they bear upon the enemy, either real or imaginary; the torpedoes are adjusted and the tubes trained; switches are thrown on for searchlights and signals; and, often within a minute, the ship is transformed from tranquility and apparent inertness into a state of alert and vigorous aggressiveness.

Constant drilling is carried on with devices for training the gun's crews in loading, pointing, and firing the guns. These drills have resulted, within a few years, in an extraordinary increase in rapidity and accuracy of fire. Other drills have for their object to familiarize the men with the use of rifles, revolvers, broadswords, etc.; and others still aim largely at physical development, being in the nature of gymnastics. With the same end in view, coupled with the further thought of affording recreation, athletic sports are encouraged, and outfits for boxing, baseball, and football are supplied by the government to all ships, and commanding officers are directed to afford all reasonable facilities for the use of these and for competition between different ships. All large ships have their athletic teams, many of them with records of which they have a right to be proud. Most ships also have racing boat crews; and races, both rowing and sailing, are frequent when ships are in company.

The stations of the crew for all the drills that have been outlined above are laid down in a book known as the *Watch*

Quarter and Station Book, which is prepared by the executive officer and kept in his office. Each man is furnished with a slip of paper called the **station billet**, giving his number, station to which he is asssigned, and full information as to all his duties.

The office of the executive officer is presided over by the **ship's writer**, who is one of the most important men in the ship. In addition to keeping track of the stations of the men, he keeps all records and makes out all details that have to do with the crew. For each man on the ship, there is kept an *enlistment record*, which is begun when he enters the service and gives his history continuously until his discharge, showing the various ratings that he has filled and his proficiency in them, his ability in seamanship, ordnance, signals, etc., his conduct and his health. This record is transferred with the man from ship to ship, and at the end becomes a part of the permanent files of the Navy Department.

The following is a sample of the daily and weekly routine of a man of war, many small details being omitted:

DAILY ROUTINE IN PORT

5.30 A. M.	Reveille. All hands turn out except those who have had night watches. 30 min. allowed for stowing hammocks, for coffee, and for smoking.
6.00	Turn to (viz., begin work). Scrub clothes and clean ship. Time and opportunity allowed for bathing, etc.
6.30	Send market boat ashore for provisions.
7.00	All hands. Men who have been sleeping-in, turn out.
7.20	Spread mess gear (viz., make preparation for breakfast).
7.30	Breakfast. Crew dress in prescribed uniform.
8.00	Colors (viz., hoist the ensign, band playing National Anthem).
8.15	Turn to (viz., resume work). Clean bright work (brass and steel) of ship and guns.

8.45	Sick call (viz., all sick report to surgeon).
9.00	Knock-off bright work. Clear up the decks and make everything shipshape, etc.
9.30	Quarters (viz., all hands go to stations at guns or elsewhere, for muster, inspection, and drill). Divisions are mustered and inspected by their officers and report made to the executive officer whether all are present.
9.40	1st drill period. Drills as prescribed.
10.30	2d drill period. Drills as prescribed.
11.00	End of forenoon drills.
11.20	Stand by scrubbed clothes (clothes lines are lowered and clothes removed from lines). Sweep decks.
11.50	Spread mess gear (prepare for dinner).
12.00	Dinner.
1.00 P. M.	Turn to.
1.30	Afternoon drill period.
2.00	End of drill period. Sweep decks.
4.00	Knock-off work; artificers, carpenters, blacksmiths, etc., quit work.
4.30	Sweep and clean up decks.
5.00	Quarters (muster, followed by setting-up drill for 10 min.).
5.30	Spread mess gear.
6.00	Supper.
6.30	Turn to.
Sunset	Retreat. Ensign lowered, band playing National Anthem. Hoist boats; make all secure for the night.
7.30	Pipe down hammocks. Hammocks are taken from place where stored and slung ready for use.
8.00	Chief engineer, warrant officers, master at arms, captain of hold, etc. report to executive officer that their respective parts of the ship are secure. Master at arms reports that the galley fires and certain lights on lower decks are out.

8.55 Bugle call, preliminary to tattoo.

9.00 Tattoo (bugle). Pipe down for the night. Turn in and keep silence. Muster anchor watch. Taps.

Division of Time on Shipboard.—The day on shipboard is divided into **watches** which are of 4 hr. each, except that the period from 4 to 8 P. M. is divided into two watches of 2 hr. each, called *dog watches*. The object of this is to make an odd number of watches during the 24 hr. so that the starboard and port watches of the crew will not be on duty at the same time every day. The watches are designated as follows:

12 noon to 4 P. M.	Afternoon watch
4 to 6 P. M.	First dog watch
6 to 8 P. M.	Second dog watch
8 P. M. to midnight	First watch
Midnight to 4 A. M.	Mid watch
4 to 8 A. M.	Morning watch
8 A. M. to 12, noon	Forenoon watch

The time on shipboard is marked by strokes on the ship's bell, and is expressed by the number of bells (strokes) that have been struck; thus, 1 bell is one stroke of the bell, 6 bells is six strokes of the bell, and so on. Counting from 12 o'clock, noon, which is 8 bells, the half hours through the day and night run as follows:

12.30 P. M.	1 bell	7.30 P. M.	7 bells
1.00 P. M.	2 bells	8.00 P. M.	8 bells
1.30 P. M.	3 bells	8.30 P. M.	1 bell
2.00 P. M.	4 bells	9.00 P. M.	2 bells
2.30 P. M.	5 bells	9.30 P. M.	3 bells
3.00 P. M.	6 bells	10.00 P. M.	4 bells
3.30 P. M.	7 bells	10.30 P. M.	5 bells
4.00 P. M.	8 bells	11.00 P. M.	6 bells
4.30 P. M.	1 bell	11.30 P. M.	7 bells
5.00 P. M.	2 bells	12 midnight	8 bells
5.30 P. M.	3 bells	12.30 A. M.	1 bell
6.00 P. M.	4 bells	1.00 A. M.	2 bells
6.30 P. M.	5 bells	1.30 A. M.	3 bells
7.00 P. M.	6 bells	and so on as before	

BRIEF NOTES AS TO ETIQUETTE OF A MAN OF WAR

The following brief notes will be of value to a recruit unfamiliar with the customs of the Navy, and may be of interest to others:

1. In saluting an officer, an enlisted man should stand at attention and touch his cap. *Attention* is an erect position with both heels together.

2. He should always salute when addressing an officer and when addressed by him. Also when meeting him on shipboard or on shore, and this whether he is in uniform or not.

3. When an officer is moving about the ship in the performance of his duty, it is not required that men shall salute him every time he passes, nor are men who are themselves actually at work expected to stop their work to salute. But it is always better to show an excess of courtesy in this matter than a lack of it.

4. When the commanding officer passes along the deck, all men near whom he passes should stand at attention and salute.

5. When the commanding officer leaves the ship or comes on board, in uniform, the signal for "silence" is sounded on the bugle and everybody on deck stands at attention.

6. The same ceremony is observed for an officer from another ship making an official visit.

7. When the ensign (national flag) is hoisted at 8 A. M. or hauled down at sunset, the band plays the "Star Spangled Banner" and all officers and men face aft (toward the flag) and stand at attention. As the flag reaches the peak, in hoisting, or the rail, in lowering, all salute. The flag is sometimes called *the flag*, sometimes *the ensign*, and sometimes *the colors*.

8. When one ship of war passes near another (of any nationality), the call for "silence" is sounded by bugle, and all men on deck face toward the side on which the other ship is to be passed and stand at attention.

9. All officers and men coming on to the quarter deck face toward the colors and salute.

10. Men in a boat which is lying alongside the ship stand up and salute as an officer passes in another boat. When a boat is in charge of a coxswain only the coxswain salutes.

11. In the case of a squad of men in charge of one, only the man in charge salutes.

12. Petty officers are entitled to be treated with respect, but are not saluted.

13. In cases where an accommodation ladder is shipped on each side, enlisted men use the port side, the starboard ladder being reserved for officers.

14. Except on duty, enlisted men shall keep clear of the starboard side of the quarter deck, this being reserved for the captain and the officers of the deck.

15. Men given an order by an officer, stand at attention, salute, and give "Aye, Aye, Sir!" and then execute the order promptly.

NOTE.—The term "Aye, Aye" is often used incorrectly in reply to a question. It is not at all the same thing as "Yes," but is an expression of readiness to obey. In other words, it is the response to an order, not to a question.

16. A man on shipboard wishing to see an officer, goes to the place appointed for communicating with the officer of the deck (this place, wherever it may be, is technically called *the mast*) and states his wishes. If the officer of the deck considers it proper to do so, he sends for the officer who is wanted. The mast is the place for formal communication between officers and men, as for example, where a man has a grievance and wishes to see the captain or executive. Similarly, men charged with offenses are brought to the mast and their cases are investigated there.

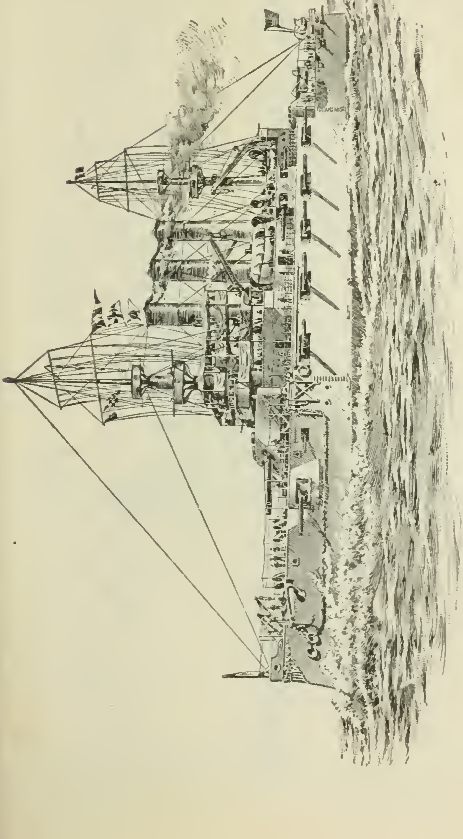
THE CLASSIFICATION OF WAR SHIPS

General Considerations.—The weight that a ship of given size will carry, and still float, is limited, while the amount of weight that we would like to make her carry, in armor, armament, engines, and coal supply, is practically unlimited. This being the case, we are compelled to accept a compromise, the nature of which will depend on the purpose for which the particular ship in question is to be used. If we give her the heaviest guns and thickest armor, we shall have comparatively little weight remaining for engines and coal. "Very well," we say, "we want this ship for fighting, not for running away. Let us give her first of all guns and armor; and then do the best that can be done in the way of speed and coal supply." Thus we get the *battle ship*. But suppose that we want a ship not to oppose the fighting ships of the enemy, but to avoid these and to chase and capture her fleetest merchant steamers; such a ship must carry nearly all her weight in powerful engines and large coal supply. She needs few guns and no armor. This is a *commerce-destroying cruiser*. Suppose, again, that we wish to strike a mean between these two extremes, preserving in a considerable measure the fighting qualities of the battle ship and associating them with a speed and coal supply approximating to those of the fast cruiser; this gives us the *armored cruiser*, powerful enough to give a good account of herself in battle, even if obliged to fight a battle ship, but able, as a rule, to avoid such odds by reason of her speed, and able, also by reason of her speed, to overtake all but the fastest of the enemy's cruisers and merchant steamers.

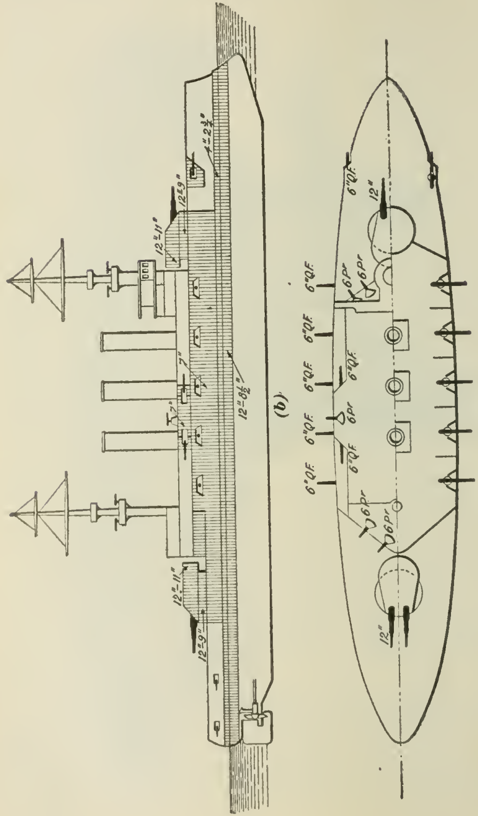
The following classes of ships are recognized by the great Naval Powers:

Battle ships are ships of large size, carrying the heaviest guns and thickest armor, but with moderate speed and rather small coal supply. They are designed to fight the most powerful ships of an enemy, but not, as a rule, to go far from a base. Such vessels carry their heavy guns in *turrets*. A representative type of this class is the new battleship "Maine" shown in Fig. 1 (*a*), which has a displacement of 12,500 T., and an average speed of 17 knots. Diagrams (*b*) and (*c*) show, respectively, the armor protection and batteries carried by the ship.

Armored cruisers are ships of large size carrying guns and armor much lighter than those of a battle ship, but heavier than those carried by any other class of ship (except monitors). They have much higher speed than battle ships, and carry sufficient coal for steaming long distances and operating at a distance from the base. They have a wider range



(a)
Fig. 1. U.S.S. *Maine*



(c)

FIG. 1

of usefulness than any other class. The Russian cruiser "Gromoboi," shown in Fig. 2, is a fair type of this class.

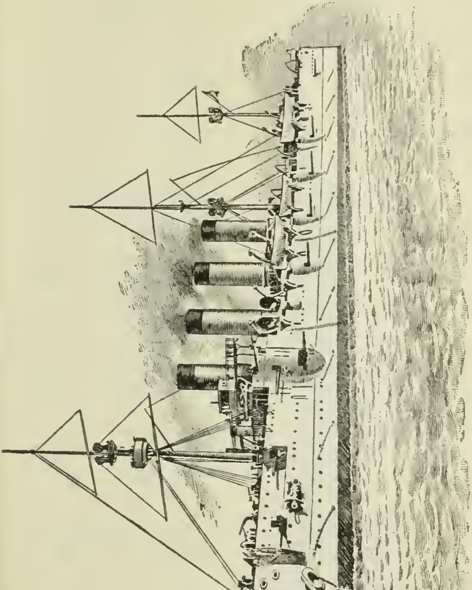
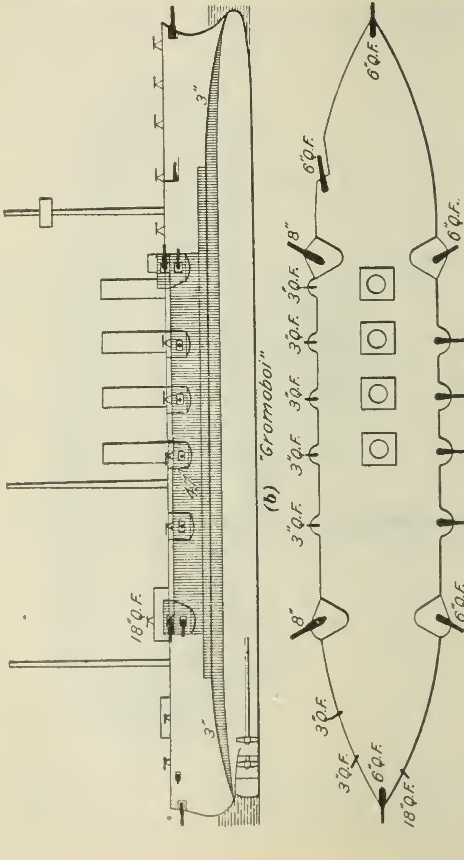


Fig 2 *Armored Cruiser Gromoboi*

(a)

This ship has a displacement of 12,367 T., a speed of 20 knots, and a coal-carrying capacity of 2,500 T. It will be noticed that the distribution of armor on the "Gromoboi" shown



(b) "Gromoboi"

(c)

Fig. 2

in Fig. 2 (*b*) is about the same as on the "Maine," but that the armor on the latter ship is much heavier.

Protected cruisers are ships of moderate size with no side armor, but having their vital parts (engines, boilers, and magazines) protected by a curved deck of steel from 2 to 4 in. thick. They have good speed and large coal supply, with guns of moderate power, and are designed for cruising on distant stations in time of peace and for blockading, scouting, and commerce destroying in time of war. They are designed also for fighting, but not against armored ships. The German cruiser "Kaiserin Augusta," diagrams of which are shown in Fig. 3, belongs to this class of ships.

Cruisers and gunboats are ships of moderate and small size, without armor or armored deck, with moderate speed and light guns, but often with very large coal supply. They are designed for cruising in time of peace and for blockading and commerce destroying in time of war; also for fighting against similar ships of an enemy. Ships of this class are often *sheathed;* that is, their bottoms are covered with wood, which in turn is covered with copper, to prevent the fouling and pitting to which the bottom of a steel ship is subjected, if not frequently docked. A sheathed ship can remain out of dock for several years, if necessary. They are often fitted with masts and sails.

Monitors are a special type, confined almost entirely to the United States Navy, resembling battle ships in guns and armor and in carrying their large guns in turrets, but differing from all other types of ships in that they are very low in the water, and thus present a very small target. The first monitor, designed by John Ericsson, was the forerunner of the battle ship. They are effective fighters in smooth water, but not in a rough sea, because the waves break over their low decks and make it impossible to work their guns, and because they have the further peculiarity of rolling very rapidly. They are essentially harbor defense ships. A type of this class of vessel, the U. S. S. "Wyoming," is shown in Fig. 4 (*a*), (*b*), and (*c*).

Torpedo boats (Fig. 5) are light, low craft, very long and narrow, of great speed, made as nearly invisible as

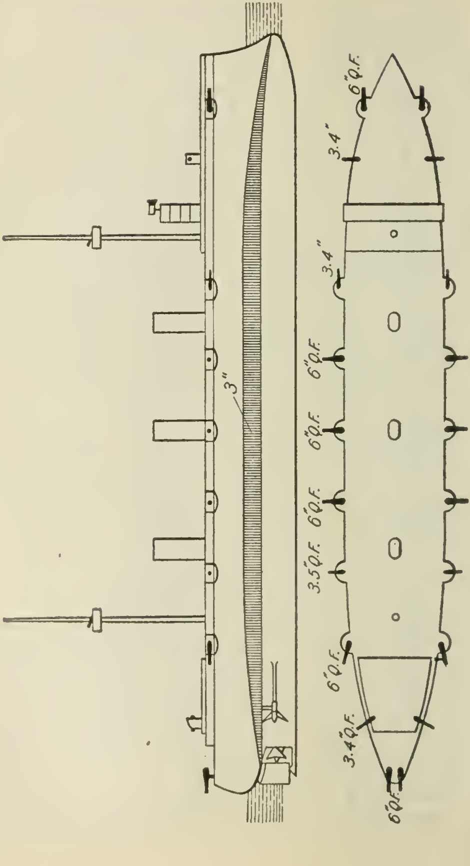
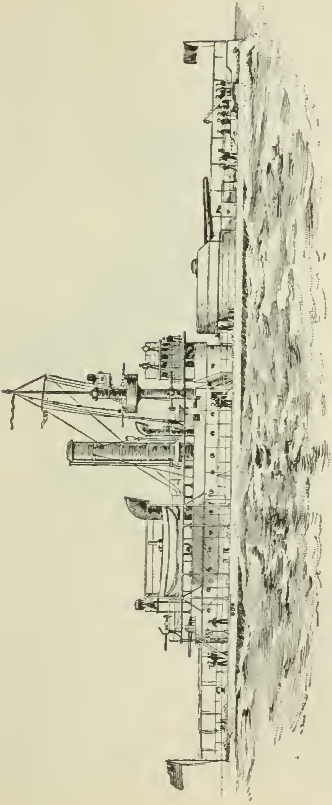


FIG. 3



(*a*)
FIG. 4. *U.S.S. Wyoming*

possible by their shape and color. They are armed with torpedoes, and in some cases with a few light guns; they are designed to attack larger ships with torpedoes, usually under cover of darkness. Torpedo boats are, as a rule, small vessels, their displacements varying from about 25 to 250 T., and are fitted with powerful engines to drive them at the required high speed. Their interior space is consequently ingeniously arranged and utilized in every possible way to accommodate the crew, boilers, engines, fuel, stores, and other equipments. In Fig. 6 is shown the

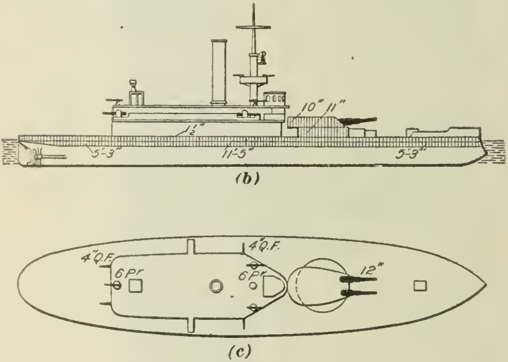


FIG. 4

interior arrangement of a modern torpedo boat. The several compartments designated by numbers are as follows. *1*, chain locker; *2*, tank; *3*, torpedo hoist; *4*, spare torpedoes; *5*, shaft for war heads; *6*, crew's quarters; *7*, magazine; *8*, storeroom; *9*, coal bunker; *10*, boilers; *11*, stoke hold; *12*, main engine; *13*, auxiliary engine; *14*, magazine; *15*, torpedo tube; *16*, wardroom and sick bay; *17*, storeroom; *18*, mess room; *19*, pantry; *20*, 6 pdr. quick-firing gun; *21*, 12 pdr. quick-firing gun; *22*, binnacle; *23*, chart room; *24*, bridge; *25*, searchlight.

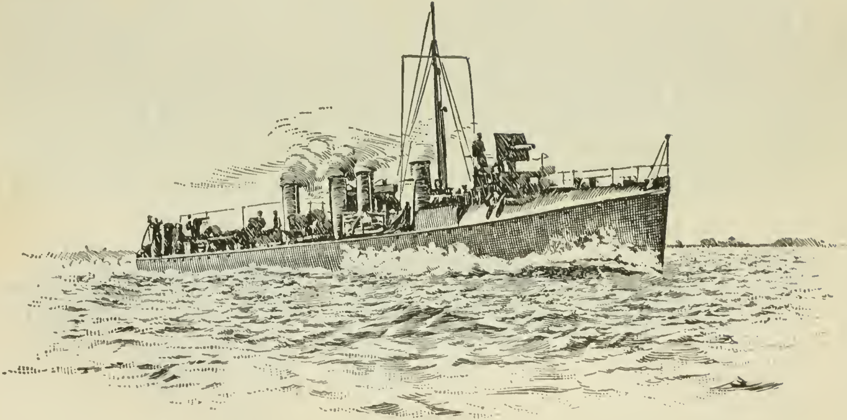


FIG. 5

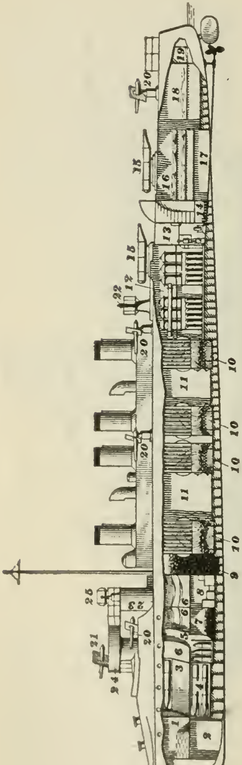


Fig. 6

Torpedo-boat destroyers are greatly enlarged torpedo boats, with higher speed and better sea-going qualities. Armed with torpedoes, but carrying also several guns of fair size, this type was evolved with a view to running down and destroying the torpedo boats of an enemy. Being large enough to keep the sea even in bad weather, they can accompany a fleet of battle ships and protect them from torpedo boats, while at the same time themselves serving to attack the enemy with torpedoes.

Other ships that are essential to a properly organized navy are scout ships (large and fast), colliers, supply ships, hospital ships, distilling ships (to supply the large amount of fresh water needed by modern boilers), repair ships, and despatch boats.

A **squadron** is a small number of ships under the command of one officer.

A **fleet** is several squadrons grouped under the command of an admiral.

A **flotilla** is a group of small craft, torpedo boats, etc.

MAN-OF-WAR BOATS

Launches are large heavy boats designed primarily for carrying cargo or for carrying large bodies of men in landing operations.

Cutters are like launches, but much smaller, and are used for both cargo and passenger boats; both launches and cutters are fitted for carrying light field guns.

Whale boats are lighter than cutters and of a different model, being sharp at the stern as well as at the bow; they are used for miscellaneous work, being light and handy.

Dingies are small boats pulling usually four oars, used for light work of any kind.

The **barge,** used only in a flagship, is the personal boat of an admiral.

The **gig** is the personal boat of the captain; it is usually a small whaleboat.

Steam launches and *steam cutters* are boats of fair size run by steam and used for the general work of the ship.

In Fig. 7 are shown the various rigs of man-of-war boats for sailing, of which (*a*) is the gaff and boom rig used on launches of the U. S. Navy; (*b*) is known as sprit rig; (*c*) dipping lug foresail and standing lug mainsail; (*d*) sliding gunter; (*e*) balance lug; and (*f*) standing lug.

BUGLE CALLS

Signals for many of the events of daily routine are made by bugle calls. Each class of boat has a call, and the individual boats of the class are distinguished by one, two, or more blasts after the call: thus, the signal for manning the third cutter is the cutter call followed by three blasts.

Other bugle calls are: reveille, tattoo. taps mess-gear quarters, retreat, assembly, silence.

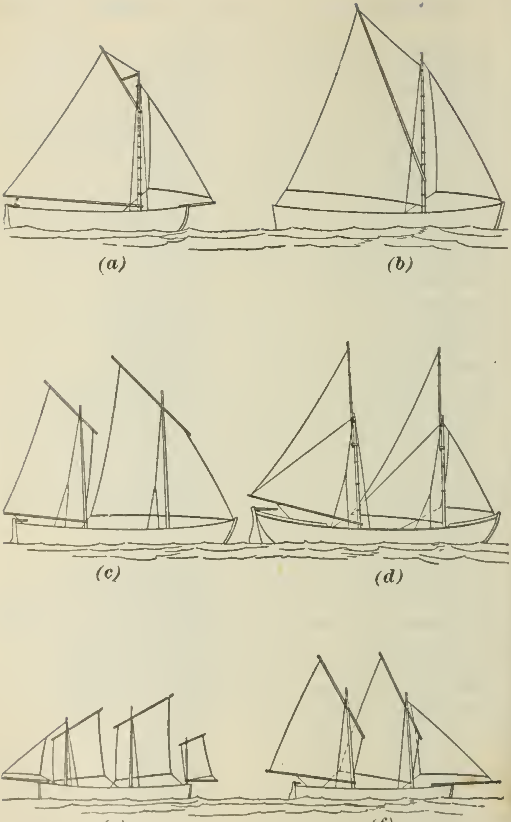


FIG. 7

NAVAL ORDNANCE

GUNS

The guns carried on shipboard as a part of the armament of the ship (except shoulder pieces and revolvers, which are technically known as *small arms*) are of great variety, as regards both size and mechanical principles; ranging from light automatic guns of musket caliber firing 500 shots per min., to the monster 13-in. rifles of 60 T. weight, mounted on a carriage of enormous strength, within a turret protected by a hundred tons of armor, firing a projectile weighing ½ T., and burning 500 lb. of powder at every round.

Classification of Guns.—All modern guns are built up of steel, and all are *rifled* and *breech-loading*.

A **built-up gun** is one in which several layers of steel are built up, one over another, on a principle to be hereafter explained.

A **rifled gun** is one in which the barrel is grooved along that part of its bore through which the projectile is to be driven by the powder gases, the grooves running spirally along and around the bore.

A **breech-loading gun** is one that is loaded from the breech, the projectile being entered first and pushed forwards to the beginning of the rifled bore. The powder is then entered, in the rear of the projectile, and the breech closed by a heavy plug or block. The method of fitting this plug, and the mechanical arrangement by which it is opened and closed, constitute the essential features of the various types of breech mechanism used with different types of guns. Some of these breech mechanisms are suitable only for small guns, others only for large ones, while a few are adaptable to any caliber. The great object of most inventors has been to obtain rapidity of action; and in some types of mechanism, the operations of unlocking the plug, withdrawing it from the gun, and swinging it out of the way, are all done by a single sweep of a lever. These are technically known as *rapid-fire*, or *quick-fire*, *mechanisms*. They are confined to guns of 7-in. caliber and under.

In guns up to and including the 5-in. caliber, the powder is commonly packed in a copper cartridge case. and the base of the projectile is forced into the mouth of the case and gripped there, forming a complete cartridge like that for a musket or a revolver. Such ammunition, Fig. 1, is technically known as **fixed ammunition.** The copper case not only holds the powder, but also prevents the escape of gas to the rear when the gun is discharged, thus doing away with the necessity for a special arrangement for this purpose (a *gas check*), which will be described in connection

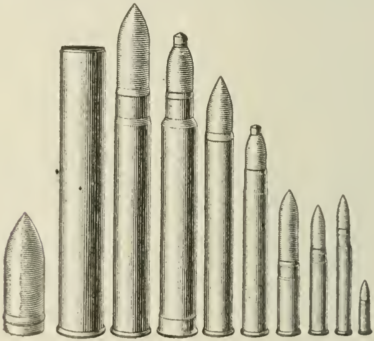


Fig. 1

with guns that do not use cartridge cases. The breech mechanism of a gun using a cartridge case must include an extractor for withdrawing the case after firing. For guns larger than 5-in. caliber, the powder is put up in bags and loaded separately from the projectile. Guns using fixed ammunition are called *rapid-fire guns.*

Other classes of guns are *machine guns*, which are fired rapidly and continuously by turning a crank or lever, the cartridges being fed in through a hopper; *automatic guns* in which the shock of discharge of one cartridge extracts the empty case and loads and fires the next cartridge, and so on indefinitely as long as the supply of ammunition holds out; and *semiautomatic guns* in which the shock of discharge does a part of the work of the automatic guns, but the loading is done by hand.

Principles of Gun Construction.—The power of guns has been enormously increased within the last quarter century, following upon the wonderful increase in the efficiency of powders, and this has called for a corresponding increase in the strength of guns. The old-style gun, whether smooth bore or rifled, was made from a single piece of metal—cast iron, wrought iron, bronze, or steel. There is a limit to the possible strength of such a gun, since after a certain thickness of wall has been reached, no increase in thickness adds anything to the strength of the gun. This is easily explained. When the powder inside the gun explodes, the pressure developed is felt first by the inner layers of the metal. These layers are expanded and transmit the strain to the layers next outside them, which in their turn expand and transmit the strain to the parts beyond, and so on. Thus the successive layers into which we may imagine the walls of the gun to be divided take up the strain, not all together, but one after the other, from inside out, each one taking a little less than the one inside. When the walls are sufficiently thick for the extreme outer layer to feel the strain just before the inner layer is ruptured, it will be useless to add more layers, because these would not take any part in resisting the strain until the inner layers had been stretched beyond the rupturing point.

In the modern system of gun making, the gun is built up of hoops or bands of tempered steel shrunk one upon another, on what is called the principle of *initial tensions.* Suppose that we have two hoops of steel, one larger than the other and of such dimensions that the inner diameter of the larger is slightly less than the outer diameter of the smaller. If we expand the larger by heat, slip it over the smaller one, and allow it to cool and set, the result will be two-fold: first, the outer tube will be stretched and thus put under an initial tension; and second, the inner tube

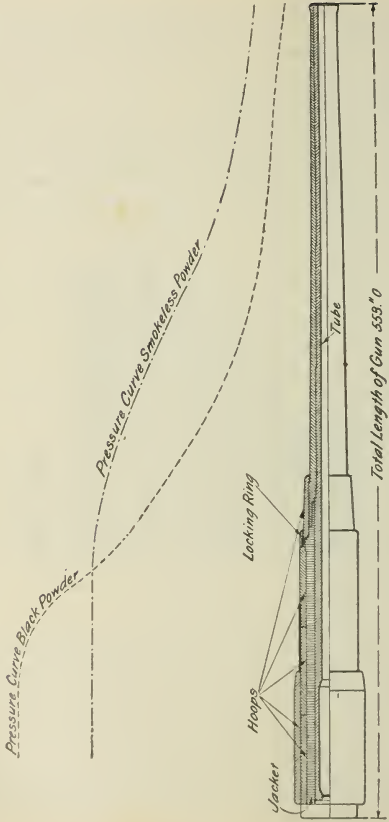

Pressure Curve Smokeless Powder
Pressure Curve Black Powder
Tube
Total Length of Gun 553."0
Locking Ring
Hoops
Jacket

FIG. 2

will be more or less compressed. In this condition, the first effect of a pressure from the inside will be to expand the inner tube, relieving the compression without putting any strain upon the metal. By the time it has enlarged sufficiently to begin to feel a strain, the outer tube will feel the effect of the enlargement and will resist this by reason of its own initial tension, and thus both tubes will act together in resisting the pressure from within. The laws that govern the behavior of steel under these conditions are so well known that it is possible to calculate the exact amount of shrinkage required to make the various parts of a gun act together to the best advantage, and instead of using two layers only, we can use as many as we like and put them together in such a way that all will act together in resisting the pressure in the bore. Thus the gun is made very much stronger than would be possible if it were in a single part.

Another very great advantage of building up the guns in this way is that all the parts, being small, can be more perfectly tempered and annealed, and any defects in them can be more easily detected, than if they were larger.

In practice, three layers are commonly used, as shown in Fig. 2. The inner layer is a *tube*, running the whole length of the gun and forming the bore and chamber. Over the after part of this is shrunk the heavy *jacket*, and over this, a layer of *hoops*. The hoops are continued forwards of the jacket along the tube, only two layers being needed at this part, as the pressure is lower here than it is toward the breech. The dotted curve above the gun shows the way in which the pressure varies throughout the bore. It will be seen that the thickness of the wall of the guns corresponds in a general way with the shape of this curve.

Gun Steel.—The steel of which guns are made is of the very finest quality known, and a quality that, 25 yr. ago, could not have been produced in the world. It is, indeed, one of the most interesting facts in connection with the extraordinary development of our Navy that the demand for a constantly improving quality of material has led to improvements in the manufacture of steel far exceeding those that might have been expected from the demands of ordinary industries.

Properties of Steel.—In the popular conception, the most important characteristic of steel is its *tensile strength;* the strength, that is to say, with which it resists rupture. In gun steel, this is less important than its *elastic strength*, or the strength with which it resists permanent deformation or change of form. So long as a gun is exposed only to pressures below its elastic strength, or "within its elastic limit," it expands to the pressure and then returns to its original shape, acting like a great spring; and it may be repeatedly subjected to such pressures without being in the least weakened or deformed. But if it is once subjected to pressure beyond its elastic limit, it takes on a permanent enlargement, which not only deforms it, but weakens the metal.

Other important qualities in gun steel are *toughness*, *ductility*, and *hardness*, the last-named quality being especially important in the bore, which is called upon to resist the wear arising from the motion of the projectile and the friction of the powder gases as they rush down the bore. The friction of these gases, combined no doubt with some chemical action that is intensified by the high temperature, produces a scoring of the bore that is technically known as *erosion*, and which gradually enlarges the bore and thus reduces the accuracy of the gun. The harder the steel of the bore, the less it is eroded.

Ductility is the opposite of brittleness, and is that quality which causes the steel to stretch before rupturing, instead of flying apart suddenly and without warning, like glass and similar substances. Steel is tested by breaking test pieces in a testing machine under varying tensions and noting: (*a*) the tension at which it ceases to spring back if the tension is released, or the *elastic limit;* (*b*) the tension at which it breaks, or the *tensile strength;* (*c*) the amount by which it is stretched in breaking, or the *elongation;* (*d*) the amount by which the cross-sectional area is reduced by stretching, or the *reduction of area*.

Composition of Steel.—Steel, as known to metallurgists until within quite recent years, was an alloy of iron and carbon, the percentage of the carbon varying considerably, but being always less than 2%. Steel with .3% to .5% is a *low, soft,* or *mild steel;* steel having from 1% to 2% is ***high steel.*** Low steels approach wrought iron and high steels cast iron, in their characteristics.

It has recently been found that other substances can be advantageously added to the alloy of iron and carbon. The most important of these substances for gun steel is nickel, about 3% of which is used in the so-called *nickel*

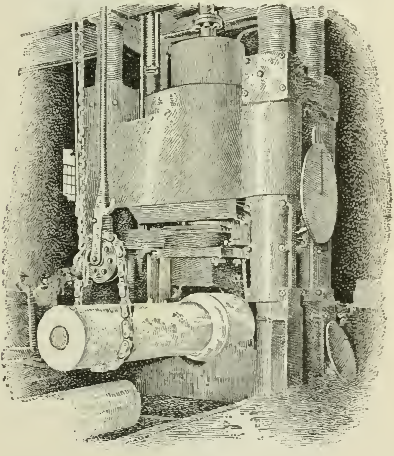


FIG. 3

steel. which is now very generally used for guns and armor. This amount of nickel takes the place of a part, but not the whole, of the carbon. The nickel increases both the tensile and the elastic strength.

The Treatment of Gun Steel.—Steel ingots for guns are first cast, then forged under a hammer or press into the right shape for which they are designed. Fig. 3 shows an ingot in the 5,000-ton forging press of the Bethlehem Steel Co. As in the forging irregular strains may be set up, the next process is one of *annealing;* this consists in heating the ingot to a red heat and allowing it to cool slowly. In this process, the particles of the metal gradually readjust themselves and settle into a condition of uniform crystallization and of freedom from strain. The forging is then tempered in oil; that is to say, it is heated to a high temperature and plunged into a bath of oil, which cools it rapidly, and, in the rearrangement of structure that results, modifies all its characteristics, increasing very greatly the hardness, toughness, and elasticity, but reducing the ductility; or, in other words, rendering it brittle. To restore the ductility and at the same time to relieve any internal strains that may have been set up within the mass by uneven cooling in the process of tempering, the ingot is now reannealed. This final process, to a certain extent, undoes the effects of the tempering; but whereas it reduces only a little the elastic and tensile strength, it almost entirely restores the ductility, and it also relieves the strains produced in tempering. By reducing the hardness, it also prepares the ingot for the machining to which it is next subjected.

Manufacture of the Guns.—Most of the guns for the Navy are manufactured at the Washington gun factory, but contracts have in some cases been made with private firms such as the Bethlehem and Midvale Steel Companies for delivering the guns complete. The various parts of the gun are received at the factory in the shape of rough ingots for the tube, jacket, and hoops. The first operation is to rough bore and turn them, very careful inspection being made during these and subsequent operations for imperfections of any kind in the metal. The shrinkage surfaces are then finished very carefully to dimensions that have been determined by calculations, the calculations being based on the known characteristics of the particular ingots to be used. The variations allowed in dimensions of the shrinkage surfaces are never more than .001 or .002 in. The amount of shrinkage is greater for large than for small guns, and greater for the outer parts (hoops over jacket) than for the inner parts (jacket over tube).

The outer surface of the tube and the inner surface of the jacket having been accurately finished to the shrinkage dimensions, the tube is placed in the shrinkage pit, muzzle down, and the jacket in a hot-air furnace, where it is subjected to a temperature of 600° F. for a length of time that

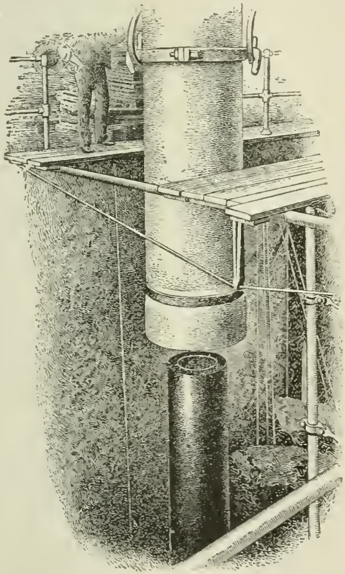


FIG. 4

experience has shown to be necessary. It is thus expanded sufficiently to admit of slipping it over the tube. It is then lifted by a crane and swung into position directly above the end of the tube, Fig. 4, where it is carefully centered and then lowered into place. In the meantime a stream of water has been started inside the tube; this keeps the tube cool and causes the jacket to cool from the inside out. As it cools it grips the tube, compressing it slightly, as already explained, and at the same time taking on a slight initial tension itself. When all parts are cool, the tube and jacket, which now form one piece, are lifted and placed in a lathe, where the outer surfaces are finished to the proper dimensions for receiving the hoops. The hoops are placed on in substantially the same manner as the jacket.

At certain points of the construction, *locking bands*, or hoops, are used, so fitted, either with screw threads or with shoulders, upon the other parts, as to lock all the various parts together so that all shall help to resist *longitudinal* strains, or strains in the direction of the axis of the gun. These locking arrangements are shown in Fig. 2.

Rifling the Bore.—The final operation is that of cutting the grooves of the rifling. This is done by a set of cutters mounted on a long rifling bar connected with a mechanism that moves the cutters down the bore and at the same time revolves them, the motions of translation and rotation being regulated automatically to give the required twist to the grooves. Several grooves are cut at one time, and the cutters are then revolved as much as necessary to cut another set.

Star Gauging.—When the gun is finished, the bore is carefully measured by a **star gauge.** This is one of the most important instruments used in connection with ordnance, as it affords the only method of measuring the diameter of the bore of a gun—a measurement that is often wanted in service when it is thought that a gun may have been injured by some accident; such, for example, as the explosion of a shell in the bore.

The star gauge consists of a long brass sleeve made in several sections that can be screwed together to give the length required for working at any part of the bore. On the end of this sleeve is a head carrying three radial points of tempered steel, connected with a wedge inside the head in such a way that as the wedge is moved forwards or backwards, the points are forced out or drawn in. The

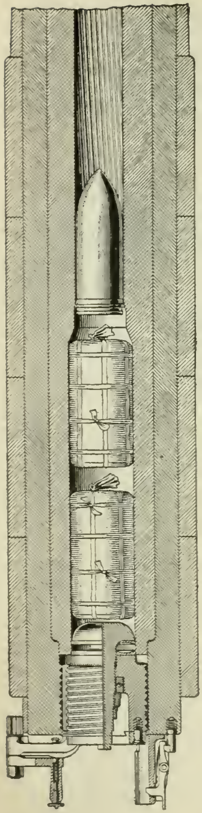


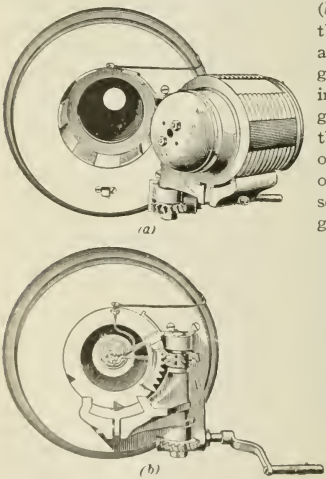
Fig. 5

wedge is actuated by a long rod running inside the sleeve and having a handle at the outer end. This handle has a pointer that moves along a scale on the sleeve, indicating how far the rod (and hence the wedge) is moved in or out. The bevel of the wedge being known, this motion back and forth gives the measure of the motion of the points in and out. For each caliber of gun, there is a set of standard points; and in preparing the star gauge for use, these points are adjusted so that they just fit the diameter of a standard ring when the scale on the rod is at zero. The gauge is then put in the gun and carefully fixed at the point where the measurement is desired. The points are then forced out against the bore, and the reading of the scale (which is fitted with a vernier) gives the diameter. In star gauging a gun, a measurement is usually made at every inch of its length.

In Fig. 5 are shown the details of a gun as loaded and ready for firing. Although not shown in the figure, the greater part of the length of the gun is given up to the rifled bore. In rear of the rifling, the bore is enlarged to form the **powder chamber,** and in rear of this comes the threaded **screw box,** in which the breech plug is held. At the rear end of the rifled bore is a slight slope against which the **rotating band** of the projectile (to be described hereafter) brings up when the projectile is pushed into its seat. This is the **band slope,** and a little in rear of this is the **chamber slope,** carrying the diameter up to that of the chamber. At the forward end of the screw box is the **gas-check slope,** against which the gas check is seated when the bore is closed.

BREECH MECHANISMS OF GUNS

Breech Blocks.—In all guns of and above the 3-in. caliber the same general system is used for closing the breech; this is the **French,** or **interrupted-thread, system** shown in Fig. 1 (*a*) and (*b*). On the outside of the cylindrical block, is a male screw thread engaging a female thread in the screw box of the gun. If both of these threads were continuous, the block could only be seated by screwing it in with a great number of turns. To avoid this, the threads are interrupted, or slotted, over several sections of the circumference, as shown in the figure. By bringing the threaded parts of the plug opposite the blanks of the screw box, the plug may be pushed nearly into its seat, where by turning it through a part of a circle, the threads are engaged and the plug is forced home with considerable pressure, which



(*a*) (*b*)
Fig. 1

holds it up rigidly against the force of the powder gases when the gun is fired.

Several modifications of the above general principle are in use, having for their object increased rapidity of action. Thus, the **Elswick breech plug,** Fig. 2, is conical, this shape giving the advantage that the plug can be swung around to the side at the same time that it is being withdrawn; in other words, its motion from the first is on the arc of a circle.

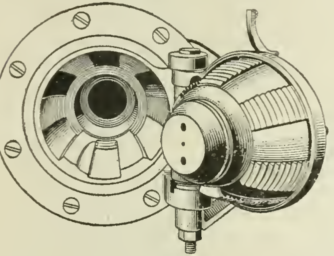


FIG. 2

In the **Welin breech block,** Fig. 3, the whole surface is divided into three parts, and each part is divided into four steps, of which three steps are threads of different lengths, and the fourth step is blank. By placing the block as shown in the figure, it can be pushed in, and to lock it calls only for a turn through one-twelfth of the circumference. With this arrangement, the threads cover a much larger proportion of the surface of the block than with other systems, and therefore, for a given strength a shorter and lighter block can be used.

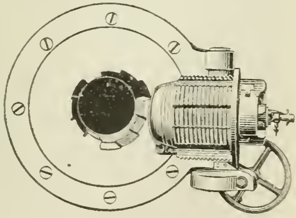


FIG. 3

In the small calibers, moreover the use of a short block makes it possible to swing the block around as in the Elswick system, without hitting the opposite side of the screw box.

Other systems of breech closure are the **Hotchkiss,** in which a block is thrown up across the breech for closing and allowed to fall by its own weight for opening, and the **Driggs-Schroeder** in which a block is pivoted in rear of the breech and turned up and down for closing and opening, the last motion of closing bringing into play a beveled surface that forces the cartridge home.

Breech Mechanisms.—In any mechanism using a slotted screw block, there are certain operations that must be performed. For opening, the block must be rotated sufficiently to unlock the threads, withdrawn to the rear as far as may be necessary for clearing the screw box, and swung off to one side, leaving the breech of the gun clear for loading. In closing the block, the operations are reversed. In the earliest breech-loading guns, the block was rotated by a lever, pulled to the rear by an entirely independent motion, and swung to the side by a third motion. A mechanism was soon devised by which the rotation and withdrawal of the plug were so related to each other that the continuous turning of a crank accomplished both, the motion of the crank actuating a miter-wheel, which first rotated and then withdrew the block without any change to the crank-action. It was a simple step to add the third motion, that of swinging the block; and the resulting mechanism, in which the block is rotated, withdrawn, and swung clear by the continuous turning of a crank, is in use in most of our turret guns at present.

This system is not rapid enough for guns of smaller caliber, and is replaced in such guns by various systems, known by the names of their inventors, in which all the operations of working the breech block are accomplished by a single sweep of a lever. The systems used in the United States Navy are the Haeseler, Dashiell, Fletcher, Elswick, Vickers, and Maxim-Nordenfelt, for guns of 3-in. caliber and above, and the Hotchkiss, Driggs-Schroeder, and Maxim-Nordenfelt for small guns only. Space does not permit an attempt at describing these, but it is not difficult to understand that there are many combinations of gears, cams, and levers by which a single movement of an arm may first rotate a block, then withdraw it, and finally swing it to the side.

Gas Checking.—When a great gun is fired, the pressure in the bore may be anywhere from 10 to 20 T. to the sq. in. Under this pressure, the tendency of the heated gases to escape is such that they seek any minute channel that may be open to them and rush through this with tremendous violence. The problem of sealing every such channel is thus of great importance, and every system of breech closure must provide for an absolutely tight joint around the block, while at the same time leaving the block perfectly free to open. Where a cartridge case is used, the case itself serves as a gas-check, the elastic metal of the case being set out tightly against the walls of the gun.

With guns that do not use fixed ammunition, the *De Bange* system of gas checking, or obturation, is universally adopted. In this system, Fig. 4, which is the invention of a French officer, a tight joint is made at the forward end of the breech block *B* by a plastic pad *a* composed of asbestos and tallow. This pad is in the shape of a ring and is carried on the stem *c* of the mushroom *m* lying in the assembled mechanism, between the after face of the mushroom head and the forward face of the breech plug. The pad is enclosed by two steel rings, which help to keep it in shape. The surface of the pad is slightly beveled, as is also the gas-check seat in the gun; and the action of the threads on the block as the latter is rotated in closing, jams the pad firmly up against the seat forming a tight joint, which is made tighter when the gun is fired by the pressure of the gases forcing back the mushroom and squeezing the pad between the mushroom and the block.

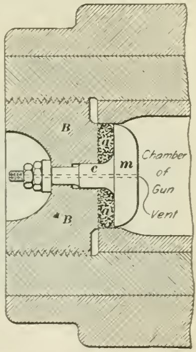


FIG. 4

Firing.—Guns are fired by **primers**, which are worked by either electricity or percussion. Primers for fixed ammunition are inserted in a recess at the base of the cartridge case. For ordinary ammunition, they are inserted in a lock that screws on to the rear end of the mushroom stem. A *vent* running through the mushroom admits the flame from the primer to the chamber, where it ignites the charge (see Fig. 4). As both brown powder and smokeless powder are very slow of ignition, a considerable quantity of black powder is used in the base of the charge. This is called the *ignition charge*. All primers are *vent-sealing;* that is, they are made of metal thin enough to be expanded against the walls of the recess that contains them, and thus prevent the escape of gas around them.

Figs. 5, 6, and 7 show the several forms of primers at present used in the United States Navy. In Fig. 5 is represented the ordinary form of *percussion primer* used in

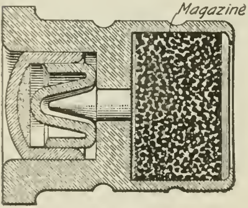


Fig. 5

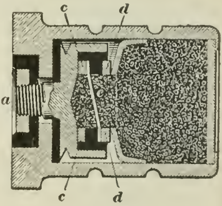


Fig. 6

cartridge cases of fixed ammunition. The striking of the hammer on the primer explodes the fulminate of mercury immediately under it, and the flame from this ignites the black powder in the magazine.

The ordinary form of *electric primer* for fixed ammunition is shown in Fig. 6. The electric circuit, open at the firing key, is connected with a firing pin, which makes contact at *a* when the breech is closed. From *a*, the circuit continues through the insulated metal base plug to the ring *c*, thence through the platinum wire bridge *e* to a second ring *d*, which is in electrical contact with the cup that forms the base of the powder pocket. This cup, in turn, communicates with the walls of the primer and then with the walls of the gun, and the gun is connected to the hull of the ship; that is (electrically speaking) to earth. As the circuit is grounded on the other side of the firing key, the closing of this key completes the circuit, raises the wire of the bridge *e* to incandescence, and ignites a wisp of guncotton that is wrapped around the wire, thus firing the primer and igniting the charge.

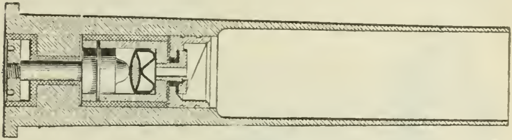


Fig. 7

Fig. 7 shows a *combination primer* (percussion and electric), the principle of which will be readily understood from what has preceded. This primer is used for ordinary breech-loading guns where the flame has to make its way through a long vent, and since this calls for a considerable quantity of powder, the primer is necessarily much longer than the ordinary. The combination primer for fixed ammunition is identical with this in all respects except the length.

PROJECTILES

The **projectiles** for rifled guns are elongated and are held point foremost, as they drive through the air, by the rapid rotation about their axis, imparted to it from the twist of the rifling. To make the projectile engage the rifling, it is fitted with a *rotating band c, c*, Fig. 1, of soft copper a little larger than the bore of the gun, the projectile itself being a little smaller than the bore. When the projectile is loaded, it passes freely through the enlarged powder chamber and enters the bore, but the band brings up against the band slope and prevents the projectile going farther. When the gun is fired, the pressure of the gases drives the soft band through the grooves, and sends it whirling down the bore and out at the muzzle, spinning around its axis 100 times per sec. In Fig. 1 (*a*) and (*b*) is shown, respectively, a projectile before and after firing at an armor plate; the right-hand figure shows the effect of the rifling on the soft-copper band.

The projectiles now commonly used in naval guns are shown in Fig. 2, of which (*a*) is the ***armor-piercing shell***, (*b*) the *common shell*, and (*c*) *shrapnel*. Both armor-piercing shell and common shell are made of forged and tempered steel. They differ from each other chiefly in the size of the interior cavity, which carries the bursting charge, and in the thickness of the walls. In order that they shall have the same weight when filled, the common shell is considerably longer than the armor piercer.

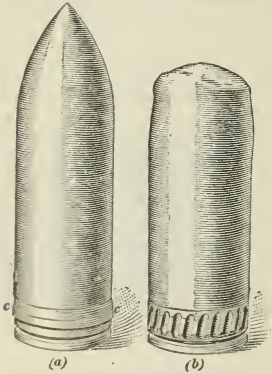


Fig. 1

Armor-piercing shells are intended, primarily, to penetrate the heavy armor of battle ships and armored cruisers. It is very desirable that they should burst after getting through; but whether or not they can be made to do this depends on the kind of explosive with which they are loaded (black powder, guncotton, lyddite etc.) and on the nature of the fuse that is used to explode them. Both of these matters will be considered later. A good armor-piercing shell should penetrate a thickness of hard-faced armor equal to its own caliber. Thus a 6-in. shell should penetrate 6 in. of armor without breaking up.

Common shells are designed to penetrate the unarmored parts of ships, and parts protected by comparatively thin armor. As they carry a very large bursting charge, they cannot fail to be very destructive to the interior of a ship and to the personnel if they can be made to burst inside. Here again the question of the bursting charge and the fuse comes in, but this difference may be noted between an armor-piercing and a common shell; that the former accomplishes its principal purpose if it penetrates or breaks up the enemy's armor, even if it does not explode; whereas the latter fails of its principal purpose if it does not explode inside the enemy's ship.

Shrapnel are used only against exposed masses of men, whether on shore, on the deck of a ship, or in boats. This class of projectiles is always fitted with time fuses, set to explode at a certain point of their flight, the idea being that they will explode above and in front of the body of men against whom they are fired. As a result of the explosion, not only the fragments of the shell, but all the small balls with which the interior is filled, are scattered over a wide area.

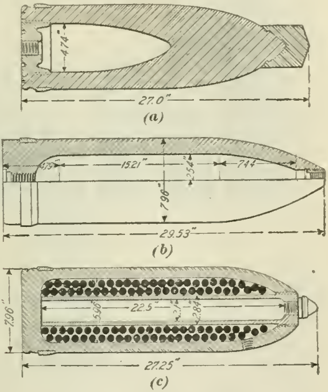


FIG. 2

Capped Projectiles.—The capped projectile, types of which are shown in Fig. 3, is a development of the last few years, and has increased the penetration, other things being equal, by about 15%. The action of the cap has not been satisfactorily explained, but the following indicates the direction in which the explanation is to be found: When a projectile strikes an armor plate, the plate springs back more or less under the blow, and at the same time a considerable part of its face is "dished" a little, the whole of this action resulting from the elasticity of the plate and its supporting structure. This spring of the plate is unfavorable to penetration; the point of the projectile would break through the face of the plate more easily if the latter had no spring to it. When a capped projectile strikes a plate, the cap does the work of driving back the plate and dishing it, and the point, when it breaks its way through the cap,

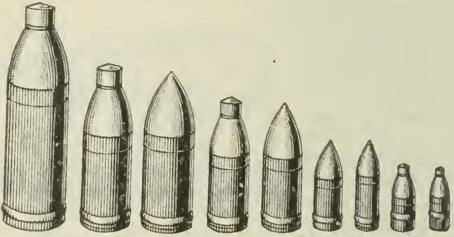


Fig. 3

finds the plate comparatively rigid. This is a favorable condition for the action of the point, and it gets through more easily than it would if the plate were yielding while it (the point) was trying to get in. We must, of course, recognize that the total work done in the plate is no greater in one case than in the other, but that the division of the work into two parts—the elasticity being exhausted before penetration begins—seems to make the penetration greater than it would otherwise be. All armor-piercing shells are now capped.

FUSES

Fuses are divided into two general classes—*time* and *percussion*.

The time fuse is one that can be so arranged as to cause the explosion of a shell at the end of a certain interval of time. This is accomplished by means of a column of slow-burning composition that is ignited in some way on the firing of the gun, the length of the column being such that it will burn for the desired interval of time before communicating flame to the bursting charge. The length of the column can be adjusted for the desired interval before the shell is fired. Time fuses are used in the Navy for shrapnel only, these being the only projectiles that are exploded before striking the target at which they are fired.

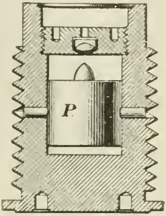


FIG. 1

A **percussion fuse** carries a percussion cap that is exploded on striking a target, provided that the shell meets sufficient resistance to slow it down materially. The cap is exploded by a sharp-pointed plunger, which drives forwards when the shell is suddenly slowed down or arrested. It is, of course, very important to hold the plunger securely until the time of firing, so that it cannot possibly strike the cap and explode it by accident. Many arrangements have been devised for this purpose; and it is the nature of this device that, to a great extent, determines the individuality of the many patented fuses that are in common use. Two characteristic devices are shown in Figs. 1 and 2.

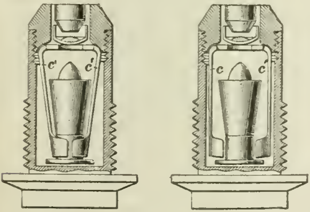


FIG. 2

In the Navy percussion fuse, Fig. 1, the plunger P is held in place by a brittle wire that is strong enough to resist any ordinary shock to which a projectile might be subjected in handling, even if dropped from a considerable height. The shock of discharge of the gun is sufficient to break the wire, and as the projectile moves forwards, the plunger is thrown to the rear of the cavity in which it fits. When the shell strikes, the plunger flies forwards and pierces the cap. The flame from the explosion of the cap flashes through several channels (not shown) to the interior of the shell, where it ignites the bursting charge and explodes the shell.

In the *Driggs fuse*, Fig. 2 (*a*), the plunger is held in place by two springs c, c', that are thrown outward as in (*b*), when the shell is fired from the gun, by the centrifugal force due to the rotation of the shell. This releases the plunger and leaves it free to act. This principle of a spring or catch holding the plunger under ordinary circumstances, but released by the spinning of the shell, has been applied in a great variety of ways, some of them extremely ingenious.

Base Fuses.—All fuses are now used in the base of the shell, leaving the point of full strength for penetration. This makes it important to have a gas-tight joint where the fuse screws in, as a leak of gas into the interior of the shell will cause the shell to explode in the bore.

Delayed-Action Fuses.—A delayed-action fuse is one in which the mechanism is so arranged that the explosion of the shell, instead of taking place immediately upon impact against armor, is delayed until the shell has had time to penetrate, thus causing the explosion to take place inside the ship instead of outside. Many very ingenious fuses of this kind have been devised, but their mechanism, being somewhat complicated, cannot be explained here for lack of space.

GUN MOUNTS

The structure on which a gun is carried, and by which it is controlled in pointing and firing, is called a **mount,** or, sometimes, a **carriage.** The requirements of a carriage are that it shall admit of easy and rapid pointing, both in azimuth and in elevation; that it shall lend itself to maximum rapidity of fire; that it shall absorb the inevitable recoil of the gun without undue strain; that it shall have sufficient strength to withstand such strains as, under the most extreme conditions, will result from the recoil; and that it shall return the gun automatically to the firing position (technically, "to battery") immediately after the recoil. As a rule, the mount is in two parts, one of which can move in and out upon the other. The gun is attached to the movable part, the *top carriage*, and this top carriage recoils with the gun. In the simplest style of mount, used only with the smallest guns, the top carriage, carrying the gun, moves laterally around a heavy pivot fitting into the lower part of the mount, but no recoil is provided for, the shock of firing being absorbed by the "give" of the mount. This puts a great strain on the mount and the part of the ship to which it is secured, and is not practicable with guns larger than the 6-pdr.

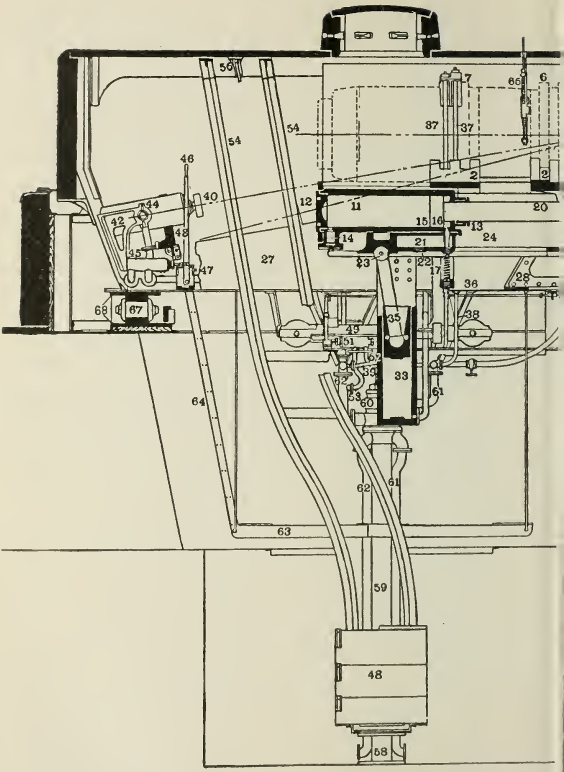
In a great majority of the mounts now in use, the recoil is absorbed by a piston moving through a liquid in a cylinder. This liquid is usually water, to which a certain percentage of glycerine is added to prevent freezing. The piston rod is attached to the top carriage, and the cylinder to the lower carriage (or the reverse). To admit of a flow of liquid past the piston, grooves are cut along the interior surface of the cylinder, affording channels through which the liquid makes its way from one side of the piston to the other as the piston is forced through. Evidently, the width of these grooves determines the freedom with which the piston can move; that is to say, the freedom of recoil. As it is desirable that the recoil should be very free at first, and checked gradually, the grooves are made wide at that part of their length which corresponds with the beginning of motion, and are gradually "choked" down toward the opposite end. The length, width, and depth of the grooves evidently determine the length and velocity of recoil, and these dimensions are carefully calculated for each class of gun.

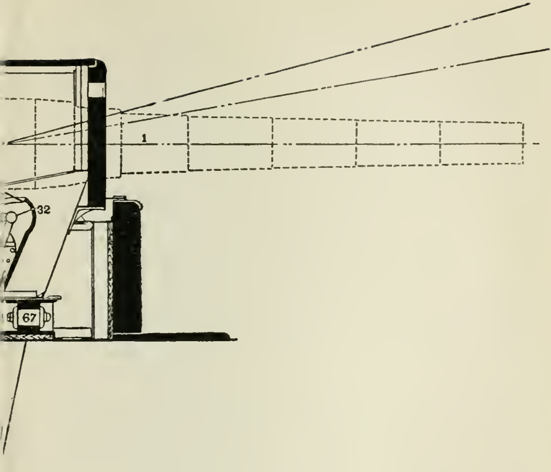
For returning the gun to the firing position after recoil, heavy spiral springs are used in the cylinders. These springs are compressed by the recoil and must, of course, play an important part in checking the recoil, their resistance being added to that of the liquid. As soon as the recoil is arrested, the springs run the gun out ready for another fire.

The gun is, whenever practicable, secured near its center of gravity to the top carriage, so that it will be balanced perfectly, and its bearings are made so nearly frictionless that very little power is needed to elevate or depress. The little power required is furnished by a beveled gearing in the hands of the pointer, who, with his eye ranging along the sights, endeavors to keep the gun pointed on the target in spite of the rolling and pitching of the ship.

The lateral training is done by another set of gear-wheels, worked by another gun pointer, who also is provided with a sight, and whose duty it is to keep the gun trained upon that point of the enemy's length at which he is told to aim. The pointer who has charge of the elevation controls the firing key and fires the gun; his object should be to keep his sight on the target at all times. This is called *continuous aim*, and has only recently been made possible by the improvement in gun mounts and sights. The importance of it in the case of a single shot may be explained as follows: There is a perceptible interval between the instant when the pointer decides to fire and the instant when the projectile actually leaves the muzzle of the gun. This interval for an 8-in. gun of 50 calibers is found to be, roughly, $\frac{1}{10}$ sec. Suppose the ship to be rolling 10 times per min., through 6° on each side of the vertical. The muzzle of the gun will sweep through 12′ of arc in $\frac{1}{10}$ sec., and this at a range of 2,000 yd. corresponds to an error in height on the target of 21 ft. Thus, if the pointer decides to fire at a given instant, his sights being exactly on the point of the target which he wishes to hit, his aim may be thrown off by 21 ft. by the time the projectile leaves the muzzle of the gun, unless he continues to keep the sights on the target during the actual discharge of the gun. Where a string of shots is to be fired, the advantage of continuous aim is greatly increased. Assuming that the system can be carried out ideally, and assuming also that the lateral aim is maintained perfectly, as it easily can be, it should be possible to fire as rapidly as the gun can be loaded, and to make a hit every time.

Turret Mounts.—In the case of large guns mounted in turrets, the lower carriage is composed of heavy slides bolted to the turret and turning with it. The gun rests in a cradle that moves in and out on the lower carriage


56
54
54
7
66
6
87
37
2
2
46
40
44
42
48
45
47
12
11
15
16
13
20
24
14
21
23
22
17
27
28
36
68
67
38
35
49
51
52
32
39
33
53
60
61
64
62
61
63
59
48
58


1
32
67

exactly as in the mounts for lighter guns. The elevation is done by very heavy rams, usually hydraulic. The lateral training of the turret trains the guns also. A vertical framework in the rear of the gun furnishes guide rods for an ammunition car, which runs up and down like an elevator bringing ammunition from the magazines below to the loading position in the rear of the guns. A rammer worked by hydraulic or electric power, and installed directly in the rear of the gun, pushes the projectile and the powder charge from the ammunition car into the gun. The rammer is telescopic in its working; that is to say, when not in use it shortens on itself. A description of a turret mount would demand more space than can be given here; the attached illustration, however, gives a general view of mount for the 13-in. gun of the U. S. S. "Oregon," and by referring to the accompanying numbers the essential parts of the mechanism are readily identified.

1, gun; *2*, saddle; *6*, front straps; *7*, rear straps; *11*, recoil cylinder; *12*, rear bonnet; *13*, stuffingbox and gland; *14*, opening for pump pressure and check-valve; *15*, pressure side; *16*, reverse side; *17*, spring valve; *20*, piston rod, head, and nut; *21*, overflow chamber; *22*, connection for waste pipe; *23*, lug for elevator connecting-rod; *24*, slide; *27*, turret girders; *28*, deck lugs; *29*, collar for pressure pipe; *32*, pivot bolts; *33*, elevator; *35*, elevator connecting-rod; *36*, elevator valves; *37*, elevator valve rods and levers; *38*, elevator pressure pipe; *39*, elevator exhaust pipe; *40*, hydraulic rammer in loading position; *42*, hydraulic rammer brackets; *43*, hydraulic rammer transom; *44*, hydraulic rammer trunnions; *45*, hydraulic rammer valves; *46*, hydraulic rammer operating lever; *47*, hydraulic rammer fulcrum for lever, and guide for valve stem; *48*, ammunition car; *49*, ammunition car motor run in; *51*, ammunition car motor valves; *52*, ammunition car motor pressure pipe; *53*, ammunition car motor exhaust pipe; *54*, ammunition car guide rails; *56*, ammunition car bracket and sheave; *58*, pedestal for central column; *59*, central column; *60*, water section; *61*, pressure pipe; *62*, exhaust pipe; *63*, platform; *64*, ladder to turret; *65*, sights; *67*, rollers; *68*, roller paths.

SIZE AND POWER OF UNITED STATES NAVAL ORDNANCE

Nature of Gun	Caliber, Inch	Weight, Tons	Total Length, Feet	Total Length of Bore, Inch	Length of Rifling, Inch	Length of Chamber, Inch	Weight of Service Charge: Brown Powder, Pounds	Weight of Service Charge: Smokeless Powder, Pounds	Weight of Projectile, Pounds	Brown Powder: Muzzle Velocity (Service), Foot-Seconds	Brown Powder: Muzzle Energy, Foot-Tons
3-in. (14 pr.)	3	.87	12.5	149.7	125 5	21.3		5	14	3,000	874
4-in. q. f., mark I.	4	1.5	13.7	157.3	130.3	24.7	12 to 14		33	2,000	915
4-in. q. f.	4	1.5	13.7	157.5	128.1	25.4			33	2,000*	
4-in. q. f., mark VII., of cals.	4	2.56	17.0	200.0	168.4	31.6		15	32	2,900	1,999
5-in. q. f., mark I.	5	2.8	13.5	150.3	120.8	27.1	26 to 29		60	2,000	1,660
5-in. q. f.	5	3.1	17.4	191.5	164.4	32.0	28 to 30		50	2,300	1,834
5-in. q. f., mark V.	5	4.46	21.3	250	212.9	37.2		27	60	2,900	3,503
6-in. b. l. r., mark I.	6	4.8	15.8	176.0	136.7	36.9	50		100	2,000	2,773
6-in. b. l. r., mark II.	6	4.9	16.1	180.1	144.9	32.7	45 to 48		100	2,000	
6-in. b. l. r., mark III., of 30 cals.	6	4.8	16.3	183.8	147.3	34.0	44 to 47		100	2,000	
6-in. b. l. r., mark III., of 35 cals.	6	5.2	18 8	213.8	177.3	34.0			100	2,080	2,990
6-in. b. l. r., mark III., of 40 cals.	6	6.0	21.3	243 8	207.3	34.0			100	2,150	3,204
6-in. q. f.	6	6.0	21.3	243.8	204.3	37.0	44 to 47		100	2,150	3,200
6-in. q. f. mark VI.	6	8.17	25.0	293.7	245.3	48.4		46	100	2,900	5,838
7-in. q. f.	7							74	165	2,900	9,646

NOTE.—The weight of fixed ammunition for q. f. 4-in. and 5-in. guns is 58 and 95 lbs., respectively. 10″ = 2,200, 12″ = 2,300, 13″ = 2,300. The charges are kept down to suit the sight bars.

* With smokeless powder 4″ = 2,200, 5″ = 2,650, 6″ = 2,550, 8″ = 2,300.

SIZE AND POWER OF UNITED STATES NAVAL ORDNANCE—(*Continued*)

Nature of Gun	Caliber, Inch	Weight, Tons	Total Length, Feet	Total Length of Bore, Inch	Length of Rifling, Inch	Length of Chamber, Inch	Weight of Service Charge: Brown Powder, Pounds	Weight of Service Charge: Smokeless Powder, Pounds	Weight of Projectile, Pounds	Brown Powder: Muzzle Velocity (Service) Foot-Seconds	Brown Powder: Muzzle Energy, Foot-Tons
8-in. b. l. r., mark I.	8	12.3 12.9	21.5	239.9	195.2	42.1	105 to 115		250 250	2,000 2,000	6,932
8-in. b. l. r., mark II.	8	13.0	21.5	239.9	195.2	42.1					
8-in. b. l. r., mark III., of 35 cals.	8	13.1	25.4	290.5	212.8	45.1			250	2,080	7,498
8-in. b. l. r., mark III., of 40 cals.	8	15.2	28.7	330.5	282.8	45.1			250	2,150	8,011
8-in. b. l. r., mark V., of 45 cals.	8	18.0	28.6	335.0	271.0	64.0		115	250	2,800	13,602
10-in. b. l. r., mark I., of 30 cals.	10	25.7	27.4	306.3	247.3	57.2	225 to 240		500	2,000	13,864
10-in. b. l. r., mark I., of 35 cals.	10	27.1 28.2	30.5	343.8	283.7	57.2			500	2,060	14,709
10-in. b. l. r., mark II., of 30 cals.	10	25.1	27.4	307.3	247.3	57.2			500	2,000	13,864
10-in. b. l. r., mark II., of 35 cals.	10	27.6	31.2	354.9	294.9	57.2			500	2,100	15,285
10-in. b. l. r., mark III., of 40 cals.	10	33.4	33.3	389.0	313.4	75.6		240	500	2,800	27,204
12-in. b. l. r., mark I.	12	45.2	36.8	419.2	343.1	74.1	425		850	2,100	25,985
12-in b. l. r., mark III., of 40 cals.	12	52	41.8	480.1	388.1	91.9		350	850	2,800	46,246
13-in. b. l. r., mark I.	13	60.5	40.0	454.5	370.5	80.9	550		1,100	2,100	33,627
13-in. b. l. r., mark II.	13	60.5	40.0	454.5	370.5			280	1,100	2,300	40,350

NOTE.—The weight of fixed ammunition for q. f. 4-in. and 5-in. guns is 58 and 95 lb., respectively. 10″ = 2,200, 12″ = 2,300, 13″ = 2,300. The charges are kept down to suit the sight bars.

EXPLOSIVES

An **explosive** may be defined as a substance that, existing normally in a solid or liquid state, and occupying, in that state, a comparatively small volume, is capable of being suddenly converted into gas with very great increase of volume; or if it is prevented from expanding freely, then with very great increase of pressure.

There are great differences between explosives in the suddenness with which their explosion is effected; some substances, like nitroglycerine, being converted into gas almost instantaneously, while others require an appreciable time. This difference is of very great importance in the application of explosives to military purposes. We are accustomed to think of the explosion of powder in a gun as taking place instantaneously. The time occupied is extremely short, but it is many times as long as that required for the explosion of nitroglycerine. To understand the difference, we must recognize the fact that an explosion is, after all, only a case of *combustion*—a case, that is to say, of the combination of certain substances with oxygen. In ordinary cases of combustion, as of burning, the substance that burns (usually some form of carbon) finds the oxygen for its combustion in the air; and as this supply is very diffuse, and diluted by large quantities of nitrogen, the combustion takes place slowly. In the case of gunpowder, the oxygen for the combustion of the carbon exists in a concentrated form in one of the solid ingredients of the powder, where it is in intimate contact with the carbon and other substances that are to be burned. This results in an enormous increase of rapidity in the combustion, the gases being given off so rapidly as to constitute an explosion. In gunpowder, we have an example of a mechanical mixture between the substances that are to be oxidized and the substances that supply the oxygen for the oxidation (combustion). Evidently, there will be a much more intimate contact, and an even more sudden combination, if we associate the oxygen and the substance with which it is to combine in a single substance. Nitroglycerine is a substance of this kind. It contains carbon and nitrogen, both of which are oxidizable substances, and it also contains the oxygen necessary to oxidize them. In appearance nitroglycerine resembles a heavy oily liquid. If this liquid receives a shock, the original arrangement of its components is broken up, and the oxygen instantly combines with the carbon and nitrogen to form various gases, thus producing an explosion that is many times as violent as that of gunpowder, because many times as sudden. Such an explosion as this is called a *detonation*.

The volume of the gases resulting from an explosion or detonation is many times that of the solid or liquid from which they are derived, but their volume is still further increased by the heat that is liberated by the combination of the various parts. Such a liberation of heat always occurs when substances combine chemically with each other, as, for example, when the carbon that makes up a large proportion of our wood and coal combines with oxygen, or burns. It is evident that a detonating explosive, like nitroglycerine, is unfit for use as a *propellant*, that is, for propelling a projectile from a gun, because the suddenness and violence of its explosion would burst the gun before the projectile was started from its seat. What is needed for a propellant is a more gradual explosion, the force of which will be exerted more as a push than as a blow. To illustrate the difference, let us imagine that a heavy sphere of iron is lying on a smooth table. Strike this a sharp blow with the hand, and the hand will be bruised while the sphere will be hardly moved; the force exerted does not have time to overcome the inertia of the sphere. Place the hand against the sphere and push it, at first with little pressure then with much more, but with, upon the whole, no greater expenditure of force than was contained in the blow. The sphere will be moved slowly at first, then rapidly, and the hand will not be bruised at all. This is the difference between a force applied suddenly and the same force applied gradually; the first resembles, in a general way, the violence of nitroglycerine, the other, the (comparatively) gradual action of gunpowder.

The same characteristic that makes the various high explosives unsuitable for use as propellants makes them admirable for use as bursting charges in shell, since here their violence is exactly what is needed, provided that it is possible to explode them at the right moment. Unfortunately, they are nearly all extremely sensitive to shock and friction, which makes them very dangerous to handle and to store, and especially dangerous for use in a shell that is to be fired from a gun, because of the possibility of their being exploded by the shock of discharge of the gun. This danger is much less with some explosives than with others, and the whole progress of development along this line has, for many years, been directed toward the discovery of explosives that, while having a maximum of power, will be insensitive to ordinary shock, to friction, and to flame, but capable of detonation by a fuse whose action can be controlled with entire certainty. This will make it clear that the fuse is as important as the explosive itself. If the fuse is liable to act prematurely, there is still danger, no matter how trustworthy the explosive may be. As nearly all fuses contain fulminate of mercury, which is extremely sensitive to shock, the problem of designing a fuse that will be sure to act when the shell strikes, and not at any other time, is a difficult one.

Perhaps the best known of the high explosives is **nitroglycerine,** previously referred to; it is extremely sensitive, and is not very generally used in liquid form. **Dynamite** is nitroglycerine absorbed in a soft and spongy sand called Kieselguhr; in this shape it is much less sensitive to shock, and may be handled and transported with a reasonable degree of safety. It is much too sensitive, however, for military purposes, and its use is limited to blasting. *Dynamite No. 2, Lithofracteur*, and *carbodynamite* are modifications of ordinary dynamite, and contain nitroglycerine associated with some substance that is supposed to render it safe in handling and transportation.

Guncotton, formed by treating ordinary cotton with nitric acid, is in many respects the most convenient of the high explosives. When dry it is very sensitive, but when wet (with from 15% to 30% of water) it is insensitive to all ordinary shocks, but may be caused to detonate by detonating dry guncotton in contact with it. The dry cotton can be detonated in a number of ways, but the surest and most convenient way is by a fuse of fulminate of mercury. Guncotton is commonly used for the explosive charge in torpedoes, the bulk of the charge being wet cotton, while the fuse is made up of dry cotton with an exploder of fulminate. Guncotton is sometimes used in this way as a bursting charge for shells.

Blasting gelatine is a compound of guncotton and nitroglycerine, in which, singularly enough, the qualities of both ingredients are so far modified that the resulting compound while retaining nearly all the explosive power of its two constituents, is made less sensitive than either. It is probably the safest of the high explosives, with the exception of wet guncotton. *Rackarock* is a mixture of potassium chlorate and mono-nitrobenzene, the latter being an easily oxidizable form of carbon, and the former a substance rich in oxygen. *Hellhoffite* belongs to the same class of explosives.

Fulminate of mercury, which has already been mentioned, is one of the most sensitive and violent explosives known, and therefore one of the most dangerous. It is, in fact, never handled except in very small quantities. It is, however, almost indispensable in work with other explosives, because the shock resulting from its detonation has some peculiar characteristic, not fully understood, by reason of which it can detonate any high explosive with which it is in contact. Moreover, the flame from its detonation ignites (and so explodes) gunpowder. It is this substance that is used in percussion caps and in the cartridges of muskets and revolvers; it is also used in almost all fuses for exploding large shells, when extreme care must be taken to place the fulminate in such a way that it cannot be set off by the shock of firing the gun. This is not as difficult as the same problem is when connected with a large quantity of explosive, such as that which must be used to fill the shell. If the shell were filled with fulminate, nothing could prevent its instantaneous detonation in firing the gun, and as a result the gun would be blown into fragments. The few grains of fulminate used in detonators can be disposed of in such a way that it will not feel the shock with violence enough to explode.

Among the most common of the high explosives in use for military and other purposes are picric acid, and the various derivatives of this acid known as *picrates*. These substances are all high explosives, and many of them are so extremely sensitive that they cannot be used for military purposes. Others are so little sensitive that a very large charge of fulminate is required to detonate them. The well-known English explosive *lyddite* is picric acid, and *melinite*, the French explosive, is derived from the same acid. Shimose powder, used by the Japanese with great effect in their war with Russia, is known to be one of the many picrates.

One of the dangers in connection with picric acid arises from the fact that this substance, when brought in contact with iron or steel, forms the picrate of iron, which is almost as sensitive to shock and friction as is the fulminate of mercury. It is therefore necessary to coat the inside of the shells with lacquer or asphaltum, and to be very careful that the acid does not at any stage of preparation or handling come in contact with bare iron.

Gunpowder.—Ordinary gunpowder (*black gunpowder*, as it is now called) was invented some 6 centuries ago, and, strangely enough, remains today practically unchanged in composition, although variations have been introduced from time to time in the proportion of the ingredients, and important variations in the size and shape of the grains. It is a mixture of charcoal, sulphur, and potassium nitrate (commonly called *saltpeter*), in the following proportions: charcoal, 15%; sulphur, 10%; potassium nitrate, 75%. Here we have an easily oxidizable substance, charcoal (carbon), and a substance rich in oxygen, potassium nitrate. Broadly speaking, the explosion consists in the production from these solid substances of three highly heated gases—nitrogen, carbon-monoxide, and carbon-dioxide. The first of these exists originally in the potassium nitrate, where it is combined with the oxygen. When the nitrate breaks up, the nitrogen is left free (as a gas), and the oxygen combines with the carbon to form the two other gases that have been named. The sulphur assists in the various chemical changes, but does not itself form a gas. It appears at the end of the explosion in combination with the potassium, forming certain solid products which are responsible for the smoke and the deposit in the bore, both of which are objectionable features.

For many years, chemists and artillerists have been in search of a powder whose explosion would give only gaseous products. There were many advantages to be anticipated from such a powder. It would be more powerful, because all its energy would go into the gas that propels the projectile. It would be smokeless, because the smoke of black powder is due to solid particles. And it would leave no residue to foul the bore of the gun. In all this, there was reason enough for seeking a new explosive; but it is only within quite recent years that it has been regarded as an absolute necessity. With the introduction of rapid-firing guns into the Navy, it became necessary to have a powder giving little or no smoke, if these guns were to be of any use for the objects for which they were intended. For instance, in repelling the attack of torpedo boats, the use of black powder would entirely defeat the purpose of the guns, as after the first few shots the cloud of smoke would completely obscure the whereabouts of the attacking force and render the guns useless. It would, in fact, play directly into the hands of the enemy by creating a curtain behind which they could push home their attack with impunity.

The fact that the smoke given by black powder is due entirely to the solid products resulting from the combinations formed by the potassium of the potassium nitrate, after that substance has given up its oxygen for the combustion of the charcoal, naturally suggested the idea of using some nitrate that would give up its oxygen in the same way, but whose further compounds would be gaseous. Ammonium nitrate is a substance of this kind, but it has the faculty of absorbing water from the atmosphere so rapidly that it is totally unsuited for use in gunpowder. It has, nevertheless, been the basis of many formulas for smokeless powder, but none of these have been successful.

About 1890, there was brought out in Germany a powder that, from its peculiar color, came to be known as *brown* or *cocoa powder.* The composition of this was kept secret, but analysis showed it to contain a much smaller proportion of sulphur than black powder, and a larger proportion of saltpeter and of moisture. These peculiarities, however, were not sufficient to account for its superiority over black powder. Yet this superiority was very marked. It gave a higher velocity to the projectile, with much less strain on the gun, and the smoke was notably less than with black powder. The secret of its manufacture was closely guarded, but chemists recognized the fact that this secret lay in the nature of the charcoal used, and that this charcoal was not as fully charred as that which was used for black powder. Starting from this point, several manufacturers developed cocoa powders that equalled, and in some cases exceeded, the original German article. It is now known that the original powder was made from straw that was charred by superheated steam which did not reduce it to pure carbon, but left much of the natural structure of the straw. This partially burned straw retained oxygen, hydrogen, and other substances in proportions that proved favorable to the performance of the powder.

Cocoa powder entirely drove out black powder for large guns. Although a distinct reduction was made in the amount of smoke, in addition to improvements in other respects, it still left much to be desired, and the search for a really smokeless powder was continued.

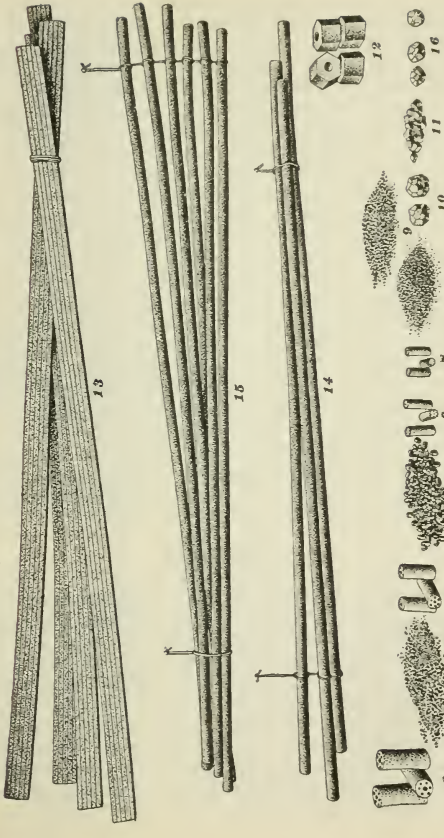
It was natural that attention should be turned to the high explosives, since all the products of these explosives are gases; and shortly after the discovery of nitroglycerine and nitrocellulose (guncotton), near the middle of the 19th century, efforts were made to temper the violence of these explosives sufficiently to make them suitable for use as propellants. Guncotton was much more promising for this purpose than nitroglycerine, and many promising results were obtained by the early experimenters with it, some of whom wrapped threads of the cotton spirally around wooden or other cores, while others reduced the cotton to a powder and mixed with it certain inflammable but non-explosive substances, hoping by this means to tame and control the burning of the mixture. These mixtures frequently gave good results; but they were unreliable and occasionally detonated with destructive violence. The most important step in advance came with the discovery that certain substances would entirely dissolve guncotton, completely destroying the cellular structure that makes up its fibers, and reducing it to a gelatinous mass that, when allowed to set, takes on a hard, horny, semitranslucent character, such as is familiarly seen in celluloid. Any substance existing in this form is called a *colloid*. It was found that in the colloid form, nitrocellulose burned rapidly, but without any disposition to detonate, and that its burning could be as perfectly controlled as that of black or brown gunpowder. Moreover, it lost nothing of its power, since its chemical composition remained unchanged. Thus the great problem of a smokeless powder was solved. Among the substances that have the power to dissolve nitrocellulose, one of the most convenient is *acetone*, an aromatic liquid resembling alcohol. Another convenient solvent is a mixture of ether and alcohol.

The nitrocellulose having been dissolved in either of the above solvents, the excess of the solvent is removed as far as possible by compression and evaporation, but a considerable quantity remains in the powder after it is fully dried and gives the characteristic odor that is always associated with smokeless powder.

The colloid is pressed into grains of the desired size and shape, after which it is dried. It is then ready for use. The smokeless powders now used by the United States, France, and Russia are produced as just described; that is to say, they are nitrocellulose powders pure and simple.

There is a class of smokeless powders that are a combination of nitrocellulose with nitroclygerine. As these are both violent explosives, it is rather surprising to find that mixing them produces a substance whose action can be perfectly controlled; a substance, in short, that makes an almost ideal smokeless powder. The explanation is that the nitroglycerine acts as a solvent for the nitrocellulose, dissolving it as perfectly as does acetone, and forming a perfect colloid. Powders of this class are distinguished from those that contain nitrocellulose only by referring to them as nitroglycerine powders; but it must be remembered that only a small percentage of their composition is really nitroglycerine. The well-known English powder *cordite* is of this class. It is very effective as a propellant, giving considerably better results than the nitrocellulose powders, but it develops so much heat in burning that it wears away the bore of the gun very rapidly, by what is called erosion. This makes it less satisfactory, on the whole, than the nitrocellulose powders, and there is talk among English artillerists of substituting one of these for the cordite at present in use.

Granulation of Powder.—With any composition of powder, whether black, brown, or smokeless, the size and shape of the grains have an important effect on the action of the powder in the gun. Broadly speaking, a small grain is favorable to rapid combustion, and a large grain to slower and more gradual burning. A small granulation is adapted to a small gun, and a large granulation to a large gun. There are, however, many other considerations that enter into the problems of the most suitable granulation for a given gun. When the powder is ignited, it burns slowly at first, developing a pressure that, while still low, starts the projectile moving down the bore. This motion of the projectile increases the volume in which the gases can expand, and so would lower the pressure if it were not that more and more gas is given off, so that the pressure is not only maintained but is rapidly increased for a time; after which, the powder being nearly or quite consumed and the space continuing to increase very rapidly, as the projectile is driven toward the muzzle, the pressure falls off almost as rapidly as it at first increased. In a powder that burns too rapidly for the particular gun in which it is used, the pressure rises suddenly to a maximum, which perhaps puts a dangerous strain on the gun, then falls off so quickly that it communicates only a low velocity to the projectile. An ideal powder will give a low maximum pressure, but will sustain this pressure well down the bore toward the muzzle of the gun. To do this we need what is called a *progressive powder*, or one, that


2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

will burn slowly at first, then more and more rapidly, keeping up the pressure behind the projectile until it actually leaves the gun. For this purpose, we must have our grain of such a shape that, as it burns, the burning surface will increase. Evidently this cannot happen with any grain that burns entirely from the outside, as the grain would grow steadily smaller and the surface would be reduced. If the grain is pierced with holes that allow it to burn from the inside outwards, as well as from the outside inwards, we will have a constantly increasing burning surface and therefore a progressive powder. This is the object of the holes with which many forms of powder grains are pierced. Such a grain, if having one hole only, is called *single perforated* or *tubular;* if having several holes, *multiperforated.* Many powders are made in solid flat strips or in sticks.

Various forms of granulation are shown in the figure, page 223, each form being designated by a number, as follows: *2*, 13-in. smokeless; *3*, flake musket; *4*, 8-in. 35 cal. smokeless; *5*, 6-pdr. smokeless; *6*, 4-in. 50 cal. smokeless; *7*, 5-in. 40 cal. smokeless; *8*, black musket; *9*, black cannon; *10*, black hexagonal; *11*, black Schagticoke rifle; *12*, brown prismatic; *13*, 7-in. 45 cal. strip, experimental smokeless; *14*, 8-in. 35 cal. stick, multiperforated smokeless; *15*, 12-in. 40 cal. single-perforated smokeless; *16*, sphere hexagonal smokeless.

TORPEDOES

The **torpedoes** of the present day are all *automobile;* that is, they carry in themselves their own motive power. In the *Whitehead torpedo*, which is in almost universal use, this power is supplied by an engine run by compressed air, the air being stored in a reservoir that occupies considerably more than half the total volume of the torpedo. Fig. 1 shows a Whitehead torpedo in section. Reference to this figure will make the following description clear so far as the general principles of its mechanism are concerned. A description of the details would call for many times the space that can be given to it here.

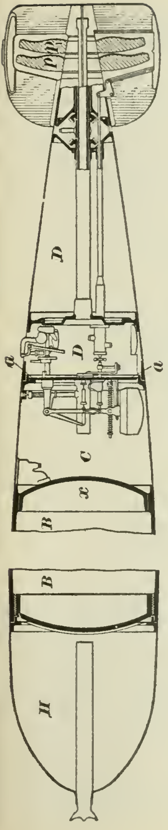


FIG. 1

War Head.—The bursting charge of high explosive (usually guncotton) is contained in the *war head H*, and is exploded, in case the torpedo strikes a solid object, by the action of the fuse, which, as will be seen, projects beyond the head. A plunger in this fuse is driven in, on striking, and pierces a percussion cap containing fulminate of mercury. The explosion of this cap detonates the high explosive in the war head with tremendous force; a force amply sufficient to blow a hole in the plating of any ship, and also, in most cases, to explode the magazines of the ship herself. The bursting charge, in the latest type of torpedoes, is 132 lb.

Exercise Head.—In firing the torpedo for drill, an *exercise head* is substituted for the war head. This exercise head is of the same dimensions and weight as the war head, but contains no explosive. It is sometimes made of very thin and soft metal so that it collapses on striking, thus proving that a hit has been made.

Air Flask.—Immediately abaft the head is the *air flask B*, which is charged with air under a pressure of more than 2,000 lb. to the square inch. In the figure, this air flask has been omitted for lack of space; it is equal in length to distance from point *x* to tail of torpedo. In battle, the flask is always kept charged, and so perfect are the fittings of the valves communicating with it that the leakage is hardly perceptible. Sufficient air is carried for a run of 2 mi., and it is required that the first 1,200 yd. of this distance shall be made at a speed of 35 kn.

Immersion Chamber.—The compartment C next abaft the air flask is the *immersion chamber*, containing the mechanism called the *hydrostatic piston*, by means of which the torpedo is made to run at any desired depth below the surface of the water. The details of this mechanism are complicated, but its general principle is perfectly simple. The

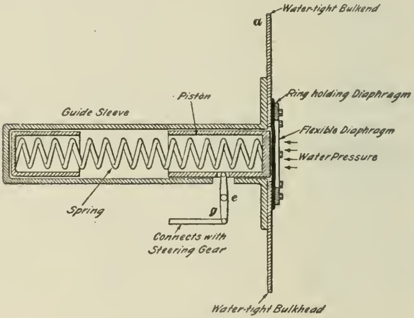


FIG. 2

object is to steer the torpedo down if it rises too high, and to steer it up if it sinks too low. The hydrostatic piston is actuated by two forces that oppose each other; one of these is a spring, the tension of which can be regulated by screwing up a nut; the other is the pressure of the water, which, of course, varies with the depth. The piston is connected by a series of levers with a horizontal rudder at the tail of the torpedo, so that as the piston moves backwards or forwards it cants the rudder up or down, and so steers the torpedo up or down. In Fig. 2 (which is diagrammatic merely) a is a water-tight bulkhead separating the immersion chamber from the adjoining (engine room) compartment. (See also, Fig. 1.) The immersion chamber is absolutely water-tight, but the engine-room compartment is open to the sea. Thus the water-pressure is felt on one side of the bulkhead *a*, but not on the other side. A round hole is cut in the bulkhead and covered by a flexible rubber diaphragm. Inside this immersion chamber, a piston moving in a guide tube is held against the rubber diaphragm by a spring, which opposes its own tension to the pressure of the water on the other side of the diaphragm. If the water pressure exceeds the tension of the spring, the diaphragm is buckled in slightly, compressing the spring and forcing back the piston. If, on the other hand, the water pressure is less than the tension of the spring, the spring extends itself and forces the piston the other way, buckling the rubber diaphragm outwards into the engine compartment.

Attached to the piston, and moving with it, is one end of a rod *g*, pivoted at *e* and connected through a system of levers with the horizontal rudder at the tail of the torpedo. If this rudder is canted upwards, it steers the torpedo toward the surface; if canted downwards, it steers the torpedo down.

By screwing up a nut (not shown in the diagram), the tension of the spring can be varied according to the depth at which it is desired to have the torpedo run. Suppose that it is desired to have it run at 10 ft. below the surface so that it will strike the enemy's ship 10 ft. below the water-line. The adjusting nut of the spring is then screwed to a mark (previously determined by experiment) that we know will make the tension of the spring exactly equal to the water pressure 10 ft. below the surface. Suppose that after the torpedo is launched, it starts off 15 ft. below the surface. The water pressure on the diaphragm is too strong for the spring, the spring yields, the piston moves forwards, the rudder is canted upwards and steers the torpedo toward the surface. Perhaps it now rises a little too high, allowing the spring to overcome the water pressure and force the piston back; this cants the rudder the other way and steers the torpedo downwards a little. After a few variations up and down, each one less marked than the one preceding, the torpedo steadies itself at the proper depth and keeps this throughout the run. The actual working of the rudder is accomplished by a small steering engine, the valve of which is controlled by the rod from the hydrostatic piston. This, of course, does not change the fact that it is the hydrostatic piston that governs the steering.

Main Engine.—The engine is in the compartment *D* next abaft the immersion chamber, which compartment, as already explained, is open to the sea. The engine is connected with the air flask by a pipe (not shown in figure) in which are two valves. One of these, the stop valve, is opened just before the torpedo is fired, the other opens automatically as the torpedo passes out of the tube, being governed by a lever that projects above the torpedo in such a position that it strikes against a projection on the tube and is thrown back, opening the valve. Even this, however, does not start the engine. If it did, the propellers would begin to spin with great violence (technically to *race*) before the torpedo entered the water. Another lever must be tripped before the air can reach the valve chest of the engine; this is a small lever so placed that as the torpedo enters the water, the resistance of the water throws down the lever and allows the engines to start.

Propellers.—To insure the straight running of the torpedo. two propellers p p_1 are used, placed "tandem," one being right-handed and the other left-handed. The after one is keyed to the shaft and turns with it. The forward one is keyed to a sleeve on the shaft and worked from the shaft by a set of beveled gearing. The necessity for two propellers turning in opposite directions arises from the tendency that a propeller always has to throw the stern to one side or the other, according as it is right- or left-handed.

Steering.—It will be noted that the torpedo, as thus far described, has no arrangement for steering to right or left. Until quite recently no such arrangement has been considered necessary or practicable. It has been assumed that the torpedo will follow the course in which it is launched, and great care is taken to insure this by making the body perfectly symmetrical and balancing the weights as exactly as possible. When a torpedo is completed, it is tested as to accuracy in running, and any defect is corrected by moving a small vertical vane on the tail-piece, which, once adjusted, is clamped securely and never thereafter disturbed. It is well known that, as a matter of fact, torpedoes, however carefully tested and adjusted, behave very erratically in service. Cases have been known in which, after running a certain distance, they have turned and run straight back toward the ship from which they were fired.

The Obry Gear.—A very ingenious device, known as the *Obry gear*, has recently been introduced, which can either be used to keep the torpedo true to the course on which it is launched, or can cause it to change its course after running a certain distance and take up a wholly different course, decided upon just before firing. Suppose that a torpedo boat having two tubes, one on each broadside, is running toward a battle ship that she proposes to attack. Under ordinary circumstances, she would have to change her course before firing, in order to bring one tube to bear, and the chance of making a hit while changing course would be very slight. If the torpedoes are fitted with the Obry gear, she can turn both tubes off on the bow or broadside and launch both torpedoes at once, the Obry gear having been set in such a way that each torpedo, after running 50 yd., for example, will turn and head directly toward the enemy, as shown in Fig. 3.

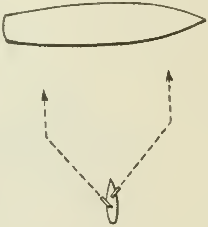


FIG. 3

The essential part of the Obry gear is a gyroscope, or flywheel, that is set spinning at a very high velocity. The principle of the gyroscope is this: A flywheel which is spinning in a given plane has a very strong tendency to continue spinning in that plane, and to resist any effort to turn it into another plane.

In Fig. 4 is shown a view of the Obry gear, *a* being the gyroscope and *b* the sector containing the actuating spring.

The axis of the gyroscopic wheel is placed in a fore-and-aft direction in the torpedo, and no matter how the torpedo turns to right or left the spinning gyroscope by its inherent directive force will cause the torpedo to turn back to its original direction. In torpedoes using the Obry gear, vertical rudders are fitted for steering right and left, as in the case of the rudder of a ship or boat, and these rudders are connected with the gyroscope. If, then, it is desired to fire the torpedo on a certain course and cause it to keep that course, the gyroscope is set spinning in the plane of

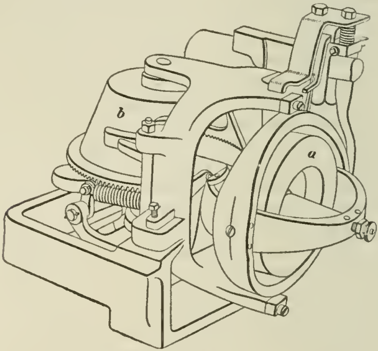


FIG. 4

the course, and if the torpedo swerves to either side, the resistance of the spinning gyroscope moves the rudders and steers it back. If we wish to run the torpedo for a short distance and then cause it to turn, as in Fig. 3, the gyroscope is turned into the plane of the final course that we wish to make the torpedo take up, and connect the rudders in such a way (by means of appropriate mechanism) that the gyroscope will take control of the steering after a certain length of run and swing the torpedo into the plane in which it (the gyroscope) is already spinning.

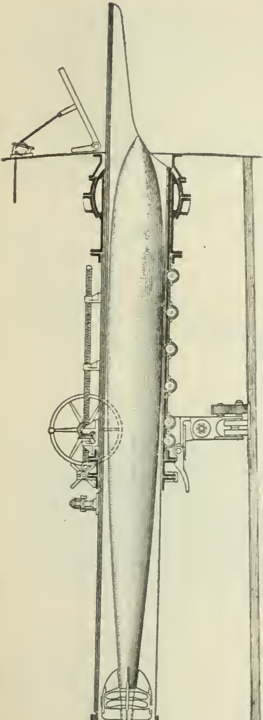


FIG. 5

The details of the Obry mechanism are secret and, of course, complicated, and the device is not yet entirely perfected. There is no doubt, however, of its entire practicability, and it will probably be in use within a very short time.

Sinking Gear.—If a loaded torpedo misses its mark and fails to explode, it would be left floating, a menace to friends and foes alike. Arrangements, therefore, are provided, such that if it does not strike after running a certain distance, a valve opens automatically and causes it to fill with water and sink.

Launching Tubes.—Torpedoes are fired from long tubes, or *guns*, which, however, differ from ordinary guns in that the impulse they give to the torpedo is sufficient only to launch it clear of the ship and into the water, when its own engines take charge and drive it forwards. On torpedo boats and torpedo-boat destroyers overwater tubes are used; these tubes are on deck, and are entirely exposed to the projectiles of an enemy's ship.

If a projectile strikes the fuse, it may explode the torpedo and so destroy the boat carrying it. This is a risk that must be taken by vessels of this class, but it is one that cannot properly be taken by larger ships, and on such ships torpedoes, if carried at all, are carried below the protective deck and are fired from underwater tubes. Fig. 5 represents an overwater launching tube containing a torpedo ready for firing, and in Fig. 6 is shown the torpedo just clear of the tube.

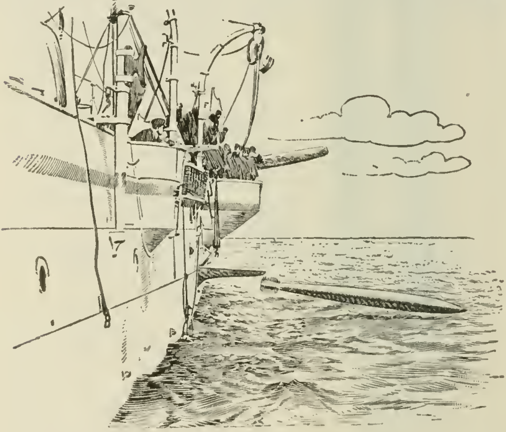


FIG. 6

An overwater tube can be trained and pointed like a gun, so far as lateral aim is concerned, but underwater tubes are fixed and can be pointed only by the steering of the ship. In the case of an underwater tube, special arrangements are required to keep water from entering the ship and also to prevent the nose of the torpedo from being thrown off by the motion of the ship through the water, thus spoiling the aim.

The Torpedo Director.—The aiming of a torpedo from a moving ship to strike another moving ship calls for quick and accurate estimate of the speed, course, and distance of the enemy, and accurate knowledge of the speed of the torpedo; and the application of these data to the solution

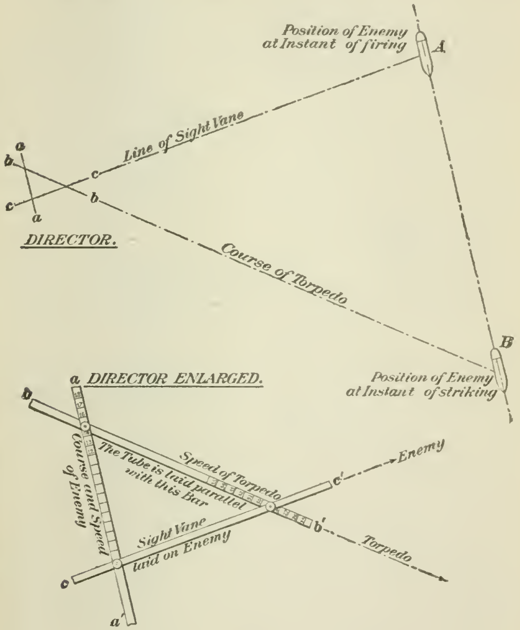


FIG. 7

of a triangle. To fire directly at a ship ½ mi. distant and moving 15 kn. would result in missing the mark by hundreds of yards. The torpedo must be aimed ahead of him by an amount at which it will not do to guess. To solve the problems graphically, the *torpedo director*, Fig. 7, has been devised. In this instrument, three bars are clamped upon each other with movable clamps that may be secured by setscrews. One bar $a\,a'$ is graduated for the speed of the enemy and is laid parallel with his course. The second bar $b\,b'$ is graduated for the speed of the torpedo. The third bar $c\,c'$ is a sighting vane, and is directed toward the enemy's ship. In the upper diagram of Fig. 7 the three lines $a\,a'$, $b\,b'$, and $c\,c'$ represent the torpedo director, A the position of the enemy at instant of firing the torpedo, and B the position of enemy at instant of striking. The only unknown factor in connection with the use of this instrument is the speed of the hostile ship; but if this is accurately estimated (which is possible) the torpedo stands a fair chance of striking the target.

Torpedo Boats.—There has been much discussion within the last few years with regard to the advisability of fitting battleships to carry torpedoes. The discussion has ended, so far as the United States Navy is concerned, in the decision to carry them, but to use underwater tubes only. This decision is undoubtedly wise, but it is none the less true that the most important sphere of usefulness for the torpedo is found when it is used by a torpedo boat against a battle ship or fleet of battle ships. A ship attacked on a dark night by a horde of these little crafts closing in upon her from all directions without warning is perhaps in the most dangerous position in which she could be placed. The effective range of the torpedo is not less than 1,500 yd., and at that distance there is little hope of seeing a torpedo boat even with the aid of a searchlight. If the boat is seen, the defense of the battle ship lies in the rapid fire of her light guns, but the chance that they will hit so small and indistinct an object at a range of nearly a mile and inflict such damage as to render the torpedo boat ineffective, is very slight; and where a large number of boats attack at once, their success should be almost assured. The torpedo of the present is a vastly more dangerous weapon than that of even a few years ago; and in the naval warfare of the future its history will be very different from what it has been in the past.

SHIP BUILDING

PRINCIPLES OF CONSTRUCTION

To design and build a floating structure that will afford comfortable living accommodation for many hundreds of persons, convenient storage, not only for the necessaries of life for this community, but for great quantities of freight, with space for engines and boilers powerful enough to drive the whole mass through the water at two-thirds the speed of an express train, as well as space for the fuel needed to maintain this speed for long periods of time; to make this structure strong enough to withstand the shocks of the heaviest gales and to have a hope of living safely through the heavier shock of grounding or collision; all this is a task whose magnitude can hardly be overstated. And if to these requirements we add the manifold items demanded by the offensive and defensive features of a man of war, we have what may not unreasonably be regarded as the most complex problem of creative work with which the human mind is called upon to deal.

Preliminary Considerations.—In designing a ship, it is necessary first of all to form some idea of the size and weight that she will have; the weight to include not only the ship proper, but the full load that she is to carry. It is a principle of hydrostatics that any floating body will settle in the water until the part of it which is immersed displaces a volume of water exactly equal in weight to the whole of the floating body. If, then, a ship is to weigh, complete, 10,000 T., the volume of that part which is to be below the water line must be exactly equal to the volume of 10,000 T. of water. Provided that this volume is kept constant, the factors of it may be varied by making the immersed body long and fine and deep, or short and broad and shallow. In and upon the underbody thus fixed the weights are to be distributed. In this distribution, if the ship is a man of war, comes an inevitable conflict between the demands for heavy guns, for thick armor, for powerful engines, and for large coal supply, which must be settled by a compromise dictated by considerations of the special duty for which the ship is to be used.

Stability.—In the arrangement of the weights and the dimensions of the hull, the first consideration is the *stability* of the ship; or, in other words, its safety from the possibility of capsizing. The stability depends on what is called the *metacentric height*, which may be thus explained. Suppose that the ship is lying at rest in the water and in an upright position, as in Fig. 1 (*a*). The center of gravity is

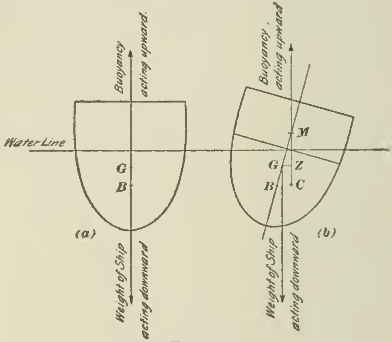


FIG. 1

at *G*, and we may consider the whole weight of the ship to be concentrated at this point and acting downwards. This downward force is balanced by the buoyancy of the immersed section, constituting an upward force that may be considered as concentrated at *B*, the center of figure of the immersed section. These forces being equal and opposite, and acting along the same straight line, the body remains at rest. If the ship is inclined—as she continually will be by the action of winds and waves and many other causes—the center of gravity remains where it was before (unless there is some shifting of weights), but the center of buoyancy changes its position because the form of the immersed section has been changed, Fig. 1 (*b*). Suppose that the new position is at *C*; now, the weight of the ship is at *G*, acting downwards as before, but the buoyancy acts upwards through *C*, on one side or the other of *G*. The distance *G Z* between the lines of action of *G* and *C* is a lever, at the ends of which these forces act to turn the ship. In this case, the line *C Z M*, along which the buoyancy acts, cuts the original line of its action *G B* at the point *M*. This point is called the *metacenter*. Since it is above *G*, the forces that act on the ship when inclined from the vertical will tend to bring her back to an upright position, and the ship will be *stable;* that is, when she is heeled or rolled to either side the forces called into action will bring her back to an upright position. If the line *C Z M* should cut the line *G B* at a point below *G*, the force called into play when the ship was heeled or rolled would act to heel her still farther, and she would capsize. As the center of gravity of a given ship cannot be varied greatly in the design of the hull (since we must assume an approximate distribution of weights as decided upon), the position of *G* is fixed, and the designer must shape his under-water hull so as to place the center of buoyancy in such a position that the metacenter will be far enough above the center of gravity to give the ship a strong disposition to return to an upright position when moved out of this position by any change whatever. The height of the metacenter above the center of gravity is called the *metacentric height*.

A ship that has a considerable metacentric height is stiff, but not steady. She will not roll very deeply, but she will roll very quickly. As quick rolling is unfavorable for gun fire, men of war are usually given rather slight metacentric height, and this has in some cases been carried so far as to reduce the stability beyond the point of safety. It is supposed to have been this defect of design that caused the capsizing of the British battle ship "Captain," in the Bay of Biscay on Sept. 1, 1870. This ship had a very slight metacentric height and rolled little and slowly; but when she found herself in a seaway that rolled her in spite of her sluggishness, she had not sufficient righting moment (or righting leverage) to return to an upright position.

Strain.—It is clear that a structure designed to meet the strains to which a ship is subjected must have great strength. At one instant, the ship may be resting on the crest of a wave, Fig. 2 (*a*), which supports her amidships, while the ends hang altogether unsupported; an instant later, the ends

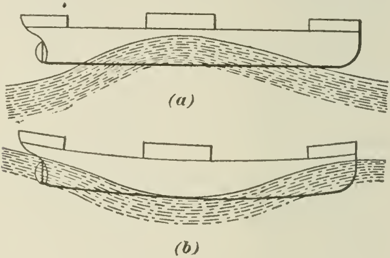


FIG. 2

may be buoyed up and the midship section unsupported, as in Fig. 2 (*b*). And the strains created thus are only a few of the total strains that will be felt by a ship rolling and pitching in a sea, while being driven through it by her powerful engines.

Composition of the Hull.—In the following brief description of the most important features of a ship, reference will be made to Figs. 3 and 16, representing the midship section of a small steamer of very simple construction. Following the description of this, note will be made of departures from this type in the more elaborate construction of large merchant vessels and men of war.

The *frame* is built of three principal parts: two angle bars, with their flanges facing each other, connected by a vertical floor plate of iron or steel riveted along its edges to the flanges of the angle bars, as shown in section at *B C*, Fig. 3. The outer angle bar is technically the *frame bar*, the inner one the *reverse bar*. The space between the bars is greatest at the midship line, and is gradually reduced toward the turn of the bilge, above which point the bars come together and are riveted to each other, flange to flange, the floor plate being dispensed with, as shown in section taken at *A B*. The frames are continuous from gunwale to gunwale, crossing the keel without a break. (This is not true of ships having double-

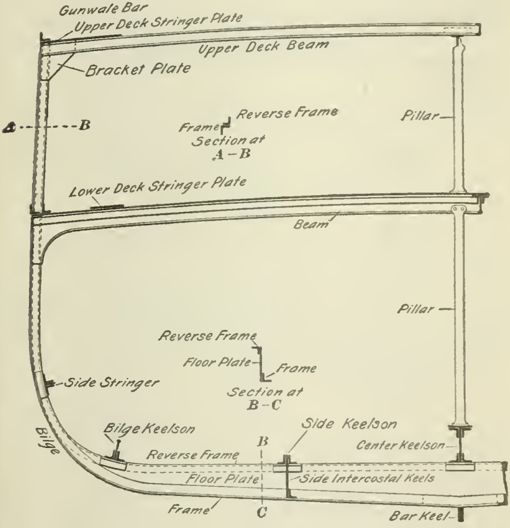


FIG. 3

bottoms, as will be seen hereafter.) The keel, in this case a *bar keel*, Fig. 4, extends fore and aft throughout the length of the ship, being made up of as long sections as can be obtained. The frames are rigidly secured to it by the first strake of the outside plating, known as the *garboard strake.* This strake is bent like an angle iron, one flange (narrow) being riveted to the sides of the keel, while the other and much broader flange is riveted to the frame and the adjoining strakes of plating as shown in detail in Fig. 5 (*a*). In (*b*) and (*c*) of the same figure is shown a second and third type of keel, known, respectively, as the *side-bar keel* and *flat-plate keel.* Above the floor plates lies another longitudinal girder, running the whole length of the ship. This is the main or center *keelson.* It is secured to the frames, binding them rigidly together, and forms, with the keel, the backbone of the ship. The longitudinal framing further includes a number of side keelsons and stringers, some running the full length of the ship, others a part of the length only. And here it may be noted that all longitudinal girders on the bottom of the vessel are called *keelsons*, and those on the sides, above the bilge, *stringers.* At some distance on each side of the center line comes the *side keelson*, worked intercostally; that is, in short lengths between the frames—intercostally being thus distinguished from continuous. The sections of this keelson are very firmly secured to the frames and the bottom plating, and add greatly to the longitudinal strength of the ship, though less than if they were continuous. The method of securing the side keelson to the frames by angle bars is shown in Fig. 3. Outside the side keelson comes the *bilge keelson*, which, being on top of the floor, is continuous; and along the side above the bilge is a side stringer. (In a larger ship there would be several of these.) The legs of the frames are tied together across the ship by *beams*, one of these being used for every second or third frame. The beams connect with the frames by bracket plates, or *knees*, riveted to both. As the beams not only resist the tendency of the frames to open out but also keep them from closing in, they serve as both ties and struts.

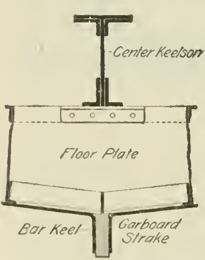


FIG. 4

The decks are laid over the beams and add much to the longitudinal stiffness. They are reenforced by a special

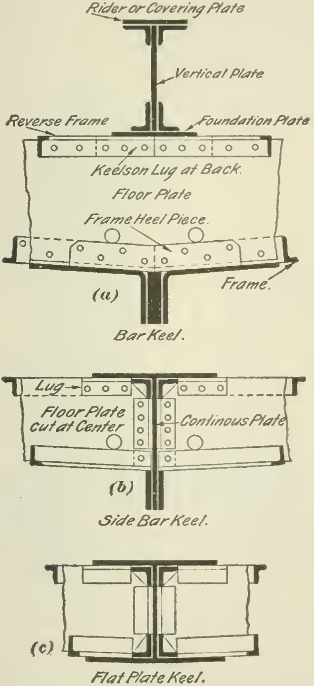


FIG. 5

string piece, broad and flat, laid along the beams throughout the length of the ship, and known as a *deck stringer*. This acts like the deck planking, but is heavier, and is, moreover, found running along every tier of beams, even if these beams do not carry a deck. At their forward ends, the keel and center keelson are connected to the stem, which is in fact a vertical continuation of these girders at the bow of the ship. At the after end, they are secured to the foot of the rudder post, as indicated in Fig. 6. At both bow and stern, additional strength is given by heavy triangular pieces called "breasthooks," Fig. 8, set into the angle that terminates the body of the ship, and connecting the ends of the stringers already described. Fig. 7 is a view of the stern of a vessel, taken in dry-dock, showing rudder, starboard propeller, and the plating riveted to the stern parts.

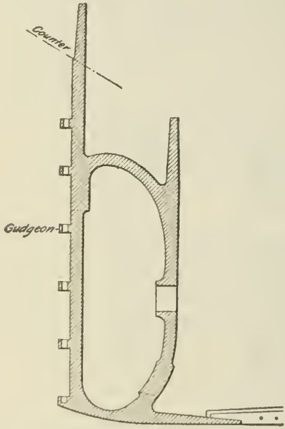


Fig. 6

The construction that has just been described is that of a very simple merchant vessel. In larger vessels, there are wide divergencies from this, but the general principles are not greatly different. One of the most important divergencies is the double-bottom construction, used with many merchant steamers for carrying water or ballast, and in men of war to give security in case of grounding and of damage by torpedoes. Figs. 9 and 14 illustrate this construction.

In Fig. 9 we note that the keel is of the flat type, similar to the one shown in Fig. 5 (*c*), and that the center keelson, instead of standing on top of the floors, is directly above the keel and riveted to it; also, that it cuts through the frames, being itself a continuous girder throughout the length of the ship. The same is true of the five longitudinals that will be seen between the center keelson and the armored deck. It follows that the frames in this part of the ship cannot be continuous, but must be worked intercostally between the longitudinals. This detracts somewhat from the transverse stiffness of the ship, but is very favorable to longitudinal strength. Moreover, extreme precautions

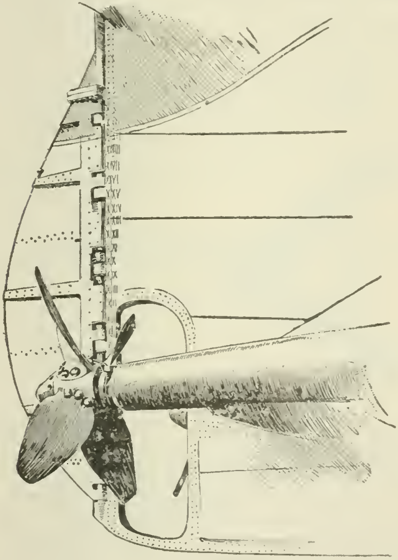


FIG. 7

are taken to make the joints as strong and rigid as possible. This construction is confined to that part of the ship (about two-thirds of the total length) that has a double-bottom proper. Beyond this part, at both bow and stern, the frames are made continuous, and the longitudinals (except the center keelson) are intercostal. A comparison of Fig. 14 with Fig. 15 will show other points of difference between the framing along the midship portions and at the ends, which cannot be described here for lack of space. In Fig. 10 is shown a construction in which a water-tight platform running throughout the length of the ship forms a double bottom.

In Fig. 9 the double bottom extends on each side of the keel to the fourth longitudinal, which thus forms the side boundary of the water-tight cellular construction. These longitudinals are therefore made water-tight by very careful construction and by calking. The center keelson and the second longitudinal on each side are also made water-tight, so that the double bottom is divided longitudinally into four sections, two on each side of the keel. The third longitudinal in each side has openings through which the water can pass and through which a man can crawl for purposes of cleaning and inspection. Similarly, every fourth or fifth frame throughout the double-bottom is made solid and water-tight, the others having manholes like those in the longitudinals. The actual construction of the open frames is shown in Fig. 11, where *c* is the frame bar, *b* the reverse bar, and *a a* bracket-plates corresponding to the floor plates of Fig. 3.

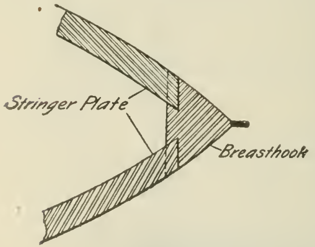


FIG. 8

In Fig. 12 is shown a ship in process of construction, giving an excellent view of the framing and the double-bottom construction. In this ship, the third longitudinal on each side, very conspicuously shown, forms the boundary of the double-bottom, and the first and second longitudinals do not run throughout the whole length of the ship.

The outside plating is riveted to the frames, and adjoining plates are riveted to each other. Several methods of bringing the edges of the plates together are shown in Fig. 13. It will be clear that the plating must add very much to the strength of the ship, both longitudinally and transversely.

Compartments.—A ship is divided internally into *compartments* for various purposes by *bulkheads* (partitions), some running longitudinally and others transversely. These, being riveted solidly to the frames, beams, etc., add very greatly to the strength and stiffness of the ship.

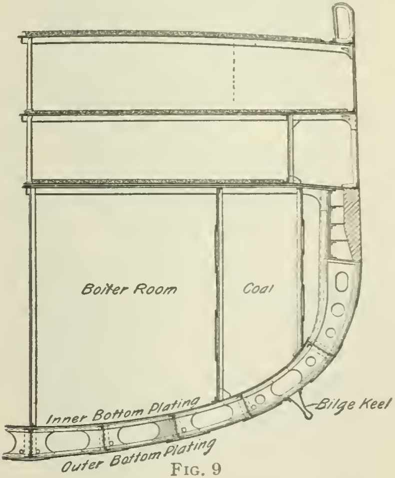


Fig. 9

In all modern steamers, a certain number of the bulkheads are made water-tight, to prevent the flooding of the whole ship from a leak in one compartment. In men of war, the water-tight compartments are very numerous. Communication is afforded by means of doors, also water-tight, which in the most recent ships can be closed by an electrically governed mechanism operated from the bridge.

Well up toward the bow is a bulkhead of exceptional strength. known as the "collision bulkhead," designed to afford security in the event of a head-on collision.

It is important that the water-tight compartments

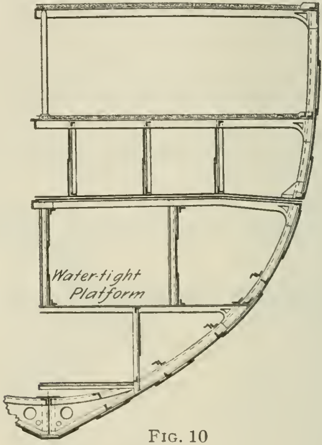


FIG. 10

should not be too large, and this is especially true of those which are near the ends of the ship or which are confined

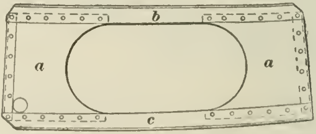


FIG. 11

to one side. The flooding of a single very large compartment on the starboard bow of the British battleship "Victoria" led to the capsizing of that ship when she was

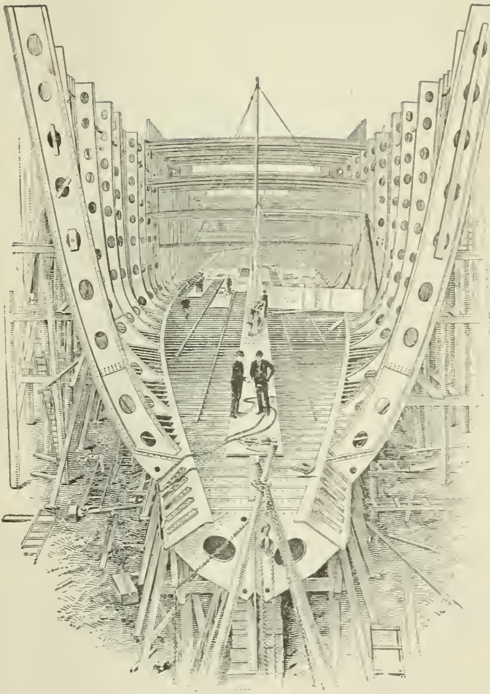


FIG. 12

rammed by the "Camperdown" in 1893. Had the "Victoria" had no water-tight compartments at all, she would doubtless have sunk, but the catastrophe would not have been so sudden, and the loss of life much less.

The interior division of a man of war is necessarily more complicated than that of a merchant steamer. This subdivision, together with many other interesting details of

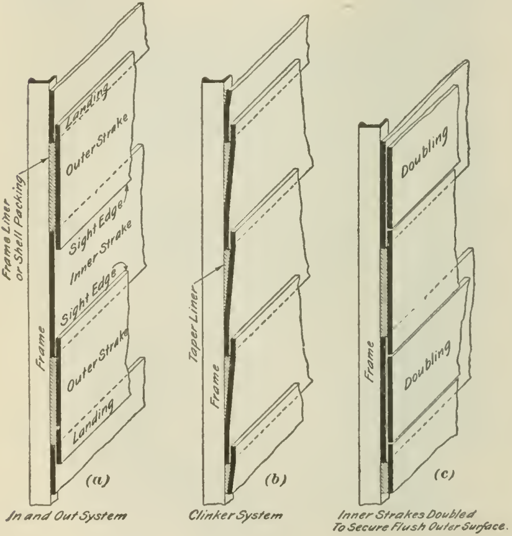


FIG. 13

the structure of a man of war, is shown in Figs. 14, 15, and 16, which are reproduced from Knight's "Modern Seamanship" by the courtesy of the D. Van Nostrand Company, publishers. The elaborate bracing shown in Fig. 15 is needed to strengthen the bow for ramming.

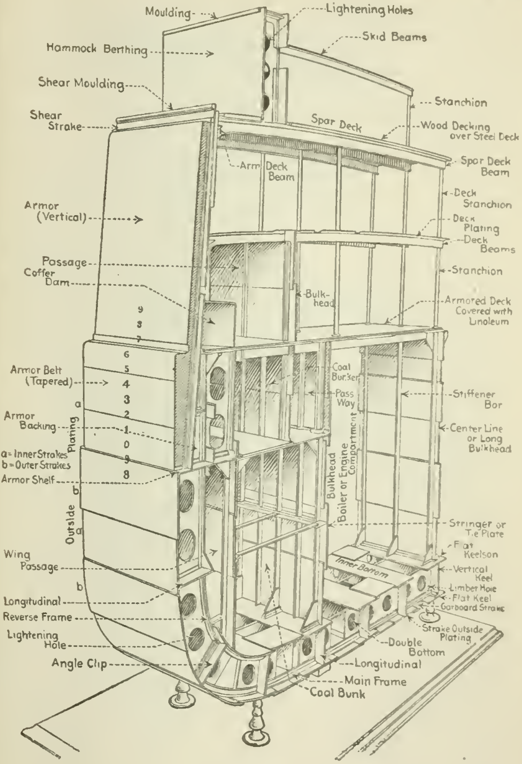

Moulding
Lightening Holes
Skid Beams
Hammock Berthing
Shear Moulding
Stanchion
Shear Strake
Spar Deck
Wood Decking over Steel Deck
Arm Deck Beam
Spar Deck Beam
Deck Stanchion
Armor (Vertical)
Deck Plating
Deck Beams
Passage
Coffer Dam
Stanchion
Bulk-head
Armored Deck Covered with Linoleum
9
8
7
6
5
4
3
2
1
0
9
8
Armor Belt (Tapered)
Coal Bunker
Pass Way
Stiffener Bar
a
Armor Backing
Plating
Center Line or Long Bulkhead
a= Inner Strakes
b= Outer Strakes
Armor Shelf
Bulkhead
Boiler or Engine Compartment
b
Outside
a
Stringer or Tie Plate
Flat Keelson
Wing Passage
Inner Bottom
Vertical Keel
b
Limber Hole
Longitudinal
Flat Keel
Garboard Strake
Reverse Frame
Strake Outside Plating
Lightening Hole
Double Bottom
Angle Clip
Longitudinal
Main Frame
Coal Bunk

FIG. 14

Many men of war have heavily armored decks protecting their vital parts—that is, their engines and boilers, ammunition rooms, etc. This deck is nearly flat amidship, but curves down toward the side to meet the upper edge of the side armor. Such a deck may be rather thin on the flat part, but must be thicker on the slopes, as here a shell striking it would have a more direct impact.

The side armor rests upon an *armor shelf* built into the frames, which is shown in Figs. 9 and 14. The armor is secured by heavy bolts running through a thick backing of teak, and screwed into the inner face of the armor plate.

Armor.—The armor of modern ships is invariably of steel, and is subjected to special treatment to give it the qualities that are found to be necessary for resisting the impact of heavy shells. These qualities are, first, hardness, to resist penetration, and second, toughness, to resist breaking up. These qualities are antagonistic to each other; ordinarily, a steel that is tough is rather soft, while one that is hard is almost necessarily brittle. The armor primarily used for ships was of wrought iron, which was tough but soft.

The first steel armor—introduced a quarter century ago—was much like wrought iron, though inferior to it. There was no difficulty about making hard steel, but this was too brittle. The first move toward combining the two properties consisted in welding a hard steel face on a tough wrought-iron back. This *compound armor*, as it was called, gave good results, the hard face resisting penetration, and the soft back holding the plate together. In more recent years a better solution of the problem has been found in making a homogeneous plate of steel, and hardening the face of it by a special process of tempering. Two such processes have been invented, the *Harvey* and the *Krupp*. These processes give a plate in which the hard face and the tough back are combined without the weld, which was a plane of weakness in the old compound plate. In comparing armor plates with each other, it is convenient to refer their resisting power to that of wrought iron, since this is almost perfectly uniform, and its characteristics do not change from year to year. Accordingly, we say that Harveyized armor has a resisting power of 2 (or a figure of

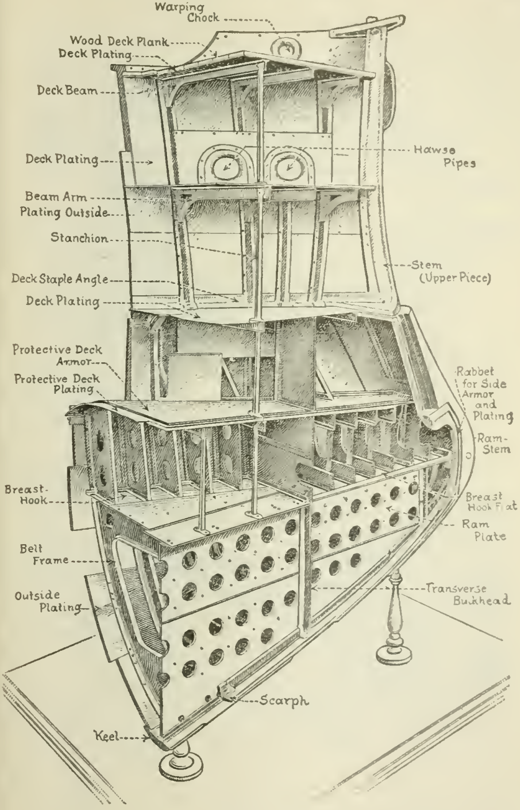

Warping Chock
Wood Deck Plank
Deck Plating
Deck Beam
Deck Plating
Hawse Pipes
Beam Arm
Plating Outside
Stanchion
Stem (Upper Piece)
Deck Staple Angle
Deck Plating
Protective Deck Armor
Protective Deck Plating
Rabbet for Side Armor and Plating
Ram-Stem
Breast-Hook
Breast Hook Flat
Ram Plate
Belt Frame
Outside Plating
Transverse Bulkhead
Scarph
Keel

FIG. 15

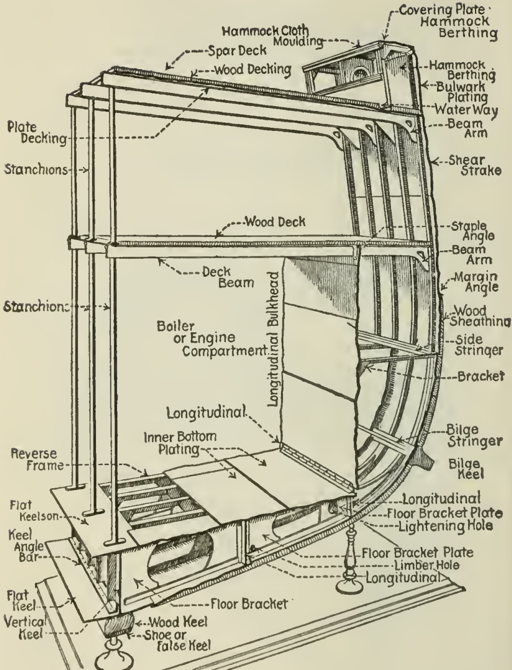

Covering Plate Hammock Berthing
Hammock Cloth Moulding
Spar Deck
Wood Decking
Hammock Berthing
Bulwark Plating
Water Way
Beam Arm
Plate Decking
Stanchions
Shear Strake
Wood Deck
Staple Angle
Beam Arm
Deck Beam
Longitudinal Bulkhead
Margin Angle
Stanchions
Wood Sheathing
Boiler or Engine Compartment
Side Stringer
Bracket
Longitudinal
Inner Bottom Plating
Bilge Stringer
Reverse Frame
Bilge Keel
Longitudinal
Flat Keelson
Floor Bracket Plate
Lightening Hole
Keel Angle Bar
Floor Bracket Plate
Limber Hole
Longitudinal
Flat Keel
Floor Bracket
Vertical Keel
Wood Keel
Shoe or False Keel

FIG. 16

merit of 2), meaning that a given thickness has a power of resistance equal to twice that thickness of wrought iron.

The very latest and best armor made, which is treated by the Krupp process, or *Kruppized*, has a resisting power of 2.5, and the turrets of our latest battle ships, the "Connecticut" and "Louisiana," which carry 10 inches of this armor, have the same resisting power as if they were covered with wrought iron 25 inches thick.

NOTES RELATING TO SPEED, TONNAGE, AND COAL CONSUMPTION OF A STEAM VESSEL

SPEED OF VESSELS

The exact amount of power required to propel a vessel at a given speed cannot be deduced very readily from the elementary principles of mechanics. Instead, we must relv on empirical rules based on the actual performance of vessels. The conditions that influence the relation between power and speed are many, but only a few of the more important ones will be enumerated here. For instance, the area of the blades of the screw propeller may not be sufficient for high speed, owing to a churning of the water when the propeller is revolved beyond a certain number of revolutions. Although the power expended in revolving the propeller faster may be considerable, the increase of the speed may be very slight. A similar state of affairs may occur if the area of the buckets of a paddle wheel is too small. It may be large enough for a low rate of speed, and still be entirely too small for a higher rate, thus showing, probably, a high efficiency of the propelling instrument at a low speed, and a very poor one at a higher rate. Again, the efficiency of the engine may vary greatly for different powers developed by the same engine.

For these reasons no positive rule can be framed that will express the relations between power and speed under all conditions. By the following rule, however, the approximate number of horsepower (I. H. P.) required to propel a vessel at a certain speed may be found:

Rule.—*Multiply the cube of the speed by the cube root of the square of the ship's displacement, in tons; divide the product by the constant corresponding to the length, speed, and shape of the vessel.*

Let *I. H. P.* = indicated horsepower;
D = displacement of vessel, in tons;
K = constant referred to;
S = speed, in knots per hour.

The above rule expressed algebraically is then as follows:

$$I.\,H.\,P. = \frac{S^3 \times \sqrt[3]{D^2}}{K}$$

The terms used in this formula are explained in the order in which they appear.

Indicated Horsepower.—An engine generally absorbs a certain amount of the work done by the steam owing to friction of pistons, rods, and wearing surfaces. The actual useful or net work put out by the engine is for this reason less than that done by the steam on the pistons. The pressure acting on the pistons is ascertained by attaching to the cylinder an instrument called the *indicator*, which registers on a sheet of paper the variation of the steam pressure. The amount of power calculated from the mean effective pressure obtained from the indicator card by means of the indicator is known as the **indicated horsepower** of the engine.

Displacement. — In the technical sense in which this term is applied to ships or any other floating bodies, *displacement* refers to the displacement of the water by the total or partial immersion of any object placed in it. The volume of water displaced may be measured in cubic feet or in tons, and the weight of water displaced (which is equal to the weight of the floating object) is called the displacement.

Constant.—The constant employed in the formula is found in the following table:

TABLE OF CONSTANTS

Description of Vessel	Speed Knots	K
Under 200 ft., fair	9–10	200
Under 200 ft., fine	9–10	230
Under 200 ft., fine	10–11	210
Under 200 ft., fine	11–12	200
From 200–250 ft., fair	9–11	220
From 200–250 ft., fine	9–11	240
From 200–250 ft., fine	11–12	220
From 250–300 ft., fair	9–11	250
From 250–300 ft., fair	11–13	220
From 250–300 ft., fine	9–11	260
From 250–300 ft., fine	11–13	240
From 250–300 ft., fine	13–15	200
From 300–400 ft., fair	9–11	260
From 300–400 ft., fair	11–13	240
From 300–400 ft., fine	11–13	260
From 300–400 ft., fine	13–15	240
From 300–400 ft., fine	15–17	190
Above 400 ft., fine	15–17	240

To determine whether a vessel is fair or fine, it is usual to compare its displacement, in cubic feet, with the volume of a rectangular box having a length equal to the length of the vessel on the water-line, a width equal to the beam, and a depth equal to the draft of the vessel diminished by the depth of the keel. If the displacement is .55 of the volume of the box, or less, the vessel is fine; if above .55 and less than .70, it is fair. The quotient obtained by dividing the displacement by the contents of the imaginary box is called the *coefficient of fineness*.

Illustration.—To illustrate the application of the given rule, suppose that a vessel 260 ft. long and finely shaped is to have a speed of 15 kn.; what should be the indicated horsepower of the engine, assuming the vessel to have a displacement of 1,000 T? From the table, we find $K=200$. Inverting values in the given formula, we find the required horsepower to be

$$I.\ H.\ P.=\frac{15^3\times\sqrt[3]{1,000^2}}{200}=\frac{3,375\times 100}{200}=1,687.5.\quad \text{Ans.}$$

TONNAGE AND DISPLACEMENT

By the application of a simple method known as **Simpson's** rules, the volume of the immersed portion of a ship can be ascertained; which, if considered as water and divided by 35, will give the displacement, in tons. But as vessels vary considerably in form, the mere length, beam, and draft of a ship cannot be utilized for finding the displacement; hence, the coefficient of fineness previously mentioned must be used in the computation of displacement. Knowing the extreme dimensions of a vessel and its coefficient of fineness, the exact displacement is readily found. For example, take a vessel 100 ft. long, 20 ft. beam, and floating at 8 ft. draft, the coefficient of fineness being .6, the displacement will be $\frac{100\times20\times8\times.6}{35}=274.3$ T.

Tonnage refers to the internal capacity, or volume, of a ship. A glance at a tonnage certificate or a register of shipping for any vessel shows two distinct classes of tonnage, viz., *gross* and *net tonnage.*

Gross tonnage is the entire internal capacity measured according to certain rules, as specified in the navigation laws of the United States, and according to size and type of vessel.

Net tonnage is the remainder after having taken from the gross tonnage allowances for crew space, engine and boiler-room, shaft alley, etc. The net tonnage is supposed to represent the earning capacity of the ship, and it is therefore made the basis for port and navigation charges. The detailed rules for computing tonnage are quite complicated, and do not come within the scope of this pocketbook. They will be found, however, in the navigation laws of the United States, or under the Revised Statutes, Chap. I, Title XLVIII, Sec. 4,150 to 4,153, and Chap. 398. If it be required to ascertain the tonnage of a vessel, the best thing to do is to submit the drawings and plans to the nearest local inspector of the United States Steamboat Inspection Service.

Displacement, which is often confused with tonnage, is, as stated before, the weight of the water that the ship displaces, or, what is the same thing, the weight of the ship itself and everything on board. Hence, the displacement of a vessel varies from day to day, or from one voyage to another, according to the cargo, coal, stores, etc. on board, while tonnage, being determined by the type and internal dimensions of the ship, remains constant. When the dimensions and capacity of a certain ship are required, it is usual to give the displacement as well as the gross and net tonnage of the ship. Thus, the internal capacity of the steamship "Dakota," belonging to the Great Northern Steamship Company, is given as follows: Gross tonnage, 21,000; net tonnage, 13,500; displacement, 37,500 gross tons. The port and navigation charges for this vessel are therefore based on 13,500 net tonnage.

PROBLEMS ON SPEED

Very often the question as to the number of revolutions at which the engine must be run to drive the vessel at a certain speed comes up before those in charge of a steamer. If the revolutions per minute of the engine for a certain speed of the vessel are known, the question may be readily answered. Assuming the percentage of slip to remain constant, doubling the velocity of the stream projected by the propelling instrument, that is, doubling the revolutions of the engine, and hence of the screw propeller or paddle wheels, doubles the speed of the vessel. In other words, the speed varies directly as the revolutions of the engine.

By the term **slip** is understood the velocity of the stream projected by any propelling instrument, in reference to the surrounding water, in a direction opposite to that in which the ship moves. Since the actual velocity of the stream cannot be obtained by calculation, it has become a common practice to consider the pitch of the propeller P multiplied by the revolutions per minute R as the speed of the stream. Under this assumption, slip may be defined as the difference between the theoretical speed, P' expressed by the formula

$$P' = \frac{P \times R \times 60}{6{,}080}$$

and the actual speed of the vessel, in knots per hour; or, the difference between the speed of a vessel corresponding to the product of pitch of the propeller and the number of revolutions in a given time, and the actual speed of the vessel in the same time.

The slip is usually expressed in per cent. of the velocity of the stream propelling the vessel.

In actual practice the percentage of slip varies somewhat at different speeds and under different conditions; hence, the following rule, which is based on the assumption of a constant percentage of slip, does not give the exact number of revolutions per minute required. This can be found only by actual trial. However, it will give a very fair approximation.

Rule.—*To find the number of revolutions per minute at which to run the engine in order to give the required speed, divide the product of the revolutions producing any given speed and the required speed by the given speed.*

Let R = revolutions per minute for a given speed;

S = given speed;

R_1 = required revolutions;

S_1 = required speed;

then, the given rule, expressed algebraically, will be

$$R_1 = \frac{R S_1}{S}$$

Example.—If a vessel is propelled at a rate of 16 kn. when the engine is making 32 rev. per min., what should be the number of revolutions per minute to reduce the speed to 14 kn.?

Solution.—Applying the above rule, we find

$$R_1 = \frac{32 \times 14}{16} = 28 \text{ rev. per min.} \quad \text{Ans.}$$

Number of Revolutions Propeller Should Make to Run at Required Speed, the Pitch of Propeller Being Known.—In order to solve this problem, the slip of the propeller for the required speed must be known; and if not known from trial-trip records, must be assumed at a conservative figure. The slip of well-designed propellers varies between 5 and 15%, the average being about 10%. Owing to the slip of the propeller, it must be run at a higher number of revolutions than would be the case otherwise.

Let P = pitch of propeller, in ft.;
K = required speed, in knots;
R = revolutions per minute at required speed;
N = number of feet, in a knot (6,080);
S = per cent. of slip, expressed as a decimal.

The number of revolutions for the required speed is then found by the proportion $60 \times P : N = K : R \times (1 - S)$; whence,

$$R = \frac{6{,}080 \times K}{60 \times P \times (1 - S)}, \text{ and } K = \frac{60 \times P \times R \times (1 - S)}{6{,}080}$$

Example 1.—The pitch of a propeller is 16 ft.; how many revolutions per minute must it make to drive the ship at the rate of 10 kn. per hour, the slip being estimated at 10%?

Solution.—Applying the first formula given, and substituting values, we get

$$R = \frac{6{,}080 \times 10}{60 \times 16 \times (1 - .1)} = 70\tfrac{1}{4} \text{ rev. per min., nearly. Ans.}$$

Example 2.—A propeller having a pitch of 20 ft. makes 70 rev. per min.; from a trial-trip record, the slip is known to be 12% at that number of revolutions. What is the speed of the ship?

Solution.—Applying the second formula given, we get

$$K = \frac{60 \times 20 \times 70 \times (1 - .12)}{6{,}080} = 12.15 \text{ kn. per hr. Ans.}$$

FUEL CONSUMPTION AND SPEED

The **fuel consumption** may be said to vary directly as the horsepower developed (this is not exactly true, but only approximately). The horsepower varies directly as the cube of the speed, whence it follows that the fuel consumption will also vary as the cube of the speed (approximately).

Let S = certain speed of vessel;
C = coal consumption at speed S;
s = new speed;
c = coal consumption at speed s.

Then, $$c = \frac{s^3 C}{S^3}, \text{ and } s = \sqrt[3]{\frac{c S^3}{C}}$$

Example 1.—A steamer consumes 100 T. of coal per da. at a speed of 10 kn.; what should be the speed in order to cut the coal consumption down to 50 T. per da.?

Solution.—Using the second formula, we find

$$s=\sqrt[3]{\frac{50\times 10^3}{100}}=\sqrt[3]{500}=7.9, \text{ or } 8 \text{ kn., nearly.} \quad \text{Ans.}$$

Example 2.—A steamer consumes 80 T. of coal per da. at a speed of 12 kn. per hr.; suppose that the speed is to be reduced to 10 kn. per hr.; what would be the fuel consumption per da. at that rate of speed?

Solution.—Using the first formula, we find

$$c=\frac{10^3\times 80}{12^3}=\frac{1,250}{27}=44.8 \text{ T. per da.} \quad \text{Ans.}$$

Example 3.—If a steamer consumes 15 T. of coal per da. to produce a speed of 9 kn. per hr., how many knots would she steam if the coal consumption were reduced to 12 T. per da.?

Solution.—In this case, $c=12$, $S=9$, and $C=15$. Inserting these values in the second formula, we find the new speed, or

$$s=\sqrt[3]{\frac{12\times 9^3}{15}}=\sqrt[3]{\frac{4\times 729}{5}}=\sqrt[3]{583.2}=8.3 \text{ knots per hr., nearly.} \quad \text{Ans.}$$

Example 4.—A steamer consumes 20 T. of coal per da. at a normal speed of 10 kn. per hr. The distance to the nearest port where coal can be had is 600 mi., and the estimated quantity of coal in the bunkers is but 35 T. Find what speed should be maintained in order to reach the coaling station with the coal supply on hand.

Solution.—The best way to proceed in a case of this kind is to assume a lower speed, say 8 kn., and calculate the new coal consumption for that speed; thus, $c=\frac{8^3\times 20}{10^3}=\frac{256}{25}$ $=10.24$ T. per da., or .43 T per hr. The time required to cover a distance of 600 mi. at a speed of 8 kn. per hr. is $\frac{600}{8}=75$ hr., and at a coal consumption of .43 T per hr. the total quantity of coal required at that speed is $75\times .43$ $=32\frac{1}{4}$ T. Hence, if a speed of 8 kn. per hr. is maintained, the supply of coal on hand (35 tons) will suffice to reach the coaling station under ordinary weather conditions. Ans.

In practice it is advisable to have a good margin of coal in excess of the calculated amount, for the reason that the actual coal consumption at the reduced speed will, as a rule, exceed the calculated consumption because of the decrease in economy of the engine, induced by reducing the developed horsepower.

ROPES

Ropes in general use on shipboard, in reference to the material from which they are made, are of three kinds: *hemp*, *manila*, and *wire ropes*. Although wire rope is rapidly superseding all other kinds, even for certain running gears, fiber ropes are still used very extensively, and for certain purposes can never be replaced by steel ones.

Fiber Ropes.—The very best of the fibers used in the manufacture of cordage is the so-called **manila** fiber, which is obtained from the leaf stalks of the Musa textilis, or *textile banana*, the entire supply of which comes from the Philippine Islands. This fiber is very strong and durable, but not very flexible, and, therefore, is not well adapted to the manufacture of small cordage, though it is very satisfactory for the larger sizes. When dry it contains 12% moisture, and will absorb as much as 40% in a damp atmosphere; moisture, however, does not tend to promote the decay of this fiber. In fact, in hot, dry weather an occasional wetting of the rope is thought to prolong its life. A freezing temperature renders the fiber brittle. The hardest and strongest fiber is that from the outer layer of leaf stalks; that from the inner layers is increasingly fine and weak. The butts of the fibers are stronger than the tops.

Next in importance is the common **hemp**, which is the fiber of the stalk of the plant of that name. It is grown throughout Europe, in India, and in some parts of America. The kind best adapted to the manufacture of cordage is that grown in Russia. This fiber is more flexible than manila fiber, but less strong and less durable. It decays very rapidly if kept wet. A tarred hemp rope immersed in water is stated to have lost, in 4 mo., nine-tenths of its strength.

Hemp rope used on shipboard is invariably tarred. The tar acts as a preservative on the rope, but has a tendency to slightly reduce its strength and flexibility; the use of tar in standing rigging also serves to diminish contraction and expansion due to wet and dry weather. It is advisable that a tarred hemp rope should not be used until 6 mo., or even 1 yr., after its manufacture. This period of rest allows the tar to become uniformly distributed throughout the fiber, and the English Admiralty Board states that the rope has 10% greater durability than if it is used as soon as made. Manila ropes are never tarred. Hemp rope when not tarred is known as *white rope*.

Coir, the fiber of the outer husk of the cocoanut, is occasionally used in cordage manufacture, it is quite strong, but is short, stiff, coarse, and rough. On account of its buoyancy, and because moisture does not affect it, rope made of coir is particularly well adapted for tow ropes.

In manufacturing rope, the fibers are first spun into a yarn twisted right hand. From 20 to 80 of these yarns are twisted together left hand to form a strand. Three or four strands are then twisted right hand into a rope. Ropes composed of four strands generally have a center, or core, consisting of a small rope about which the strands are laid. (See *b*, Fig. 1.) This center rope is called the *heart*. The primary object of the twisting is to hold the fibers in place, so that each may do its share of the work. When the strands are twisted up left hand, the yarns are untwisted, but when the rope is twisted up right hand the strands are untwisted and the yarns again twisted up. There is thus a certain degree of equilibrium that the rope maker endeavors to attain, at which the tendencies of the rope and the strands to untwist are equal in amount and

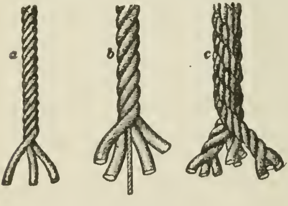


FIG. 1

opposite in direction. If the twist is great, the rope is hard and stiff, and keeps its form well, but it is not so strong as a rope with less twist.

Hawser and Cable.—A rope of 3 strands is called a *hawser*, *a*, Fig. 1. A rope of 4 strands is said to be *shroud laid*, *b*, Fig. 1. Very large ropes are made by twisting 3 hawsers together to form a *cable*, as in *c*, Fig. 1.

As a rope bends over sheaves and drums, the fibers slide on one another, and are thus worn out quite rapidly, especially near the heart of the rope; a rope will therefore last much longer if it runs over large sheaves. Rope is designated by its circumference, expressed in inches, and is issued in coils of about 113 fathoms each.

Small Stuff is the name given to various small ropes used on shipboard; they are distinguished by the number of strands and yarns used in their make up. Thus, *ratline*, used principally for seizings and rattling down the rigging, is composed of 3 strands twisted right hand, each strand containing from 4 to 8 yarns. *Spun yarn* is spun left hand, and consists usually of three yarns; it is used extensively for various purposes, such as, seizings, mousings, to serve ropes, etc. *Rope yarns* are mostly made from condemned tarred hemp rope; this too is a very much needed article around deck and aloft. A man should never go aloft without a supply of rope yarns; he will find them very useful in fixing up and strengthening worn-out mousings, stops, etc.

Wire Rope.—Wire from which ropes are manufactured is commonly either of iron or of steel. Steel wire has nearly displaced iron, as it has, for most purposes, many advantages. Iron wire ropes are, however, still made and used. The only iron suitable for this use is the best quality of charcoal iron, and most manufacturers advertise that they use Swedish charcoal iron, the malleable iron made from the pure ores of Sweden having acquired an excellent reputation throughout the world.

The greatest strength in a wire rope would be attained by laying the component wires parallel, and the strength of the cable would then be equal to the sum of the strengths of the individual wires composing it. Suspension-bridge cables are actually constructed in this way, but this system of construction is not suitable for running ropes. Such a cable is a mere bundle of wires; it has no stability of form and would spread out laterally where it came in contact with a sheave or drum. The wires would rub against one another, wear rapidly, and probably be broken one at a time by kinking or by catching on something. In order to overcome these objections, wire ropes, other than those for large suspension bridges, are made up somewhat after the model of the hemp rope; i. e., by twisting together a certain number of wires to form a strand, and a certain number of strands to form the rope. In recent years, a number of special rope sections have been introduced. The wires composing a rope are all circular and of the same diameter, the prevailing geometrical form of the rope section

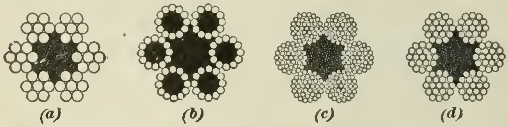


Fig. 2

being the hexagon. The simplest form of rope strand is composed of 7 wires, arranged as in Fig. 2 (*a*); 6 of these strands are commonly arranged around a core of tarred hemp to form the rope. This rope is largely used for transmission purposes in manufacturing establishments, and for shrouds, stays, etc. of the standing rigging of a ship. Fig. 2 (*b*) shows a rope consisting of 6 strands, each being made up of 12 wires, laid around a hemp center; this construction makes an extremely flexible and very light rope, and is used almost exclusively for running gear on shipboard. In (*c*) is shown the type of construction known as the special flexible hoisting rope consisting of 6 strands of 37 wires each, laid about a hemp center, combining extreme flexibility and high tensile strength. It is used largely on cranes, derricks, and dredges, and when galvanized it is frequently employed with great success for towing hawsers. Fig. 2 (*d*) shows the ordinary hoisting-rope construction. The 6 strands consist of 19 wires each, laid around a hemp center. This construction combines flexibility, needed for the rope to pass over drums and sheaves, and high tensile strength. It is probably the most universally applicable of any form of rope.

In special types of wire ropes, the hemp heart is replaced by a core of wire. Such ropes are much stiffer than those with hemp cores, and are only adapted for use as standing ropes. The substitution of the wire for the hemp core adds about 10% to the weight of the rope, but does not add materially to its strength. This is because the wires in the central strand, making a smaller angle with the axis of the rope than those in the outside strands, are not able to accommodate themselves to the stretching of the rope under load and, therefore, carry an undue proportion of the load, breaking before the wires are fully loaded.

Protection of Wire Rope.— Ropes used on shipboard are mostly made of galvanized wire, the purpose being to prevent corrosion by protecting the iron or steel of the wire against contact with air or water. Galvanizing accomplishes this in the case of standing ropes, but is not effective for running ropes. The friction of the rope against sheaves, drums, or anything else with which it comes in contact, soon wears off a portion of the zinc, and with both zinc and iron exposed and in contact with water, corrosion proceeds more rapidly than it would if the zinc were not present. A further objection to the galvanizing process is that the necessary heating of the wire has the effect of partially annealing it and, consequently, reducing its strength.

Various preparations are used for coating wire rope to prevent corrosion due to exposure to water and dampness. The most easily applied, and as effective as any, while it sticks, is raw linseed oil. The chief objection to its use is that, being a liquid, it runs or is washed off the rope in a short time, necessitating another treatment, in default of which the wires are soon corroded. In order to partially meet this objection, the oil is sometimes mixed with its weight of lampblack, thus giving it more body. The liquid condition of the pure oil is, however, a great advantage, as the oil finds its way readily into the interior of the rope, and the inside wires are thus effectively protected.

MANILA ROPE

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain	
		Tons	Pounds
3/4	.019	.28	560
1	.033	.39	784
1 1/2	.074	.78	1,568
2	.132	1.36	2,733
2 1/2	.206	2.14	4,278
3	.297	3.06	6,115
3 1/2	.404	4.27	8,534
4	.528	5.78	11,558
4 1/2	.668	7.39	14,784
5	.825	9.18	18,368
5 1/2	.998	10.97	21,952
6	1.190	12.77	25,536
6 1/2	1.390	14.56	29,120
7	1.620	16.35	32,704
7 1/2	1.860	18.14	36,288
8	2.110	19.93	39,872
9	2.670	23.52	47,040
10	3.300	27.10	54,208
11	3.990	30.69	61,376
12	4.750	34.27	68,544
13	5.580	37.86	75,712
14	6.470	41.44	82,880

NOTE.—For safe-working load, allow from one-fifth to one-seventh of the breaking strain.

Pine tar, applied hot, is sometimes used, and one application will last a long time on account of the viscous, sticky nature of the material. For the same reason, however, the preservative does not so readily reach the interior of the rope. Coal tar also is used for this purpose. In order to neutralize any acid that may be contained in either pine or coal tar, it is usual to add slacked lime, in the proportion of about 1 bu. to 1 bar. of tar. The mixture is boiled thoroughly before application. Sawdust is sometimes added, to give additional body.

GALVANIZED IRON WIRE ROPE

(Used for Shrouds and Stays)

Composed of 6 Strands and Hemp Center, With 7 or 12 Wires to the Strand

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain Tons of 2,000 lb.	Circumference of New Manila Rope of Equal Strength Inches
1	.16	1.4	2
1⅛	.20	1.8	2¼
1¼	.25	2.3	2½
1½	.36	3.2	3
1¾	.49	4.4	3¾
2	.64	5.8	4½
2¼	.81	7.3	4¾
2½	1.00	9.0	5
2¾	1.21	11.0	5¼
3	1.44	13.0	5¾
3¼	1.70	15.0	6
3½	1.95	18.0	6½
3¾	2.25	20.0	7½
4	2.55	23.0	8
4¼	2.90	26.0	8½
4½	3.25	29.0	9
4¾	3.60	32.0	9½
5	4.00	36.0	10
5¼	4.40	40.0	10½
5½	4.85	44.0	11

Note.—For safe-working load, allow from one-fifth to one-seventh of the breaking strain.

The preceding and following tabular statements relating to the weight and breaking strain for different sizes of wire ropes have been furnished by the makers, principally by Messrs. John A. Roebling Sons, Trenton, N. J., and should for this reason be considered comparatively trustworthy.

GALVANIZED STEEL HAWSERS

(Used extensively for towing)

COMPOSED OF 6 STRANDS AND A HEMP CENTER, EACH STRAND CONSISTING OF 12 WIRES AND A HEMP CORE

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain Tons of 2,000 lb.	Circumference of New Manila Hawser of Equal Strength Inches
2¼	.54	12.3	5½
2½	.67	14.4	6
2¾	.81	16.4	6½
3	.97	21.5	8
3¼	1.14	24.0	8½
3½	1.32	27.0	8¾
3¾	1.51	29.0	9¼
4	1.72	32.0	10
4¼	1.94	39.0	11
4½	2.18	42.0	11½
4¾	2.42	45.0	12
5	2.70	53.0	12½
5¼	2.95	57.0	13
5½	3.25	61.0	13½

STEEL HAWSERS FOR HEAVY TOWING

COMPOSED OF 6 STRANDS AND A HEMP CENTER, 37 WIRES TO THE STRAND

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain, in Tons	
		Cast-Steel	Special
3	1.44	31	40
3½	1.95	42	55
4	2.55	55	72
4¼	2.90	62	81
4¾	3.60	76	99
5	4.00	84	109
5½	4.85	101	131
6¼	6.25	128	166

NOTE.—For safe-working load, allow from one-fifth to one-seventh of the breaking strain.

(Used for Yacht Rigging)

COMPOSED OF 6 STRANDS AND HEMP CENTER, 7 OR 19 WIRES TO THE STRAND

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain Tons of 2,000 lb.	Circumference of New Manila Rope of Equal Strength Inches
1	.16	3.7	3
1⅛	.20	4.5	3¾
1¼	.25	5.7	4¼
1⅜	.30	6.8	4½
1½	.36	8.1	4¾
1¾	.49	10.8	5¼
2	.64	14.0	6
2¼	.81	17.6	7
2½	1.00	22.0	8
2¾	1.21	26.0	8½
3	1.44	31.0	9
3¼	1.70	36.0	10
3½	1.95	41.0	11
3¾	2.25	47.0	12
4	2.55	53.0	13

GALVANIZED IRON AND CAST-STEEL WIRE ROPE

(Used for Running Gear)

COMPOSED OF 6 STRANDS AND HEMP CENTER, EACH STRAND CONSISTING OF 12 WIRES AND A HEMP CORE

Circumference in Inches	Weight per Foot in Pounds	Breaking Strain	
		Iron	Cast-Steel
1	.11	1.14	2.28
1⅛	.13	1.60	3.20
1¼	.17	2.15	4:30
1½	.24	2.78	5.56
1¾	.33	3.47	6.94
2	.43	4.29	8.58
2¼	.54	6.13	12.30
2½	.67	7.20	14.40
2¾	.81	8.21	16.40
3	.97	10.70	21.50
3¼	1.14	12.00	24.00

NOTE.—For safe-working load, allow from one-fifth to one-seventh of the breaking strain.

SPLICES AND BENDS

Splicing is the operation of joining two pieces of rope so as to obtain one continuous piece with no appreciable increase of diameter at the splice. There are several kinds of splices but the principal ones are the *short splice*, the *long splice*, and the *eye splice*. The principle of all splicing consists of joining or "marrying" the strands, thinning them out, and tapering them so that the diameter at the

Fig. 1

splice is the same or only slightly greater than that of the rope itself. In the long splice, no increase in diameter is allowed. The only tools necessary for splicing hemp or manila ropes used for ordinary running gears are a *marlinespike* and a knife. The marlinespike is made of either iron or hardwood, is from 12 to 14 in. long, and about 1 in. in diameter at the thick end, the other end being sharpened to a blunt point about as shown in Fig. 1; it is always operated by the right hand, while the left encircles the rope. After pushing the extreme point through between the strands to be separated, the thick end is placed against the body of the operator; then, using both hands, the rope is twisted so as to render the work of opening the strands easy.

The marlinespike should be provided with a good laniard, attached to the hole in its thick end, and when used aloft it should be slung around the operator's neck or secured to the rigging.

The Short Splice.—To make the short splice, unlay the strands at the end of each rope for a distance about as shown in Fig. 2; this distance depends entirely on the diameter of the rope, but as the proportion will be the same for all diameters, the illustration serves as a general guide; be sure to unlay enough; a few inches too much is better than too little as the ends have to be cut off anyway. Then, place the two ends together as shown at Fig. 2 (*a*), so that each strand lies between two strands of the other rope. Hold the strands *x y z* and the rope *A* in your left hand; if the ropes are too large to hold thus, fasten them together with twine; then take one of the strands, say *n*, pass it over strand *y*, and, having made an opening, either with the thumb or with a marlinespike, in the manner illustrated in Fig. 1, push this strand *n* through under *x* and pull it taut; this operation is known as *tucking*. Proceed similarly with strands *m* and *o*, passing each over the immediately adjoining strand and under the next one. Perform precisely the same operation with the strands of the other rope, passing each strand over

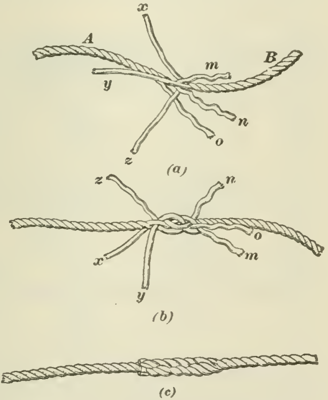


FIG. 2

the adjoining one and under the next, thus making the splice appear as at Fig. 2 (*b*). In order to insure security and strength, this tucking must be repeated by passing each strand over the third and through under the fourth; then, after subjecting the splice to a good stout pull, cut off the ends of the strands, and you have the finished splice as shown at Fig. 2 (*c*).

In slings and straps used for heavy work, the strands should be tucked twice each way, and over one-half of each strand should be *whipped*, or bound, with twine to one-half

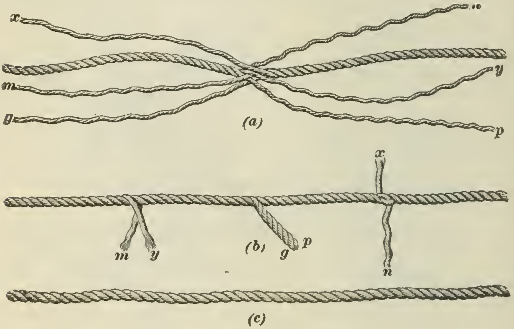


FIG. 3

of the rest, in order to prevent the strands from "creeping through" when the splice is taxed to the full capacity of its strength.

In the short splice, the diameter at the joint is greater than that of the rope, for which reason it is not a suitable splice where the rope is to be used in tackles and pulley blocks, or in places that will not admit anything larger than the rope itself. In such cases the long splice is used; this, when properly made, the untrained eye can hardly distinguish from the rest of the rope.

The Long Splice.—To make the long splice, unlay the ends as before, but about three times as far, and place them together, as shown at Fig. 3 (*a*), in the same manner as for the short splice. Then unlay one of the strands, say *x* of the right-hand rope, and in the groove thus made lay the strands *n* of the left-hand rope, taking good care to give this strand the proper twist, so that it falls gracefully into the groove previously occupied by strand *x*. Do likewise with strands *y* and *m*, unlaying *y* gradually and in its place laying the strand *m*; the result is shown at Fig. 3 (*b*). Now, leaving the middle strands *p* and *g* in their original positions, cut off all the strands as shown at (*b*); then relieve strands *n* and *x* of about one-third of their yarns,

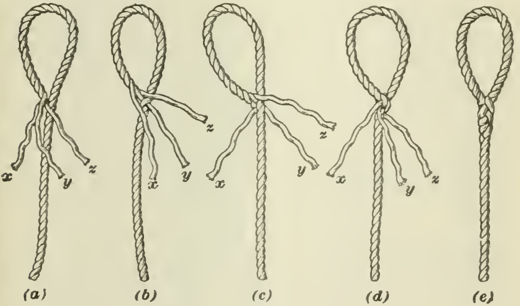


FIG. 4

and with what is left cast an overhand knot as shown—taking care that the knot is made so that the strands will follow the lay of the rope, and not cross it. Pull this knot taut and dispose of the ends as in the short splice, by passing them over the adjoining strand and through under the next, cutting off a few yarns at each tuck. Proceed similarly with strands *p* and *g*, and *y* and *m*. The splice, when it is completed, appears as at Fig. 3 (*c*). Sometimes the overhand knot is made without first thinning the strands, and then split, and the half strand put through as described; but by doing so, the surface of the splice is never as smooth as by the other method, which, for strength and neatness, is second to none.

The Eye Splice.—To make an eye splice, unlay the strands about as far as for the short splice, and bend into the required size of eye, as shown at Fig. 4 (*a*). Then tuck the end of the middle strand *y* under one of the strands of the standing part—having previously made the necessary opening with the marlinespike—and pull taut, getting what is shown at (*b*). Push the strand *x* from behind, and under the strand on the standing part next above that under which the middle strand *y* was passed, so that it will come out where *y* went in, getting what is shown at (*c*); then pass the third strand *z* under the remaining free strand in the standing part, next to the one under which *y* was passed, getting (*d*). Pull the strands taut, and from each cut out one-third of the yarns; pass each remaining two-thirds over the adjoining strand of the rope, and then through under the next, as in the short splice; then cut off one half of the yarns, and tuck the other half under its corresponding strand for the third time; give it a good stretching, cut off the ends, and thus complete the splice as shown at (*e*) Fig. 4.

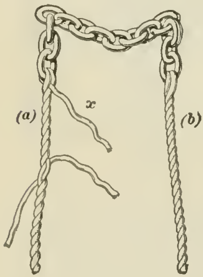


FIG. 5

In four-stranded ropes, the short and long splice are made essentially the same; in the eye splice, the first strand is tucked under two strands of the rope, the second tucking being done exactly as in the three-stranded rope.

The Chain Splice.—To make a chain splice, unlay the strands of the rope and reeve two of them through the end link; then unlay the third strand for about the distance shown, and in its place lay one of the other strands, the same as in making the long splice; make an overhand knot and dispose of the ends in the usual way; dispose of the third strand *x*—one of the two reeved through the link—as when making the eye splice, by "tucking" near the link; cut off the

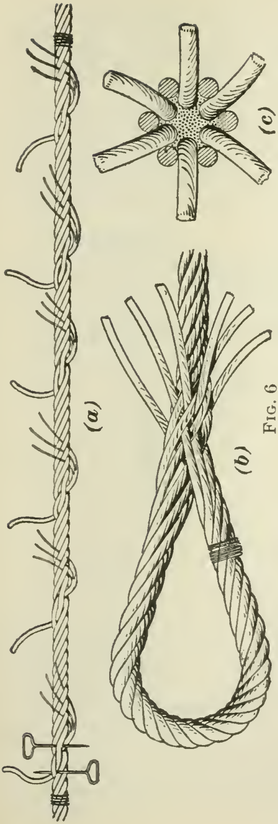


Fig. 6

ends, and the splice is complete as shown at Fig. 5 (*b*). This is a very neat and strong splice, and can be used with advantage in connection with chains that are *tailed*, or lengthened, with a rope that has to pass through sheaves or places that do not allow any increase of diameter in the rope.

Splicing in Wire.—In making a long splice in wire rope, the same principles are followed as in splicing fiber ropes. The strands are unlaid, interlaced, and each placed snugly in the groove made by unlaying the opposing strand whence the ends are tucked away in such manner as to follow the lay of the rope. Before unlaying the strands, it is advisable always to put on a good seizing at the extremities of the intended splice in order to prevent the rope from untwisting farther than is desired. The length of the splice depends, of course, on the size of the rope. When unlaying the strands, be sure to do so without taking the turn out. The strands may also be unlaid in pairs and singled up when married. The hemp heart is cut out close to where seizings are applied. Before tucking away the ends, each pair should be approximately at equal distances from one another, as shown in Fig. 6 (*a*). The beginning of an eye splice in wire is shown in Fig. 6 (*b*). When the size of the eye is fixed, put on a seizing as shown; then open up the standing part somewhat, at place where tucking is to be done, by giving the rope a certain amount of twist. This will render the tucking comparatively easy. When tucking, have 3 strands on top and 3 strands underneath the

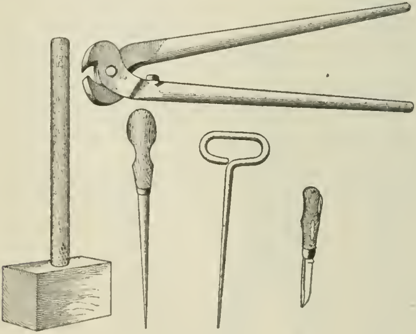


FIG. 7

standing part (assuming that the splicing is done horizontally), and dispose of them in such manner that each strand will come out in consecutive order, or as shown in Fig. 6 (*c*). It does not matter under how many strands (one or two) on the main rope they pass as long as they come out in their proper lay. The strands are now tucked once or twice, taking care not to make the tucks too short, in which case the splice will be a lumpy one. Then hammer the splice with a wooden mallet and trim off the ends snugly. The short splice is made in the same way as the eye splice.

Splicing in wire calls for special tools, such as are shown in Fig. 7, and a certain amount of skill, which can be acquired only by long practice, and proper training by a capable instructor.

BENDS AND HITCHES

In Figs. 1, 2, and 3 are shown a number of **bends** and **hitches** in common use on shipboard. The manner in which these bends are made is evident on inspection of the illustrations, and hence only a few explanatory remarks concerning the use to which some of them are put will be needed.

The **reef knot** is the best, simplest, and most used method of connecting the ends of two ropes, small-sized cordage; the **granny knot** is undesirable and unprofessional in every respect; it slips easily and is hard to untie. For the purpose of attaching two ropes of different size, the single or double **sheet bend** should be used. The **double carrick bend** is sometimes used for bending two hawsers together. The **bowline** is perhaps the most useful bend ever invented; it can be applied in various ways, from hoisting a man aloft to the bending together of two hawsers. To make it, take the end of the rope in the right hand and the standing part in the left and lay the end over the standing part; then with the standing part make a turn or loop around the end and pass the latter over and around the standing part and back through the bight again, thus completing the knot. The **figure-of-eight knot** turned in a rope will prevent it from unreeving. In Fig. 2 are shown a few methods of applying a rope to a hook. The **cross-hitch** is used for a sling or strap when the rope spreads away to its load; this hitch prevents the sling from slipping in the hook in case the load comes in contact with some obstruction while being hoisted. The **Blackwall hitch** should be made with the end twice around the hook as shown, except for very light loads; experience has proved this to be the safest way, since with only one turn the end is liable to "creep" when subjected to a heavy strain, especially in damp weather when the moisture absorbed by the rope serves as a lubricant. The **sheepshank** is useful for shortening up a rope. In this

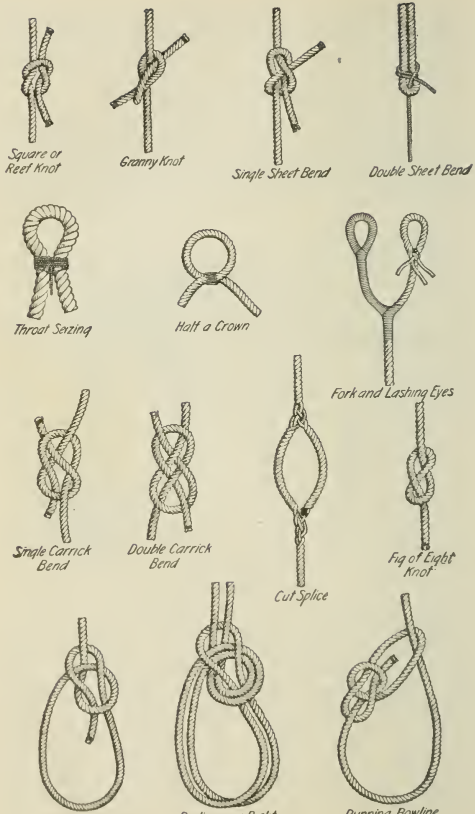

Square or Reef Knot
Granny Knot
Single Sheet Bend
Double Sheet Bend
Throat Seizing
Half a Crown
Fork and Lashing Eyes
Single Carrick Bend
Double Carrick Bend
Cut Splice
Fig of Eight Knot
Bowline
Bowline on a Bight
Running Bowline

FIG. 1

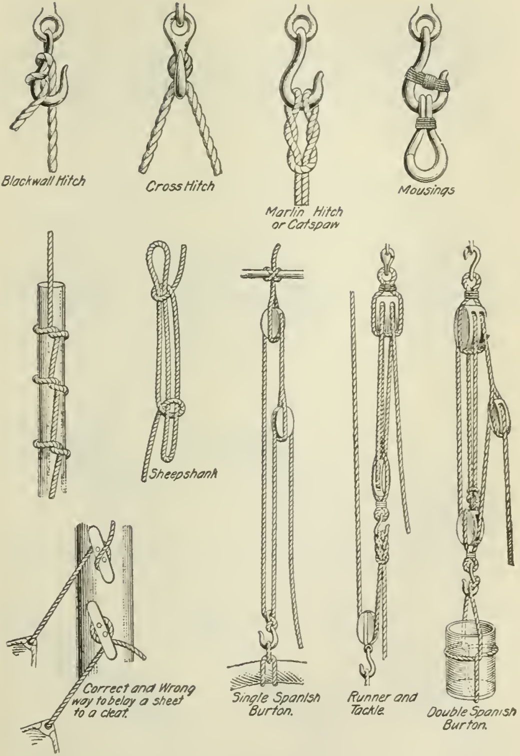

Blackwall Hitch
Cross Hitch
Marlin Hitch or Catspaw
Mousings
Sheepshank
Correct and Wrong way to belay a sheet to a cleat.
Single Spanish Burton.
Runner and Tackle.
Double Spanish Burton.

FIG. 2

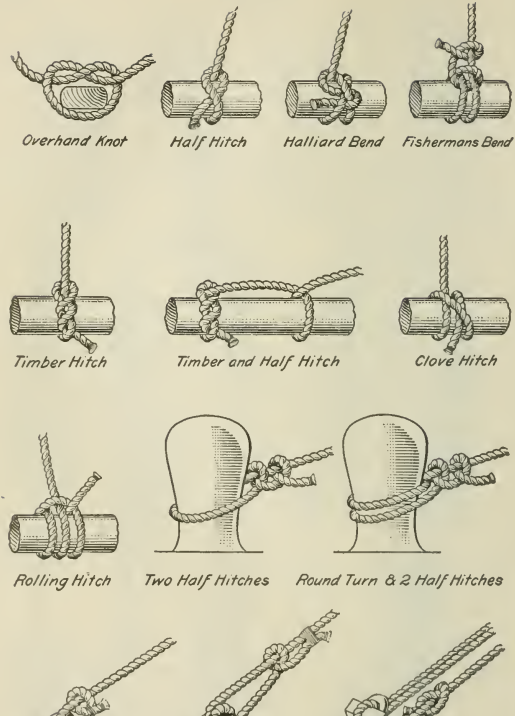

Overhand Knot
Half Hitch
Halliard Bend
Fishermans Bend
Timber Hitch
Timber and Half Hitch
Clove Hitch
Rolling Hitch
Two Half Hitches
Round Turn & 2 Half Hitches
Clinch
Round Turn & Half Hitch
Method of Doubling Up a Mooring

FIG. 3

figure is shown also the correct and incorrect way of fastening a rope—say the sheet of a sail—to a cleat; it is evident that if the sheet is belayed as shown on lower cleat, the increased strain on the sail will jam the rope and render it difficult, if not impossible, to ease off the sheet. The bends and hitches shown in Fig. 3, do not, we believe, require any explanation, and can be made by referring to the illustrations.

WIND AND WEATHER

Weather Indications by a Mercurial Barometer.—The use of the barometer as a weather glass is common both on sea and on land. But only those that have long watched and carefully compared its indications with the prevailing weather conditions are able to foretell more than that a rising barometer indicates less wind or rain; a falling barometer, more wind or rain, or both; a high barometer, fine weather; and a low one, the reverse. But useful as are these general conclusions in most cases, they are sometimes erroneous.

By attending to the following brief observations, any one not accustomed to the use of a barometer may do so with less hesitation and with immediate advantage.

The column of mercury in a good barometer usually stands, on an average, some tenths of an inch higher with or before polar and easterly winds than it does with or before equatorial and westerly winds (of equal strength and dryness or moisture) in all parts of the oceans. The terms polar and equatorial are here used with reference to winds blowing from the nearest polar direction, or from the equatorial parts of the earth.

This peculiarity of the barometer causes many mistakes to be made. The barometer is high, perhaps, but falling. Wind or rain, or both, are expected in consequence, yet neither follows to any decided extent. A change of wind from one quarter to another only takes place. Reversely, the barometer is low, but rising. Fine weather is expected; yet, instead of that, a strong wind, accompanied perhaps by rain, hail, or snow, rises from the polar direction. By such changes as these, seamen are often misled, and calamity, caused by unpreparedness, may sometimes occur as a consequence.

There may be heavy rains or violent winds beyond the horizon, and even within the view of an observer, by which his instruments may be affected considerably, though no particular change of weather occurs in his immediate locality. Sometimes, severe weather from an equatorial (southerly in north latitudes, northerly in the southern hemisphere) direction, not lasting long, may cause no great fall of the barometer, because followed by a period of wind from polar regions; and at times the mercurial column may fall considerably with polar winds and fine weather, apparently against the rule, because a continuance of equatorial winds is about to follow.

As a general rule, the barometer *rises* for northerly winds (included between the northwest and northeast), for dry or less wet weather, for less wind, or for more than one of these changes, except on a few occasions, when rain, hail, or snow, with a strong wind, comes from the north.

The barometer *falls* for southerly winds (included between the southeast and southwest), for wet weather, for stronger wind, or for more than one of these changes, except on a few occasions, when moderate wind, with rain or snow, comes from the northward.

There is little variation of the barometer between the tropics, because the wind blows generally in the same direction and with equal force, and no contending currents of air cause any considerable change in the temperature or density of the atmosphere. For violent storms or hurricanes, however, within the tropics, the barometer falls very low, but soon returns to its usual state after the storm center has passed.

It has been observed on some coasts that the barometer is differently affected by the wind, according as it blows from the sea or from the land, the mercury rising on the approach of the sea breeze and falling previously to the setting in of the land breeze.

Indications by Appearance of Sky.—Some young seamen hardly appreciate sufficiently common rules about weather, which are as true as they are trite; namely, that a red sky at sunset presages fine weather; a red sky in the morning bad weather or much wind, if not rain; a gray sky in the morning, fine weather; that soft-looking or delicate clouds foretell fine weather, with moderate or light breezes; hard-edged, oily-looking clouds, wind; that a dark, gloomy blue sky is windy, but a light, bright blue sky indicates fine weather; that, generally, the softer the clouds look the less wind, although rain may be expected; and the harder, more "greasy," rolled, tufted, or ragged, the stronger the wind will prove. Also, that a bright yellow sky at sunset presages wind; a pale yellow, wet; and that, by the preponderance of red, yellow, or gray tints the coming weather may be foretold very nearly—indeed, if aided by instruments, almost accurately.

These indications of weather, afforded by the colors of the sky, seem to deserve more critical study than has yet been given to the subject.

Indications by the Aneroid Barometer.—A rapid rise indicates unsettled weather.

A gradual rise indicates settled weather.

A rise, with dry air and cold increasing, in summer, indicates wind from the northward in north latitudes, but from the southward in south latitudes; and if rain has fallen, better weather may be expected.

A rise, with moist air and a low temperature, indicates wind and rain from the northward in north latitudes, but from the southward in south latitudes.

A rise, with southerly winds, indicates fine weather in north latitudes, the conditions being reversed in south latitudes.

A steady barometer, with dry and seasonable temperature, indicates a continuance of very fine weather.

A rapid fall indicates stormy weather.

A rapid fall, with westerly winds, indicates stormy weather from the northward.

A fall, with a northerly wind, indicates stormy weather, with rain in summer and snow in winter.

A fall, with increased moisture in the air and the temperature rising, indicates wind and rain from the southward.

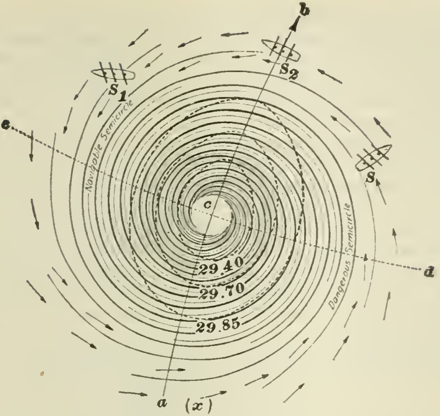
A fall, with dry air and cold increasing, in winter, indicates snow.

A fall, after very calm and warm weather, indicates rain with squally weather.

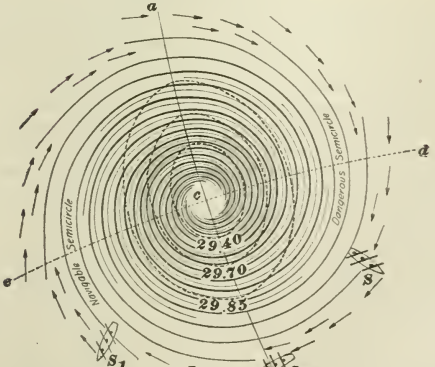
All indications pertaining to the fall of the aneroid apply to northern latitudes; in southern latitudes, wind directions are reversed.

HURRICANES

Cyclones, or **hurricanes,** have a rotary motion around a center, or focus, and a progressive, or forward, motion. The peculiarity of the rotary motion is that in each hemisphere it invariably occurs in different directions. Thus, in the northern hemisphere, the rotation is contrary to the motion of the hands of a watch, that is, from right to left; in the southern hemisphere, the rotation is with the hands of a watch, that is, from left to right. From the rotary motion of cyclones, it is evident that the wind in the front and rear of the storm must be in a direction perpendicular to the line of progression *a b*, as shown in (*x*) of the appended diagram, or nearly so; in other words, if the cyclone is moving in a north north-easterly direction, the wind in its front should be about east southeast and in its rear about west northwest. From this, an important conclusion may be drawn, namely, that if we assume the area of the cyclone to be divided into two equal parts by the line of progression *a b*, and that another line *e d* is drawn through the center *c* perpendicular to *a b*, the front quadrant *b c d*, in which the wind blows toward the line of progression, or track of center, is the most dangerous part of the cyclone, with the exception of the center itself. The rear quadrant *a c d* may also be considered as dangerous, because the direction of the wind will tend to carry the vessel that may happen to be there into the front quadrant and thence into the path of the center. These two quadrants, or the semicircle *a d b*, are therefore known as the **dangerous semicircle,** and the other


b
S2
S1
e
Navigable Semicircle
S
c
Dangerous Semicircle
29.40
d
29.70
29.85
a

(x)


a
Dangerous Semicircle
d
c
Semicircle
29.40
Navigable
e
29.70
S
29.85
S1
S2
b

(y)

half $a\ e\ b$ as the **navigable semicircle,** since the wind in the latter will blow away from in front of the storm center.

These semicircles change sides when the hemisphere is changed, the dangerous semicircle always being to the right of the line of progression in northern latitudes and to the left in southern latitudes.

From the foregoing conclusions, rules have been drawn up for the use of navigators to enable them to determine on which tack a ship should be laid-to when confronted with a storm of cyclonic character, the object of these rules being to prevent the wind veering by the ship's head and to insure its veering or shifting constantly farther aft so that she may be constantly "coming up" to the wind, whereas in the former case she would be "breaking off" from the wind, and, even with sails set, would, in so violent a gale, be in danger of gathering sternboard.

SUGGESTIONS FOR THE HANDLING OF SHIPS IN OR NEAR CYCLONES

As to the handling of ships in or near a cyclone, one should bear in mind that the safety of his vessel will depend to a great extent on his good judgment as well as on his knowledge of the nature and peculiarities of revolving storms. All positive rules are, of course, more or less defective, and if blindly carried out may prove very dangerous; they are, nevertheless, of great value when judiciously used in combination with a good judgment of prevailing circumstances.

The first thing for a navigator to do when he has good reason to believe that a hurricane is approaching is to find the bearing of its center, and then to shape his course so as to avoid it.

The early indications of an approaching hurricane are as follows: Barometer above the normal, with cool, very clear, pleasant weather; a long, low ocean swell from the direction of the distant storm; light, feathery, cirrus clouds, radiating from a point on the horizon where a whitish arc indicates the bearing of the center. Later indications are a falling barometer; halos about the sun and moon; increasing ocean swell; hot, moist weather with light, variable winds; deep-red and violet tints at dawn and sunset; a heavy mountainou cloud bank on the distant horizon; barometer falling rapidly, with passing rain squalls. The most timely and trusty indication of a cyclone is often the rise of the thermometer in connection with a reversal of the normal wind. Thus, in the regions of the trade winds, a brisk westerly wind suddenly springing up should at once arouse suspicion, particularly in the hurricane season. Equally suspicious is a strong easterly wind suddenly succeeding the normal westerly winds prevailing between 40° and 45° N on the routes between the United States and Europe. Scarcely anything, except an approaching area of low atmospheric pressure, can be supposed to cause the sudden change of the East Indian monsoon in August and September. A cautious navigator, therefore, may, by attending to the abnormal and sudden change of wind direction, foresee that he is in front of a revolving gale, though his barometer remains high, the sea smooth, and none of the usual signs of hurricanes can be distinguished overhead.

To Find the Bearing of the Center.—Being convinced that the approaching storm is of a cyclonic character, the bearing of its center is determined. This is done by facing the wind, in which position the center may be assumed to bear 10 or 11 points to the observer's right in northern latitudes and 10 or 11 points to the left in southern latitudes. If, however, the ship is well within the storm area, and the barometer is falling steadily, the bearing of the center may be less than 10 points; and if the barometer has fallen as much as ½ in., the bearing may be considered as 8 points.

To Determine Position of Ship in Relation to Storm Track. Having the approximate bearing of the storm center, the next thing to do is to find the position of the ship in relation to the track, or line of progression, of the storm. This can be determined by observing the shifting, or veering, of the wind. In the northern hemisphere, if the wind shifts to the right, the ship is to the right of the track, as at S, in diagram (x) of the preceding illustration, or in the dangerous semicircle; if it shifts to the left, the ship is to the left of the track, as at S_1, or in the navigable semicircle.

These conditions are reversed in the southern hemisphere. There, if the wind shifts to the right, the ship is to the right of the track, as at S_1, (y), or in the navigable semicircle; while, if the wind shifts to the left, the ship is at S (y), or in the dangerous semicircle (in both cases the observer is assumed to be looking in the direction *toward which the storm is advancing*). But if the wind is "steady," shifting but very slightly and increasing in velocity, it indicates that the ship, whether in the north or south hemisphere, is on the track and in front of the center, as at S_2, (x) and (y).

To Find Whether Center Is Approaching or Receding. When a ship is well within the area of a hurricane the approach of the center is indicated by a rapidly falling barometer, increase of wind, heavy squalls, intense lightning and rain, heavy and confused sea, continued shifting of the wind, except when on the track of the center.

The receding of the center is usually indicated by a rising barometer, more steady wind decreasing in velocity, weather clearing, but sea very confused and dangerous.

Brief Rules for Action to Avoid Center.—Having determined the bearing of the storm center and the position of the ship in reference to the progressive motion of the storm, the following rules for avoiding the storm center should be adhered to as far as circumstances will permit:

Northern Hemisphere.—If on the track of the storm center and in front of the advancing storm, run or steam before the wind; keep a steady course until the wind shifts well on starboard quarter. Then, if obliged to lie-to, do so on the port tack.

If in the dangerous semicircle, steam or run off with the wind on starboard quarter; if obliged to lie-to, do so on the starboard tack.

If in the navigable semicircle, steam or run off with the wind on starboard quarter; if obliged to lie-to, do so on the port tack.

Southern Hemisphere.—If directly in front of the advancing storm center, run or steam before the wind; keep a steady course until the wind gradually shifts around to the port quarter. Then, if obliged to lie-to, do so on the starboard tack.

If in the dangerous semicircle, steam or run off with the wind on the port quarter; if obliged to lie-to, do so on the port tack.

If in the navigable semicircle, steam or run off with the wind on the port quarter; if obliged to lie-to, do so on the starboard tack.

Vessels, especially steamships, sometimes overtake hurricanes because their speed is greater than the progression of the storm center. In such cases, it is obvious that the ship's course should be altered so as not to approach the center.

The Storm Center.—The foregoing rules apply to cases when hurricanes are encountered in open sea. If, however, the vessel is unable, from want of sea room, to perform the necessary maneuvers, her position becomes one of great danger. Every precaution should then be taken to prepare for the passage of the storm center over the ship. In entering the center, which may be several miles in diameter, the wind suddenly ceases and glimpses of clear sky can be seen, now and then interrupted by puffy squalls. The sea is enormous and very dangerous, apparently coming from all directions of the compass. After the center has passed over, the ship is again struck by a gale of renewed energy and hurricane force, but from the opposite direction. This constitutes one of the most critical dangers known to seamen. Apparently, the best thing to do when caught in the center of a hurricane is to try to get the vessel in such a position as to best meet the opposite wind, which may be expected to burst forth very quickly and violently, and thereby prevent the ship gathering sternboard, or drifting backwards in a helpless position with enormous seas breaking over her. Only strongly built vessels are able to withstand the heavy strain they are subjected to under such circumstances, and many ships whose names now figure on the list of "missing" in all probability met their fate in the center of a revolving storm.

The **typhoon** of the Western Pacific Ocean is, in many respects, the counterpart of the West Indian hurricane of the Atlantic. Both classes of storms have their origin in the vicinity of tropical groups of islands, and under similar barometric conditions; both undergo the same slow development and exhibit a similar tendency to recurve on reaching the higher latitudes.

The first barometric indication of the approach of a typhoon is the disturbance of the daily fluctuations of the mercurial column. In the low latitudes where typhoons originate, a good mercurial barometer during settled weather should show a decided maximum about 10 A. M., the reading at that hour standing between 29.85 and 29.95 in. (758.2 to 760.7 millimeters), while about 4 P. M. there should be a corresponding minimum, the reading at that hour being about $\frac{1}{10}$ in. (2.5 millimeters) less than at 10 A. M. The same thing is repeated at 10 P. M. and at 4 A. M. If the forenoon maximum is appreciably below 29.85 in., or if the descent between this and the afternoon minimum is markedly greater than $\frac{1}{10}$ in., the weather should be watched with great care. Several successive days of light, variable winds and calms; a period of hot, sultry weather; increasing moisture of the atmosphere; increasing amount of cloud and an ominous heaving of the sea, are all conditions forerunning the occurrence of the typhoon.

The average tracks of the various classes of typhoons, together with the frequency and the season of appearance of each class, are to be found on Pilot Charts of the Pacific Ocean. For a more complete account of typhoons, consult the North Pacific Pilot Chart for July, 1898.

Remarks.—It must be borne in mind that although the region and season of the year would render the navigator very cautious, yet every strong wind or gale met with, particularly in the tropical regions, must not be treated as a cyclone. When there is reason to suspect the advance of a cyclonic storm, the safest proceeding is to lie-to and carefully watch the barometer, weather indications, and shiftings of the wind. A decided drop of the atmospheric pressure of at least $\frac{1}{2}$ in., together with marked shiftings of the wind, should be experienced before the storm can be regarded as cyclonic.

Meteorological Observations at Sea.—The United States Hydrographic Office is conducting an extensive system of ocean meteorological observations. It seeks the cooperation of all navigators, requesting them to take one observation every day at a prescribed moment, which is simultaneous for every part of the globe. These simultaneous observations are charted and published by the Hydrographic Office at Washington on its Monthly Pilot Charts and Hydrographic Bulletins. By entering into this arrangement and taking part in the observational work, every seaman may contribute materially to this scientific enterprise and further the elucidation of the law of storms, as well as secure for his own use a large supply of valuable meteorological information.

When about to sail, the master or navigating officer of a vessel should call at the local branch hydrographic office and request the officer in charge to furnish him with the latest information in the shape of Lists of Lights, Lists of Beacons, Buoys, and Daymarks, Notices to Mariners, Hydrographic Bulletins, and Pilot Charts. All these publications are furnished free to masters who can satisfactorily show that they are voluntary weather observers for the United States Hydrographic Office, or that they are willing to become such. He should also request a supply of blank weather reports and envelopes sufficient to last until his return to a United States port; also of cards for barometer comparisons, with instructions as to the manner of making these comparisons, which are given in Hydrographic Office publication No. 119. The comparison cards should be filled out while the vessel is lying in port and should be mailed before sailing. They require (if mailed in a United States port) neither envelope nor postage.

For the convenience of those masters who rarely visit an American port, a limited supply of blanks, pilot charts, etc. is maintained at the U. S. consulate in each of the more important shipping centers abroad. A list of those consulates at which this is the case is published on the monthly pilot charts.

Having arrived at his destination, the forms containing the observations recorded during the voyage should be enclosed in one or more of the envelopes furnished for that purpose.

If in a foreign port, this envelope should be addressed to the United States Hydrographic Office, Navy Department, Washington, D. C., and handed to the United States consul, who is under instructions from the Secretary of State to forward it with his official mail, free of all expense. If mailed at any port outside of the United States, postage must be prepaid at letter rates.

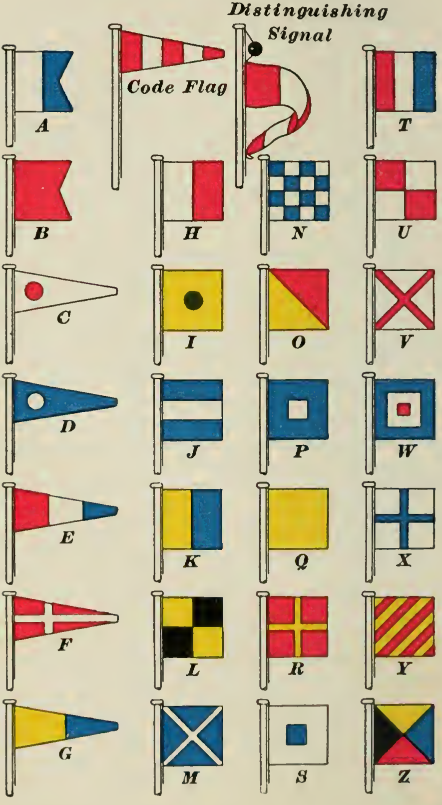
In any United States port, the package should be addressed to the nearest branch hydrographic office and mailed. The franked envelope does not require any postage when mailed within the United States, Hawaii, the Philippine Islands, or Porto Rico.

The forms should be returned promptly at the close of each voyage, or even at the first port of call. They should not be held until the return of the vessel to the United States.

On the receipt of the completed forms, either at the United States Hydrographic Office or at any of its branches, a letter of acknowledgment is at once addressed to the master of the vessel, thanking him and the officer charged with the duty of taking the observations for their services, and replying to any inquiry or request that the master or the observer may have made on the pages alloted to that purpose. These letters of acknowledgment should in all cases be preserved, as they may prove of value in identifying the bearer as an observer at the several branch hydrographic offices, and as such entitled to the various official publications.

The list of Atlantic and Pacific coast ports at which branch hydrographic offices are established is at present (March, 1904) as follows: Boston, custom house; New York, Maritime Exchange; Philadelphia, Bourse Building; Baltimore, custom house; Norfolk, custom house; Savannah, custom house; New Orleans, custom house; Galveston, Levy Building; San Francisco, Merchants' Exchange; Portland, Ore., custom house; Port Townsend, custom house.

CODE FLAGS AND PENNANTS
INTERNATIONAL CODE OF SIGNALS



SIGNALS

INTERNATIONAL CODE OF SIGNALS

The new **International Code of Signals,** shown in the attached figure, and which came into use on January 1, 1901, consists of 26 flags; viz., 2 burgees, 5 pennants, and 19 square flags, besides the code flag, which is used also as the answering pennant. Its object is to supply means of intercourse between ships meeting at sea, as well as between ships and established signal stations on land. It has been adopted by all the important maritime powers of the world, and the interpretation of the several thousand different signals composing the system are translated into the language of each nation. All ships, therefore, when meeting at sea are enabled to communicate with one another, no matter if one is an American and the other a Greek, or whether the commander of one vessel is able to master the language of the other in a verbal conversation.

Arrangement of Code Book.—The new Code Book published by the Bureau of Equipment, U. S. Navy Department, is divided into three parts, as follows:

Part I contains instructions on how to make and how to answer a signal, accompanied by suitable examples; then comes an alphabetical spelling table, numeral signals, urgent and important signals, compass signals, signals appertaining to money and all kinds of measurements, signals relating to latitude, longitude, time, barometer, thermometer, phrase signals formed with auxiliary verbs, and geographical signals. Of these signals, only those coming under the heading of "urgent and important" are made with 2 flags in a hoist; all others are made with 3 flags, with the exception of geographical signals, which are made with 4 flags in a hoist.

Part II contains an index of general vocabulary signals, and a second list of geographical signals, in which the names, of places are alphabetically arranged. The vocabulary signals are with few exceptions 3-flag signals.

Part III contains a list of storm-warning, display, life-saving, and time-signal stations of the United States; also Lloyd's signal stations of the world, and American, English, and French semaphore, distance, and wigwag codes.

Since each of the 26 letters of the alphabet is represented by a flag, it is evident that any word can be spelled by this system, and if the word to be spelled consists of more than 4 letters, two or more hoists must be used, as no hoist is to contain more than 4 flags. Explanations and instructions on this subject are to be found on pages 13 and 14 of the code book.

CHARACTER OF SIGNALS AS INDICATED BY THE NUMBER OF FLAGS IN A HOIST

One-Flag Signal.—The meaning of flags and pennants hoisted singly and with the code flag is found on pages 7 and 35 of the code book.

Two-Flag Signals.—Signals composed of 2 flags are urgent or important signals; they run from *A B* to *Z Y*.

Three-Flag Signals.—Signals composed of 3 flags are either compass, measurement, auxiliary phrases, or general vocabulary signals. Compass signals run from *A B C* to *A S T*; signals relating to money, from *A S U* to *A V J*; and those relating to weight and measures, from *A V K* to *B C N*. Three-flag signals having the code flag uppermost relate to latitude, longitude, time, barometer, or to the thermometer.

Four-Flag Signals.—Signals composed of 4 flags are either geographical or alphabetical signals. All geographical signals begin with the letter *A* or *B* and run from *A B C D* to *B F A U*. Alphabetical signals commence with the letter *C*.

SELECTED SIGNALS

The following is a selection of signals for the use of vessels meeting at sea, or vessels in sight of signal stations. By committing these signals to memory, much delay in searching for them in the code book is obviated.

Signals *Meaning*

E C—What ship is that?

S I—Where are you from?

S H—Where are you bound?

S G—When did you sail?

U B—Do you wish to be reported?

U D—Report me, by telegraph, to Lloyd's.

U R Z—Report me all well.

U E—Report me, by telegraph, to owners.

U F—Report me, by telegraph, to "Shipping Gazette."

U G—Report me to Lloyd's (either by post or telegraph).

U I—Report me to "New York Herald" office, London.

U J—Report me to "New York Herald" office, New York.

V J—I wish to signal; will you come within easy signal distance?

V M—Cannot distinguish your flags; come nearer, or, make distant signals.

V I—Repeat your signal.

S W—I wish to obtain orders from my owner—(name).

T D—There are no orders for you here.

T E—Wait for orders.

Q U—Will you forward my letters?

Q R—Send your letters.

Y E—Want assistance.

Y L—Want immediate medical assistance.

N C—In distress; want immediate assistance.

D C—We are coming to your assistance.

C X—No assistance can be rendered; do the best you can for yourselves.

F H—Send a boat.

E U—Boat is going to you.

E X—Cannot send boat.

B O—Have lost all my boats.

Code flag over *H*—Come nearer. Stop, or heave to. I have something important to communicate.

I F—Cannot stop to have any communications.

R Z—Where am I? What is my present position?

Q I B—What is your latitude brought up to the present moment?

Q Z K—What is your longitude brought up to the present moment?

Q H W—My latitude is . . .

Q Z F—My longitude by chronometer is . . .

XN—Will you show me your Greenwich time?

G U—Will you give me a comparison? Wish to get a rate for my chronometer.

I Q H—I have no chronometer.

G Q—My chronometer has run down.

M R—Have broken main shaft.

M W—One screw disabled; can work the other.

M Q—Engines completely disabled.

M X—Passed disabled steamer at . . .

H M—Vessel seriously damaged; wish to transfer passengers.

G Y—Can you spare me coal?

H C—Indicate nearest place I can get coal.

B I—Damaged rudder, cannot steer.

J D—You are standing into danger.

S A—Are there any men of war about?

X O—Beware of torpedo boats.

X P—Beware of torpedoes; channel (or fairway) is mined.

Y P—Want a tug (if more than one, number to follow).

Y O—Want provisions immediately.

Y R—Want water immediately.

C, or code flag over *C*—Yes, or affirmative.

D, or code flag over *D*—No, or negative.

DISTANT SIGNALS

Distant Signals are used when, in consequence of distance or the state of the atmosphere, it is impossible to distinguish the colors of the flags of the International Code, and, therefore, to read a signal made by those flags; they also provide an alternative system of making the signals in the Code, which can be adopted when the system of flags cannot be employed. Three methods of making distant signals are used: (1) by cones, balls, and drums; (2) by balls, square flags, pennants, and wafts; (3) by the fixed coast semaphore.

In calms, or when the wind is blowing toward or from the observer, it is often difficult to distinguish with certainty between a square flag, pennant, and waft, and as flags when hanging up and down may hide one of the balls and so prevent the signal being understood, the system of cones, balls, and drums is preferable to that of flags, pennants, and wafts.

The following special distant signals are made by a single hoist followed by the "Stop" signal. They are arranged numerically for reading off the signal.

SPECIAL DISTANT SIGNALS


2—"Preparative," "answering," or "stop," after each complete signal.


1, 2—Aground; want immediate assistance.


2, 1—Fire or Leak; want immediate assistance.


2, 2—Annul the whole signal.


2, 3—You are running into danger, or, Your course is dangerous.


2, 4—Want water immediately.


3, 2 —Short of provisions; starving.


4, 2—Annul the last hoist; I will repeat it.


1, 1, 2—I am on fire.


1, 2, 1—I am aground


1, 2, 2—Yes, or affirmative.


1, 2, 3,—No, or negative.


1, 2, 4—Send lifeboat.


1, 3, 2—Do not abandon the vessel.


1, 4, 2—Do not abandon the vessel until the tide has ebbed.


2, 1, 1—Assistance is coming.


2, 1, 2—Landing is impossible.


2, 1, 3—Bar or entrance is dangerous.


2, 1, 4—Ship disabled; will you assist me into port?


2, 2, 1—Want a pilot.


2, 2, 3—Want a tug; can I obtain one?


2, 2, 4—Want the name of ship (or signal station) in sight, or, Show your distinguishing signal.


2, 3, 1—Show your ensign.


2, 3, 2—Have you any dispatches (messages, orders, or telegrams) for me?


2, 3, 3—Stop, bring-to, or, Come nearer; I have something important to communicate.


2, 3, 4—Repeat signal or hoist it in a more conspicuous position.


2, 4, 1—Cannot distinguish your flags; come nearer or make distant signals.


2, 4, 2—Weigh, cut, or slip; Wait for nothing; Get an offing.


2, 4, 3—Cyclone, hurricane, or typhoon expected.


3, 1, 2—Is war declared, or, Has war commenced?


3, 2, 1—War is declared, or, War has commenced.


3, 2, 2—Beware of torpedoes; channel is mined.

3, 2, 3—Beware of torpedo boats.

3, 2, 4—Enemy is in sight.

3, 3, 2—Enemy is closing with you, or, You are closing with the enemy.

3, 4, 2—Keep a good lookout, as it is reported that enemy's men of war are going about disguised as merchant ships.

4, 1, 2—Proceed on your voyage.

The following distant signals, made with flag and ball, or pennant and ball, have the special signification, indicated beneath them. Jupiter, Fla. [See following page].

You are running into danger.

Short of provisions—starving.

Fire, or leak; want immediate assistance.

Aground; want immediate assistance.

LIST OF WEATHER BUREAU STATIONS ON THE UNITED STATES SEACOAST TELEGRAPHIC LINES

Atlantic Coast.—Nantucket, Mass.; Narragansett Pier, R. I.; Block Island, R. I.; Norfolk, Va,; Cape Henry, Va.; Currituck Inlet, N. C.; Kitty Hawk, N. C.; Hatteras, N. C.; Sand Key, Fla;

Pacific Coast.—Tatoosh Island, Wash.; Neah Bay, Wash.; East Clallam, Wash.; Twin Rivers, Wash.; Port Crescent, Wash.; North Head, Wash.; Point Reyes Light, Cal.; San Francisco, Cal.; Southeast Farallone, Cal.; Jupiter, Fla.

Lake Huron.—Thunder Bay Island, Mich.; Middle Island, Mich.; Alpena, Mich.

Of these stations, the following are equipped with International Code signals, and communication can be had therewith for the purpose of obtaining information concerning the approach of storms, weather conditions in general, and for the purpose of sending telegrams to points on commercial lines:

Nantucket, Mass.; Block Island, R. I.; Cape Henry, Va.; Hatteras, N. C.; Kitty Hawk, N. C.; Sand Key, Fla.; Jupiter, Fla.; Tatoosh Island, Wash.; Neah Bay, Wash.; Point Reyes Light, Cal.; Southeast Farallone, Cal.

Any message signaled by the International Code, as adopted or used by England, France, America, Denmark, Holland, Sweden, Norway, Russia, Greece, Italy, Germany, Austria, Spain, Portugal, and Brazil, received at these telegraphic signal stations, will be transmitted and delivered to the address on payment at the receiving station of the telegraphic charge. All messages received from or addressed to the War, Navy, Treasury, State, Interior, or other official department at Washington, are telegraphed without charge over the Weather Bureau lines.

DISTRESS SIGNALS

When a vessel is in distress, and requires assistance from other vessels or from the shore, the following are the signals to be used by her, either together or separately:

Daytime.—1. A gun or other explosive signal fired at intervals of about a minute.

2. The International Code signal of distress indicated by *N C*.

3. The distant signal, consisting of a square flag, having either above or below it a ball or anything resembling a ball.

4. The distant signal, consisting of a cone pointing upwards, having either above or below it a ball or anything resembling a ball.

5. A continuous sounding with any fog-signal apparatus.

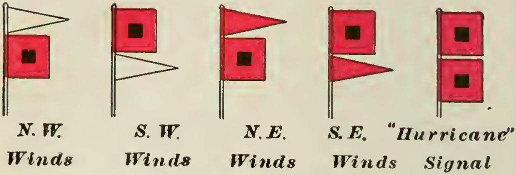
At Night.—1. A gun or other explosive signal fired at intervals of about a minute.

2. Flames on the vessel (as from a burning tar barrel oil barrel, etc.).

3. Rockets or shells, throwing stars of any color or description, fired one at a time at short intervals.

4. A continuous sounding with any fog-signal apparatus.

U. S. STORM SIGNALS



Flags 8 feet square. Pennants 5 feet hoist, 12 feet fly.

U. S. WEATHER-BUREAU SIGNALS

When number 4 is placed above number 1, 2, or 3 it indicates warmer; when below, colder; when not displayed, the temperature is expected to remain about stationary. Number 5 is used also to indicate anticipated frosts.

Not Under Control.—A vessel temporarily disabled at sea, through the breaking down of her engines, etc., but not requiring assistance, should, in daytime, hoist two black balls, or shapes resembling balls, one above the other, and at night two red lights in a similar position. Such signal means "I am not under control," and should be kept hoisted until repairs are effected or until the vessel is in a position to proceed on her voyage.

U. S. STORM SIGNALS

Storm Warning Flags. — A red flag with a black center indicates that a storm of marked violence is expected. The pennants displayed with the flags indicate the direction of the wind: red, easterly (from northeast to south); white, westerly (from southwest to north). The pennant above the flag indicates that the wind is expected to blow from the northerly quadrants; below, from southerly quadrants. By night, a red light indicates easterly winds, and a white light above a red light, westerly winds.

Hurricane Warning.—Two red flags, with black centers, displayed one above the other, indicate the expected approach of tropical hurricanes, and also of those extremely severe and dangerous storms that occasionally move across the lakes and northern Atlantic coast. Hurricane warnings are not displayed at night.

Storm signals are displayed by the United States Weather Bureau at 141 stations situated along the Atlantic and Gulf coasts, and at 27 stations situated on the Pacific coast of the United States.

SIGNALS FOR PILOT

The following signals, when used or displayed together or separately, shall be deemed to be signals for a pilot:

Daytime.—1. The Jack, or other national ensign, usually worn by merchant ships, having around it a white border one-fifth the breadth of the flag, to be hoisted at the foretop.

2. The International Code pilot signal indicated by *P T.*

3. The International Code flag *S*, with or without the code pennant over it.

4. The distant signal consisting of a cone, point upwards, having above it two balls, or shapes resembling balls.

At Night.—1. The pyrotechnic light, commonly known as a "blue light," every 15 min.

2. A bright white light, flashed or shown at short or frequent intervals, just above the bulwarks, for about a minute at a time.

LIFE-SAVING SIGNALS

The following signals, recommended by the recent International Marine Conference for adoption by all institutions for saving life from wrecked vessels, have been adopted by the Life-Saving Service of the United States:

1. Upon the discovery of a wreck by night, the life-saving force will burn a *red* pyrotechnic light, or a *red* rocket, to signify: "You are seen; assistance will be given as soon as possible."

2. A *red* flag waved on shore by day, or a *red* light, *red* rocket, or *red* Roman candle displayed at night, will signify: "Haul away."

3. A *white* flag waved on shore by day, or a *white* light slowly swung back and forth, or a *white* rocket or *white* Roman candle fired by night, will signify: "Slack away."

4. Two flags, a *white* and a *red*, waved at the same time on shore by day, or two lights, a *white* and a *red*, slowly swung at the same time, or a *blue* pyrotechnic light burned by night, will signify: "Do not attempt to land in your own boats; it is impossible."

5. A man on shore beckoning by day, or two torches burning near together by night, will signify: "This is the best place to land."

Any of these signals may be answered from the vessel as follows: In the daytime, by waving a flag, a handkerchief, a hat, or even the hand; at night, by firing a rocket, a blue light, or a gun, or by showing a light over the ship's gunwale for a short time and then concealing it.

NOTE.—It is important that all signals from shore are answered by the ship at once, particularly so at night. If signals are not answered within a reasonable time, the life-saving crew on the beach might infer that the crew of the stranded vessel have perished, and as a consequence they may abandon their efforts at rescue.

USE OIL IN HEAVY SEA

Running before a gale, use oil from bags at the catheads, or from forward waste pipes; if yawing badly and threatening to broach-to, use oil forwards and abaft the beam, on both sides. Lying-to, distribute oil from the weather bow. With a high beam sea, use oil bags at regular intervals along the weather side. In a heavy cross sea, have bags along both sides. Steaming into a heavy head sea, use oil through forward closet pipes. There are many other cases where oil may be used to advantage, such as lowering and hoisting boats, riding to a sea anchor, crossing rollers or surf on a bar, and from life boats and stranded vessels. Thick and heavy oils are the best. Mineral oils are not so effective as animal or vegetable oil. Raw petroleum has given favorable results, but is not so good when refined. Certain oils, like cocoanut oil and some kinds of fish oil, congeal in cold weather, and are therefore useless, but may be mixed with mineral oils to advantage. As a general rule, probably the best way to use oil is by filling the closet bowls forward with oakum and oil, letting the oil drip out slowly through the waste pipes. Another simple and easy way to distribute oil is by means of-canvas bags about a foot long, filled with oakum and oil, pierced with holes by means of a coarse sail needle, and held by a lanyard.

NAUTICAL MEMORANDA

Progress of steam navigation from its inception to the launching of the "Great Eastern" in 1858:

1707 Denis Papin experimented on River Fulda with paddle-wheel steamboat.

1736 Jonathan Hulls patented designs similar to modern paddle boat.

1769 James Watt invented a double-acting side-lever engine.

1775 Perier, in France, made experiments with steam as motive power for vessels.

1785 James Ramsey, in America, propelled a boat with steam through a stern pipe.

1786 John Fitch, in America, propelled a boat with canoe paddles fixed to a moving beam.

1787 Robert Miller, of Edinburgh, experimented similarly.

1788 Miller and Symington produced a double-hull stern-wheel steamboat.

1802 "Charlotte Dundas," the first practical steam tug, designed by Symington.

1804 "Phœnix," screw boat designed by Stephens, in New York; first steamer to make a sea voyage.

1807 "Clermont," first passenger steamer continuously employed; designed and built by Robert Fulton; machinery built by Boulton and Watt; made regular trips between New York and Albany; speed about 5 kn.

1811 "The Comet," first successful passenger steamer in Europe; built by Henry Bell and made trips between Glasgow and Greenock.

1816 "Witch," first steamboat built in Sweden; constructed by S. Owen; had an 8-H. P. engine and a four-bladed propeller.

1818 "Rob Roy," first merchant steamer in the world, built at Glasgow.

1819 "Savannah," first auxiliary steamer to cross the Atlantic; fitted with paddle wheels; made the trip from Savannah to Liverpool in 22 da.

1821 "Aaron Manby," first steamer—English canal boat—built of iron.
1823 City of Dublin Steam Packet Co. was established.
1824 General Steam Navigation Co. was established at London.
1825 "Enterprise" made the first steam passage to India.
1825 "William Fawcett," pioneer steamer of the P. & O. S. N. Co.
1830 T. & J. Harrison (Harrison Line) established at Liverpool.
1832 "Elburkah," iron steamer, took a private exploring party up the river Niger.
1834 Establishment of Lloyd's Register for British and foreign shipping.
1836 Establishment, at Trieste, of the Austrian Lloyd Steam Navigation Co.
1837 "Francis B. Ogden," first successful screw tug; equipped with Ericsson's propeller.
1838 "Archimedes" made the Dover-Calais passage in less than 2 hr.; fitted with Smith's propeller.
1838 "R. F. Stockton," built for a tug and fitted with Ericsson's propeller; sailed to America; first iron vessel to cross the Atlantic; first screw steamer used in America.
1839 "Thames," pioneer steamer of the Royal Mail Steam Packet Co.
1840 "Britannia," pioneer steamer of the Cunard Line.
1840 "Chile," pioneer steamer of the Pacific Steam Navigation Co.
1845 "Great Britain," first iron screw steamer, precursor of modern transatlantic steamer.
1845 Wilson Line, Thos. Wilson, Sons & Co., Ltd., established at Hull.
1847 Pacific Mail Steamship Co. established in America.
1850 Natal Line established at London.
1850 Messageries Maritimes de France established.
1850 Inman (now American) Line established at Liverpool.
1851 "Tiber," first steamer of the Bibby Line, established in 1821, at Liverpool.

1852 "Forerunner," pioneer steamer of the African Steamship Co.

1853 Union Steamship Co., now Union Castle Line, established.

1853 "Borussia," first steamer of the Hamburg-American Packet Co., established in 1847.

UNITED STATES NAVY

(*From Report of the Office of Naval Intelligence, United States Navy Department, 1905*)

Type of Vessel	Built	Tons	Building	Tons
Battle ships, first class.	12	137,329	13	192,700
Other battle ships and coast defense ironclads..............	12	47,945		
Armored cruisers.....	2	17,415	8	111,800
Protected cruisers, first class (above 6,000 tons)..............	2	14,750	3	28,800
Protected cruisers, second class (3,000 to 6,000 tons).........	15	56,393	4	12,400
Other cruisers and scouts (above 1,000 tons)..............	23	32,773	2	2,170
Totals............	66	306,605	30	347,870

Combined totals. . . .96 vessels of 654,475 tons

Note.—Gunboats and other vessels of less than 1,000 T. are not given in the table, nor are transports, dispatch vessels, converted merchant vessels or yachts, or obsolete cruisers. Vessels not begun are not included in the table. There are 16 torpedo-boat destroyers, 27 torpedo boats, 8 submarine boats belonging to the Navy, and 6 torpedo boats under construction.

1854 "Canadian," first steamer of the Allan Line, established in 1820.

1855 Establishment of the British India Steam Navigation Co.

1856 "Tempest," first steamer of the Anchor Line.

1858 "Bremen," first transatlantic steamer of the Norddeutscher Lloyd, established in 1856.

1858 "Great Eastern" launched on the Thames, Jan. 31; commenced May 1, 1854.

MERCHANT MARINE

(*From Report of the United States Commissioner of Navigation 1905*)

Districts	Number of Vessels	Gross Tonnage
Atlantic and Gulf Coasts	17,040	2,978,876
Porto Rico	42	6,180
Pacific Coast	2,492	741,825
Hawaiian Islands	61	32,386
Great Lakes	3,172	1,816,511
Western Rivers	1,466	222,124
Total	24,273	5,797,902

Classification of the Above

Type of Vessel	Number of Vessels	Gross Tonnage
Sailing vessels	13,073	1,941,878
Steam vessels	7,727	3,176,874
Canal boats	703	79,408
Barges	2,770	599,742
Total	24,273	5,797,902

NUMBER AND TONNAGE OF VESSELS BUILT IN THE UNITED STATES DURING THE YEARS 1868 TO 1903, INCLUSIVE

(*From Report of the Commissioner of Navigation*)

Year	Sailing Vessels		Steam Vessels	
	Number	Gross Tonnage	Number	Gross Tonnage
1868	910	142,742	236	63,940
1869	874	149,029	279	65,066
1870	816	146,340	290	70,621
1871	756	97,176	302	87,842
1872	645	76,291	292	62,210
1873	804	144,629	402	88,010
1874	961	216,316	404	101,930
1875	798	206,884	323	62,460
1876	698	118,672	338	69,252
1877	581	106,331	265	47,514
1878	532	106,066	334	81,860
1879	468	66,867	335	86,361
1880	460	59,057	348	78,053
1881	493	81,209	444	118,070
1882	666	118,798	502	121,843
1883	721	137,046	439	107,229
1884	706	120,621	410	91,328
1885	533	65,362	338	84,332
1886	405	41,237	240	44,467
1887	447	34,633	299	100,074
1888	423	48,590	430	142,006
1889	489	50,570	440	159,318
1890	505	102,873	410	159,045
1891	733	144,290	488	185,037
1892	846	83,217	438	92,531
1893	493	49,348	380	134,308
1894	477	37,827	293	83,720
1895	397	34,900	248	69,754
1896	369	65,236	286	138,028
1897	338	64,308	288	106,153
1898	359	34,416	394	105,838
1899	420	98,073	439	151,058
1900	504	116,460	422	202,528
1901	526	126,165	506	273,591
1902	581	97,698	579	308,178
1903	470	89,979	551	271,781

NOTE.—Canal boats and barges are not included in this table.

COMPARATIVE SEA STRENGTH OF NAVAL POWERS, JULY, 1905

NUMBER OF COMPLETED WARSHIPS OF 1,000 T. OR MORE AND OF TORPEDO CRAFT OF MORE THAN 50 T.

Type of Vessel	Great Britain	France	Germany	United States	Italy	Japan	Russia
Battleships, first class	51	19	16	12	13	5	7
Coast-defense vessels	6	17	16	12	1	5	7
Armored cruisers	29	18	4	2	5	8	3
Cruisers above 6,000 T.	21	4		2			4
Cruisers 6,000 to 3,000 T.	50	18	9	16	5	11	3
Cruisers 3,000 to 1,000 T.	56	18	27	21	12	11	7
Torpedo-boat destroyers	126	31	37	16	11	22	33
Torpedo boats	90	238	105	27	101	81	82
Submarines	9	37	1	8	1	11	13
Total number of ships	438	400	215	116	149	154	159

COMPARATIVE SEA STRENGTH OF NAVAL POWERS, JULY, 1905

Tonnage of Completed Warships of 1,000 T. or More, and of Torpedo Craft of More Than 50 T.

Type of Vessel	Great Britain	France	Germany	United States	Italy	Japan	Russia
Battleships, first class...	682,200	212,589	178,575	137,329	162,314	70,516	82,809
Coast-defense vessels....	49,900	73,368	91,315	47,445	3,913	29,527	43,391
Armored cruisers	282,400	145,085	39,047	17,415	31,891	72,738	31,288
Cruisers above 6,000 T...	201,950	31,513		14,750			25,911
Cruisers 6,000 to 3,000 T.	221,460	74,378	46,749	58,279	17,490	42,596	12,593
Cruisers 3,000 to 1,000 T.	103,960	32,868	58,859	29,497	26,216	21,276	8,760
Torpedo-boat destroyers.	44,565	9,250	12,660	6,695	3,503	7,436	10,000
Torpedo boats..........	8,036	20,735	13,924	4,200	9,076	7,317	8,000
Submarines............	1,400	3,935	120	913	107	1,265	1,485
Total tons built....	1,595,871	603,721	441,240	316,523	254,510	252,661	224,237

In the preceding tables, giving an estimate of the sea strength of the principal naval powers in July, 1905, the figures for Russia and Japan are revised to include changes brought about by the gains and losses during the war. In the classification of the ships the term *protected cruiser* has been omitted, because all cruisers, except the smallest and oldest, now have protective decks. *Scouts* are considered as cruisers in which battery and protection have been sacrificed to secure extreme speed. It should be further noted that in this comparison the following vessels are not included: Those over 20 yr. old, unless they have been reconstructed and rearmed; those not actually completed; gunboats and other vessels of less than 1,000 T.; and lastly, torpedo craft of less than 50 T. displacement.

NUMBER AND TONNAGE OF THE MERCHANT MARINE OWNED BY THE PRINCIPAL MARITIME NATIONS

(*From Report by the Department of Commerce and Labor 1905*)

Country	Sailing Vessels 50 T. and More		Steamers 100 T. and More	
	Number	Tonnage	Number	Tonnage
Great Britain	6,839	2,196,443	5,929	13.966,972
United States	3,751	1,454,152	846	1,610,466
Norway	1,740	767,981	844	925,683
Russia	3,006	545,087	533	593,742
France	1,449	535,703	556	1,139,575
Germany	914	528,267	1,193	2,767,463
Italy	1,554	517,964	351	714,887
Sweden	1,515	278,445	594	473,051
Turkey	867	174,824	99	98,066
Japan	1,521	174,624	373	556,036
Greece	911	173,636	180	321,330
Denmark	797	126,135	341	477,087
Holland	704	104,722	304	608,153
Spain	576	94,294	403	712,804
Brazil	374	76,375	186	123,597
Portugal	278	60,736	26	45,633
Chili	111	51,886	38	62,742
Argentina	163	40,540	93	73,128
Austria	120	29,118	224	540,354

LARGEST STEAMSHIP COMPANIES IN THE WORLD

Only those companies owning vessels the combined tonnage of which exceeds 100,000 gross tons are placed in this list.

Line or Company	Total Number of Ships	Total Gross Tonnage	Home Port
Hamburg-American Line	125	650,000	Hamburg
Norddeutscher Lloyd	122	583,000	Bremen
British Ind. Steam Nav. Co.	125	432,000	London
White Star Line	31	360,000	Liverpool
P. & O. Steam Nav. Co.	59	349,000	London
Union-Castle	49	314,000	London
Leyland Line	47	281,000	Liverpool
A. Holt	55	263,000	Liverpool
Nippon Yusen Kaisha	78	248,000	Tokio
Messageries Maritimes	58	239,000	Havre
Ellerman Lines, Ltd.	72	237,000	Liverpool
Elder, Dempster & Co.	113	236,000	Liverpool
Navigazione Gen. Italiana	107	231,000	Rome
Wilson Line	102	208,000	Hull
Austrian Lloyd	71	203,000	Trieste
Clan	49	189,000	Glasgow
Harrison	37	189 000	Liverpool
American Line	25	180,000	Philadelphia
Canadian Pacific	23	170,000	Montreal

LARGEST STEAMSHIP COMPANIES IN THE WORLD—(*Continued*)

Only those companies owning vessels the combined tonnage of which exceeds 100,000 gross tons are placed in this list.

Line or Company	Total Number of Ships	Total Gross Tonnage	Home Port
Comp. Gen. Transatlantique	52	169,000	Havre
Hausa	45	160,000	Bremen
Pacific Steam Nav. Co	41	151,000	Liverpool
Forenade Damps-Selskab	119	149,000	Copenhagen
Atlantic Transportation Co	19	138,000	London
Anchor Line	30	135,000	Glasgow
Allan Line	30	134,000	Glasgow
Hamburg-South American Line	32	130,000	Hamburg
Cunard Line	19	129,000	Liverpool
Dominion Line	15	125,000	Liverpool
Lamport & Holt	35	124,000	Liverpool
Chargeurs Réunis	34	115,000	Havre
Kosmos	28	109,000	Hamburg
Prince	40	108,000	Newcastle-on-Tyne
R. Ropner & Co	38	108,000	West Hartlepool
Royal Mail S. P. Co	36	105,000	London
Deutsch-Australische	23	105,000	Hamburg
Russian Steam N. & T. Co	66	102,000	St. Petersburg
Shell	33	100,000	London

DIMENSIONS OF SOME OF THE MOST NOTABLE MERCHANT STEAMSHIPS

Name of Ship	Date Built	Length Over All Feet	Beam Feet	Depth Feet	Draft Feet	Dis-place-ment Tons	Speed Knot
Great Eastern	1858	692	83	57½	25½	27,000	
Paris	1888	560	63	42	26½	13,000	20.5
Teutonic	1890	585	57½	42	26	12,000	20.0
Lucania	1893	620	65	43	28	19,000	22.1
St. Paul	1895	554	63	42	27	14,000	21.0
Kaiser Wilhelm der Grosse	1897	649	66	43	29	20,000	23.0
Oceanic	1899	704	68	49	32½	28,500	20.7
Deutschland	1900	686	67	44	30	23,200	23.5
Kronprinz Wilhelm	1901	663	64	43	29	21,280	23.5
Celtic	1901	700	75	49	36½	37,700	16.0
Kaiser Wilhelm II	1902	706½	72	52½		26,000	23.0
Baltic	1904	725	75	49	30½	40,000	20.0
Amerika	1905	670	74	52	28	22,800	20.0
Carmania (*Turbine Steamer*)	1905	675	72½	52	32	29,800	20.0

The new White Star liner "Baltic," whose dimensions are given in the preceding table, is probably better equipped electrically than any other vessel, either afloat or building. In addition to the usual electrical appliances to be found on board present-day ocean liners, the "Baltic" is equipped with an electrical device for preventing collisions with other vessels. The moment another ship enters the magnetic field of the "Baltic," the needle of the indicating instrument points in the direction of the vessel approaching, or being overtaken, and the officer in charge of the deck is thus in a position to take the steps necessary to avoid a collision. Even the rhythmic beats of an unseen steamer's screws are registered by means of this delicate apparatus. Another safeguard is an electric contrivance to show on the bridge if the ship's lights are burning properly. An electric log for ascertaining the speed of the ship is another acquisition, and an electric lead for sounding is also on the list. There is, further, an electric device for registering all signals, including steam sirens. The "Baltic" is equipped with electric refrigerating as well as electric cooking apparatus.—*Scientific American.*

TO RESTORE APPARENTLY DROWNED PERSONS

TREATMENT WHEN SEVERAL ASSISTANTS ARE ON HAND

As soon as the patient is taken from the water, expose the face to the air, toward the wind if there be any, and wipe dry the mouth and nostrils; rip the clothing so as to expose the chest and waist, and give two or three quick, smarting slaps on the chest with the open hand. If the patient does not revive, proceed immediately *to expel water from the stomach and chest*, as follows: Separate the jaws and keep them apart by placing between the teeth a cork or small bit of wood; turn the patient on his face, a large bundle of tightly rolled clothing being placed beneath the stomach (see Fig. 1); press heavily on the back over the stomach for ½ min., or as long as fluids flow freely from the mouth.

To Produce Breathing.—Clear the mouth and throat of mucus by introducing into the throat the corner of a handkerchief wrapped closely around the forefinger; turn the

Fig. 1

patient on the back, the roll of clothing being so placed as to raise the pit of the stomach above the level of the rest of

Fig. 2

the body (see Fig. 2). Let an assistant, with a handkerchief or piece of dry cloth, draw the tip of the tongue out of one corner of the mouth (which prevents the tongue from falling back and choking the entrance to the windpipe), and keep it projecting a little beyond the lips. Let another assistant grasp the arms just below the elbows and draw them steadily upwards by the side of the patient's head, and to the ground, the hands nearly meeting (which enlarges the capacity of the chest and induces inspiration). While this is being done, let a third assistant take a position astride the patient's hips, with his elbows resting on his own knees, his hands extended ready for action. Next, let the assistant standing at the head turn down the patient's arms to the side of the body (see Fig. 3), the assistant holding the tongue

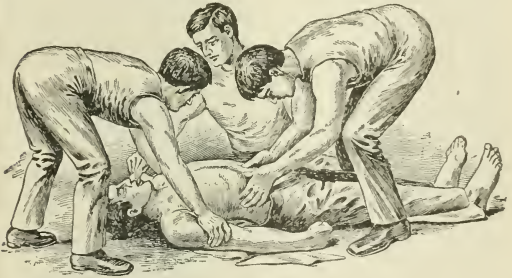


FIG. 3

changing hands, if necessary, to let the arm pass. Just before the patient's hands reach the ground, the man astride the body will grasp the body with his hands, the balls of the thumbs resting on either side of the pit of the stomach, the fingers falling into grooves between the short ribs. Now, using his knees as a pivot, he will at the moment the patient's hands touch the ground throw (not too suddenly) all his weight forwards on his hands, and at the same time squeeze the waist between them, as if he wished to force something in the chest upwards out of the mouth; he will increase the pressure while he slowly counts one, two, three, four (about 5 sec.), then suddenly let go with a final push, which will spring him back to his first position. This completes expiration.

At the instant the pressure is taken from the waist the man at the patient's head will again steadily draw the arms upwards to the sides of the patient's head, as before (the assistant holding the tongue again changing hands to let the arm pass, if necessary), holding them there while he slowly counts one, two, three, four (about 5 sec.).

Repeat these movements, deliberately and perseveringly, 12 to 15 times in every minute—thus imitating the natural motions of breathing.

If natural breathing is not restored after a trial of the bellows movement for the space of about 4 min., then turn the patient a second time on the stomach, rolling the body in the opposite direction from that in which it was first turned, for the purpose of freeing the air passage from any remaining water. Continue the artificial respiration from 1 to 4 hr., or until the patient breathes, according to the preceding instructions; and for a time, after the appearance of returning life, carefully aid the short gasps until deepened into full breaths. Continue the drying and rubbing, which should have been unceasingly practiced from the beginning by assistants, taking care not to interfere with the means used to produce breathing. Thus the limbs of the patient should be rubbed, always in an upward direction toward the body with firm, grasping pressure and energy, using the bare hands, dry flannels, or handkerchiefs, and continuing the friction under the blankets or over the dry clothing. The warmth of the body can also be promoted by the application of hot flannels to the stomach and armpits and bottles or bladders of hot water, heated bricks, etc., to the limbs and soles of the feet.

After Treatment.—When breathing has been established, let the patient be stripped of all wet clothing, wrapped in blankets only, put to bed comfortably warm, but with free circulation of fresh air, and left to perfect rest. Give whisky, or brandy, and hot water in doses of a teaspoonful, or a tablespoonful, according to the weight of the patient, or any other stimulant at hand, every 10 or 15 min. for the first hour, and as often thereafter as may seem expedient. After reaction is fully established, there is great danger of congestion of the lungs, and if perfect rest is not maintained for at least 48 hr., it sometimes occurs that the patient is seized with great difficulty of breathing, and death is liable to follow unless immediate relief is afforded. In such cases, apply a large mustard plaster over the breast. If the patient gasps for breath before the mustard takes effect, assist the breathing by carefully repeating the artificial respiration.

The foregoing treatment should be persevered in for some hours, as it is an erroneous opinion that persons are irrecoverable because life does not soon make its appearance, persons having been restored after persevering for many hours.

MODIFICATION OF TREATMENT IN CASE NO ASSISTANT IS AT HAND

To Produce Respiration.—If no assistant is at hand and one person must work alone, place the patient on his back with the shoulders slightly raised on a folded article of clothing; draw forward the tongue and keep it projecting just beyond the lips; if the lower jaw be lifted, the teeth

FIG. 1

may be made to hold the tongue in place; it may be necessary to retain the tongue by passing a handkerchief under the chin and tying it over the head. Grasp the arms just below the elbows and steadily draw them upwards by the sides of the patient's head to the ground, the hands nearly meeting as shown in Fig. 1. Next, lower the arms to the sides and press firmly downwards and inwards on the sides and front of the chest over the lower ribs, drawing toward the patient's head, as shown in Fig. 2. Repeat these movements 12 to 15 times every minute, etc.

Remarks.—In any operation for restoring to life an apparently drowned person, remember the following:

Fig. 2

Prevent unnecessary crowding of persons round the body, especially if in an apartment.

Avoid rough usage, and do not allow the body to remain on the back unless the tongue is secured.

Under no circumstances hold the body up by the feet.

On no account place the body in a warm bath, unless under medical direction, and even then it should only be employed as a momentary excitant.

U. S. NATURALIZATION LAWS

The conditions and manner of admission of an alien to the citizenship of the United States are prescribed by Section 2, 165-74 of the Revised Statutes of the United States.

Declaration of Intentions.—The alien must declare on oath before a circuit or district court of the United States, or a district or supreme court of the territories, or a court of record of any of the states having common-law jurisdiction and a seal and clerk, 2 yr. at least prior to his admission, that it is, *bona fide*, his intention to become a citizen of the United States, and to renounce forever all allegiance and fidelity to any foreign prince or state, and particularly to the one of which he may be at the time a citizen or subject.

Oath on Application for Admission.—He must, at the time of his application to be admitted, declare on oath, before some one of the courts above specified, "that he will support the constitution of the United States, and that he absolutely and entirely renounces and abjures all allegiance and fidelity to every foreign prince, potentate, state, or sovereignty of which he was before a citizen or subject," which proceedings must be recorded by the clerk of the court.

Conditions for Citizenship.—If it shall appear to the satisfaction of the court to which the alien has applied that he has made a declaration of intention to become a citizen 2 yr. before applying for final papers, and has resided continuously within the United States for at least 5 yr., and within the state or territory where such court is at the time held 1 yr. at least; and that during the time "he has behaved as a man of good moral character, attached to the principles of the constitution of the United States, and well disposed to the good order and happiness of the same," he will be admitted to citizenship.

Seamen.—Any seaman, who is a foreigner, who declares his intention of becoming a citizen of the United States, in any competent court, and has served 3 yr. on board a merchant vessel of the United States subsequent to the date of his declaration, may, on his application to any competent court, and on the production of a certificate of discharge and good conduct during that time, together with the certificate of his declaration of intention to become a citizen, be admitted to citizenship in the United States.

Persons Discharged From United States Navy or Marine Corps.—Any alien of the age of 21 yr. and upwards, who has enlisted or may enlist in the United States Navy or Marine Corps, and has served or may hereafter serve 5 consecutive years in the United States Navy, or one enlistment in the Marine Corps, and has been, or may hereafter be, honorably discharged, may be admitted to citizenship without a previous declaration of his intention to become a citizen.

Minors.—Any alien under the age of 21 yr. who has resided in the United States during the 3 yr. next preceding his arriving at that age, and who has continued to reside therein to the time of his application to be admitted a citizen thereof, may, after he arrives at the age of 21 yr., and after he has resided 5 yr. within the United States, including the 3 yr. of his minority, be admitted a citizen, but he must make a declaration on oath and prove to the satisfaction of the court that for the 2 yr. next preceding, it has been his *bona fide* intention to become a citizen.

Children of Naturalized Citizens.—The children of persons who have been duly naturalized, being under the age of 21 yr. at the time of the naturalization of their parents, shall, if dwelling in the United States, be considered as citizens thereof.

Chinese.—The naturalization of Chinamen is expressly prohibited by Section 14, Chapter 126, Laws of 1882.

Protection Abroad to Naturalized Citizens.—Section 2,000 of the Revised Statutes of the United States declares that "all naturalized citizens of the United States while in foreign countries are entitled to and shall receive from this government the same protection of persons and property which is accorded to native-born citizens."

Right of Suffrage.—The right to vote comes from the state, and is a state gift. Naturalization is a federal right, and is a gift of the Union, not of any one state. In nearly one-half of the Union, aliens (who have declared intentions) vote and have the right to vote equally with naturalized or native-born citizens. In the remaining states, only actual citizens may vote. The federal naturalization laws apply to the whole Union alike, and provide that no alien may be naturalized until after 5 yr. residence. Even after 5 yr. residence and due naturalization, he is not entitled to vote unless the laws of the state confer the privilege upon him; but in several states he may vote 6 mo. after landing, if he has declared his intention, under United States law, to become a citizen.

CUSTOM-HOUSE FEES

The following is a partial list of the custom-house fees and other charges required by law to be paid by vessels at the several custom houses in the United States:

Entry of vessel of 100 T. or more from foreign port	$2.50
Clearance of vessel of 100 T. or more to foreign port	2.50
Entry of vessel under 100 T. from foreign port	1.50
Clearance of vessel under 100 T. to foreign port	1.50
Post-entry	2.00
Permit to land or deliver goods	.20
Bond taken officially	.40
Debenture, or other official certificate	.20
Bill of health	.20
For recording bill of sale, mortgage, hypothecation or conveyance of vessel, under Act of July 29, 1850	.50
For recording a certificate for discharging and cancelling any such conveyance	.50
For furnishing a certificate setting forth the names of the owners of any registered or enrolled vessel, the parts or proportions owned by each, and also the material facts of any existing bill of sale, mortgage, hypotheeation or other encumbrance, the date, amount of such encumbrance, and from and to whom made	1.00
For furnishing copies of such records, for each bill of sale, mortgage, or other conveyance	.50
Certificate of registry, including bond and oath	2.25
Indorsement on certificate of registry of change of master	1.00
For every bond under the Registry Act	.25
Certificate of enrolment	.50
Indorsement on certificate of enrolment, of change of master, etc	.20
License, and granting the same, including bond and oath, if not over 100 T.	.70
License, and granting the same, over 100 T.	1.20
License, vessel not over 20 T., including bond and oath	.45
Indorsement on a license of change of master, etc.	.20

Certifying manifest, and granting permit for licensed vessels to go from district to district	$ .10
Receiving certified manifest, and granting permit on arrival of such vessel	.10
Certifying manifest, and granting permission to registered vessels to go from district to district	1.50
Receiving certified manifest, and granting permit on arrival of such registered vessel	1.00
Granting permit to a vessel, not belonging to a citizen of the United States, to go from district to district, and receiving manifest	2.00
Receiving manifest and granting permit to unload, to a vessel not belonging to an American citizen, on arrival at one district from another	2.00
Services other than admeasurement to be performed by the Surveyor in vessels of 100 T. or more, having on board merchandise subject to duty	3.00
For like service in vessels under 100 T., having similar merchandise	1.50
For like services in all vessels not having merchandise subject to duty	.67
Protection to American seamen	.25
Crew list	.25
General permit to land passengers' baggage	.20

MEMORANDA

MEMORANDA

MEMORANDA

MEMORANDA

MEMORANDA

MEMORANDA

SEE FOLLOWING PAGES

Passed Many Examinations

I wish to say that your Schools are all O. K. They have been instrumental in my being able to pass the following examinations: Assistant Engineer, U. S. N., Spanish American War; Warrant Machinist, U. S. N., Regular Service; Chief Engineer, U. S. Coast Survey; Chief Engineer, U. S. Quartermaster's Department, U. S. Army; and I have just passed as Local Inspector of Boilers, of Ocean Steamers of 10,000 tons. I not only passed all of these examinations, but have been appointed to all but the Local Inspector of Boilers, and I hope to be in it before the summer is over. I now fill the position of Chief Engineer on board one of the U. S. Quartermaster's Boats, U. S. Army. I would have been unable to pass all of these examinations, all of them being very hard, if I had not studied in your Schools.

Any time I can do anything for you let me know, as your School is a Godsend to practical men, but I am sorry to say that a great many do not see it. It was one of your circulars that set me thinking. It was as follows: "A man cannot stand still; he either goes ahead or lags behind."

D. C. Young,
625 Appleton St., Baltimore, Md.

PROMOTED TO ENSIGN

W. D. Greetham, Ensign, U. S. N., Washington, D. C., says he thinks very highly of the I. C. S. and is confident he owes his recent advancement to the rank of ensign to the information gained by studying the I. C. S. Navigation Course.

FIREMAN BECOMES WARRANT MACHINIST

T. G. Sprengel, Warrant Machinist, U. S. N., U. S. S. "Massachusetts," could not ship in the United States Navy as a machinist because he didn't have sufficient knowledge. He went as a fireman, second class. By studying the I. C. S. Course he has now reached the position of warrant machinist in the Navy. He says he would not take one hundred times the cost of the Course for the benefit received from it.

COAL PASSER BECOMES ELECTRICIAN

A. M. Hamrick, Electrician, U. S. N., U. S. S. "Princeton," enrolled in the I. C. S. while a coal passer in a boiler room. At the present time he is electrician on board the U. S. S. "Princeton," and his salary has been increased about 200 per cent.

OBTAINED UNLIMITED LICENSE

W. G. Michalski, 807 South Broadway, Baltimore, Md., passed the examination for chief mate on ocean-going steamers and has been given an unlimited license for that position. He also has been promoted from second officer to the position of chief officer. Mr. Michalski thanks the I. C. S. for his success.

PASSED EXAMINATIONS EASILY

William J. Ryan, 53 North Main St., Woonsocket, R. I., by studying the Ocean Navigation Course, has successfully passed examination for the position of second mate on ocean steam vessels.

EASILY UNDERSTOOD AND MOST INTERESTING

Charles Liessman, U. S. S. "Marblehead," in a letter to the Schools says the Course has proved to be most interesting and simple; that he could not help mastering the subjects.

IS PILOT ON GREAT LAKES NOW

Henry Ericksen, 670 Seventh St., Milwaukee, Wis., passed the United States examination for pilot on the Great Lakes, by means of his studies with the I. C. S. His salary has been increased 130 per cent.

The Course a Great Benefit

I found the International Correspondence Schools' Ocean Navigation Course of the greatest benefit to me. And the Reference Library Volumes not only have proved most useful when preparing for examination and as books of reference for actually working navigation at sea, but they have been admired by every officer in the service who has seen them.

HENRY B. SOULEE, Lieutenant, U. S. N.,
Bureau of Navigation,
Washington, D. C.

PASSED AN EXAMINATION

William Santimo, Brechin, Ont., by studying the Lake Navigation Course, has been able to pass an examination for a mate's certificate.

PRAISE FROM GOVERNMENT OFFICERS

Wilhelm Weidlick, Puget Sound Harbor 16, Seattle, Wash., prepared for a mate's certificate by studying the I. C. S. Course in Ocean Navigation. He passed with flying colors. Captain Pratt, of the United States Coast and Geodetic Survey, and many other prominent ship masters, declared, in this connection, that the Course is the most complete work of its kind they ever have seen.

COXSWAIN BECOMES THIRD OFFICER

Andrew E. Knudson, New York, passed the Board of Inspectors' examination and is now serving as third officer on board of the "El Vail," of New York. When he enrolled in the I. C. S. he was a coxswain in the Navy.

BECOMES FIRST-CLASS PILOT

R. R. Wilmot, 948 Jefferson Ave., Brooklyn, N. Y., was an unlicensed man, acting as third mate on a steamship when he began studying in the I. C. S. He has passed the examination for master of ocean steam vessels and for first chief pilot. He is now second officer of the S. S. "El Mar" and a member of the American Masters, Mates, and Pilots' Association. He says there never has arisen during his service at sea a problem in nautical science that he has not been able to solve by means of the knowledge gained from his Course.

FROM DECKHAND TO BOATSWAIN

Bertolf Mathiesen, 815 Witherspoon Bldg., Philadelphia, Pa., took up the Ocean Navigation Course and in a few months was promoted to the position of quartermaster on the Government dredge "Delaware," which carries 56 men. In 11 months from the time of his enrolment he was made boatswain. He gives the I. C. S. entire credit for his quick promotions.

SEAMAN TO COXSWAIN

Ferdinand Johansen, U. S. S. "Alliance," Culelera, Porto Rico, says the I. C. S. Ocean Navigation Course is excellent. He learned from it the rules of the road, safety arrangements, and information about codes and steam launches. He has advanced from ordinary seaman in the United States Navy to coxswain of a forty-foot steam launch with corresponding increases in wages.

Simple and Thorough

I take pleasure in saying that the Navigation Course of the International Correspondence Schools is the most simple and thorough method for a student to learn navigation. Having but a limited common-school education and having received a Diploma with no assistance outside the School, is a voucher of the School's guarantee. You are at perfect liberty to refer to me at any time that I can be of service to you, and it will give me great pleasure to recommend the Schools whenever I have the opportunity.

With kind regards, I remain,

William Henry Cross,
Bar Pilot, Charleston, S. C.

FROM DECK HAND TO MATE

Henry E. Farrer, South Bend, Wash., holds a mate's license that he was able to win by studying the Lake Navigation Course. At present he is mate of a tug, earning $75 a month and board. When he enrolled he was deck hand on a steamer, earning $45 a month.

FROM SEAMAN TO THIRD OFFICER

A. Frederiksen, 1310 Laguna St., San Francisco, Cal., says he does not know of a school in the United States, outside of the Naval Academy, so good as the I. C. S. Ocean Navigation School. He says every subject pertaining to ordinary practical navigation is fully treated and that the Course gives an education far beyond any required to pass the examinations for unlimited license as master or mate of steam or sailing vessels. When he enrolled in the I. C. S. he was a seaman in the United States Navy. At present he is third officer of the steamship "City of Tara." His salary has been increased 250 per cent.

COAL PASSER TO ENGINEER

W. H. Demeritt, U. S. S. "Mangrove," Key West, Fla., has advanced from the position of coal passer, in the light-house service, to second in charge of the engineering department of one of the largest steamers in the United States light-house service—the U. S. S. "Mangrove." It didn't take Mr. Demeritt long to master the Course; and at the examination he made the highest percentage on record in his district.

FROM $18 A MONTH TO $1,000 A YEAR

Stanley S. Stevens, Delaware City, Del., enrolled in the I. C. S. Marine Engineers' Course while earning about $18 a month. What he learned from the Course enabled him to pass the Government examination for marine engineers' license. He is now earning $1,000 a year and says he owes his position entirely to I. C. S. instruction.

WATCHMAN PASSES PILOTS' EXAMINATION

R. C. Ludwig, 162 Broadway, Benton Harbor, Mich., enrolled for the Lake Navigation Course while holding a position as watchman on a lake steamer. With the knowledge gained from his Course he passed the examination for first-class pilot, of all tonnage for Lake Michigan, Green Bay, and the Straits of Mackinaw. Last season he held a position as second officer on a steamer and received commendation from his superior officers. Mr. Ludwig is going to continue his studies with us until he secures a first-class license for all the Great Lakes and connecting waters. His salary has increased 70 per cent.

Commendation From a Commander

I received the Volumes of your Course in Navigation several weeks ago and have examined them with much interest. They seem to me admirably adapted both in plan and in execution to the purpose for which they are designed, and I am sure that the Course of Instruction which they represent cannot fail to be of great value to all who may take it under your guidance.

The two features of the work which have impressed me most forcibly are: first, the happy balancing of theory and practice; and second, the originality and helpfulness of the illustrations.

AUSTIN M. KNIGHT,
Commander, U. S. Navy

PASSED EXAMINATION FOR FIRST-CLASS PILOT

Thomas Wilmot, U. S. Steamer "Morrill," Milwaukee, Wis., has been able to stand a stiff examination for the position of first-class pilot, on the Great Lakes. He prepared for this by studying the I. C. S. Lake Navigation Course.

SALARY INCREASED 140 PER CENT

Johan Willadsen, Sun Oil Co., Marcus Hook, Pa., by studying the Marine Engineers' Course has advanced from the position of fireman to second engineer, on board the steamship "Paraguay." From the Course Mr. Willadsen learned all about marine machinery and boilers and secured sufficient technical knowledge to obtain a marine engineer's license. His salary has been increased 140 per cent. since he started studying the Course.

FIREMAN BECOMES ENGINEER

J. K. Munson, Shelton, Wash., a fireman when he enrolled in the Marine Engineers' Course, is now engineer of the tug "Victor" and his salary has been increased over 200 per cent. He says he will be glad to hear from anybody that wants to write to him regarding the I. C. S.

TUG-BOAT FIREMAN BECOMES MARINE ENGINEER

Joseph H. Pratt, 1349 Fifth Ave., Watervliet, N. Y., was working as a tug-boat fireman when he began his Course in the I. C. S. He advanced to the position of assistant engineer and then to that of marine engineer. His salary has doubled as a result of studying the Course.

SALARY DOUBLED

Charles Fredrickson, Fairfield, Conn., by means of the Marine Engineers' Course, has advanced from the position of fireman to that of second engineer on an ocean-going tug owned by the Lehigh Valley Railroad Company. His salary has been doubled.

OILER BECOMES ASSISTANT ENGINEER AT $90 A MONTH

Emil Stolsen, Frankfort, Mich., was employed as an oiler on one of the Ann Arbor Company's car ferries when he started to study the I. C. S. Marine Engineers' Course. He is now assistant engineer for the same company. His salary has been advanced from $37.50 to $90 a month. Mr. Stolsen says that if it was not for the I. C. S. he would have been unable to pass the examination required for a marine engineer's license.

None Too Old to Learn

It gives me great pleasure to recommend the I. C. S., especially to marine engineers. I am the owner of several steamers and felt my position very keenly, as I was not able to pass the government examinations to secure papers that would allow me to run my own boats. Although no longer a young man, I enrolled for the Marine Engineers' Course, and, in a short time, was able to pass the examination before the Government Inspectors and obtain papers for 500-ton steamers. I am convinced that if employes would fit themselves for their professions through the Schools they would command more respect from their employers.

P. F. West, Bridgeport, Conn.

FROM $90 A MONTH TO $150 A MONTH

George Gale, 310 Twenty-first St., West New York, N. Y., began the Marine Engineers' Course in the I. C. S. while employed as first assistant engineer on one of the Southern Pacific Company's steamships. The salary paid to first assistant engineers by this company is $90 a month. At present Mr. Gale is chief engineer on one of the same company's steamships, running between New York and Galveston. His salary is $150 a month. He says the knowledge of electricity gained from the Course was specially valuable to him and that the cost of the Course is one of the best investments he ever made.

MACHINIST STUDIES THE COURSE

W. A. Buckley, U. S. S. "Kentucky," care Postmaster, New York, was a machinist's apprentice in a marine engine shop when he enrolled for the Marine Engineers' Course. He found the knowledge gained from the Course to be of much value in connection with his shop work and, later, with his work on board ship. He is now chief-machinist's mate in the United States Navy.

PASSED EXAMINATION FOR LICENSE

John J. Crowley, S. S. "Larimer," Port Arthur, Tex., had just left an English ship, where he was donkeyman, and taken a position on an American steamer as fireman when he enrolled in the I. C. S. Marine Engineers' Course. By studying he soon passed the third assistants' examination for license and immediately received an appointment. He is going to take the examination for second assistant, then first assistant, and then chief.

FIREMAN TO ENGINEER

S. Watson, 113 Christiana St., Sarnia, Canada, says he considers the I. C. S. instruction the best obtainable in the lines taught. He enrolled in the Marine Engineers' Course and has advanced from the position of fireman to that of engineer of a boat.

RUNS YACHT AND AUTOMOBILE ENGINES

Merrill W. Keister, Box 367, Lake Geneva, Wis., while working as a fireman on the Great Lakes tried to get a license as engineer, but failed. Then he enrolled for the I. C. S. Marine Engineers' Course and secured the much-desired license, together with a position as engineer on a private yacht, at Lake Geneva, Wis. In the winter he runs an automobile. His salary has been advanced from $50 a month to $115 a month.

United States Naval Academy
Annapolis, Md.

DEPARTMENT OF NAVIGATION

International Correspondence Schools,
Scranton, Pa.

GENTLEMEN: At your request, I have carefully examined your textbooks on Ocean Navigation and unhesitatingly pronounce them an admirably arranged and comprehensive treatise, and one that should prove a valuable aid to any person taking up the study of Navigation.

You are to be congratulated on presenting a subject, unfortunately an intricate one to many, in a most clear and simple way.

W. C. P. MUIR,
Lieut.-Commander, U. S. N.

EARNINGS GREATLY INCREASED

W. J. Drummond, Act. Boatswain, U. S. N., U. S. S. "Siren," Navy Yard, Norfolk, Va., enrolled in the I. C. S. while a third-class quartermaster, earning $31.36 a month. His study with the I. C. S. enables him to hold the position of boatswain with a salary of $150 a month. Mr. Drummond recently has passed the examination for warrant rank.

SEAMAN BECOMES MATE

J. H. A. Johnson, Boatswain's Mate, First Class, U. S. N., Newport, R. I., is very proud of his I. C. S. Diploma, which has helped him to advance. When he started to study in the I. C. S. he was a seaman in the Navy. Now he is boatswain's mate, first class.

NOW SENIOR STEAM ENGINEER

R. E. Skeldon, Toledo, Ohio, is an example of ambition and I. C S. training combined to make success. Mr. Skeldon was employed as engineer on a Government tug on the Great Lakes when he enrolled in the Marine Engineers' Course. He applied himself to his studies and now holds the position of senior steam engineer on the floating plant engaged in United States engineering work in the Cleveland district.

NEW YORK CLUBMAN COMMENDS COURSE

I have put a great deal of spare time, for the last few years, into the self-study of navigation, having gone through "Raper's" and "Norie's" and many other textbooks; but I have never mastered it, owing, first, to the failure of everybody, until now, to make this subject sufficiently clear in the explanation of its theory, and also to the fact that none of them give sufficient examples for a student to familiarize himself thoroughly with each step. I am learning under your system. Your work, I think, is more perfect and intelligible than anything that has heretofore been published.

A. J. Moxham,
Member, New York Yacht Club

THOROUGH AND ABLE INSTRUCTION

Having just completed a Course of study in Ocean Navigation and received my Diploma, I feel that a few words of appreciation are due the International Correspondence Schools for their efforts in my behalf as one of their pupils.

The fact that I was able to pass through this Course in the comparatively short time of a little over 6 months I attribute entirely to the thorough and able manner in which all subjects are treated and to the earnest efforts on the part of the Instructors to encourage, explain, and advise on any deficiency they may note in the student's work.

J. S. Croghan,
Boatswain, U. S. Navy

New York Nautical College
New York, N. Y.

International Correspondence Schools,
Scranton, Pa.

GENTLEMEN: It has been my pleasure during the past week to carefully read thoroughly your three textbooks on "Navigation and Nautical Astronomy." I feel it obligatory to write to you for the purpose of expressing my extremely high opinion of said work. I cannot understand how it could be improved. It is masterly in every detail, yet is so clearly and concisely written that it is within the comprehension and assimilation of the average lay student. I take off my hat to the author of the books, whoever he may be.

HOWARD PATTERSON, Principal

EXPLANATIONS FULL AND CLEAR

Your Ocean Navigation Course is an excellent one, all explanations and statements being very full and clear. * * * Before I took up this Course, I tried to study navigation from Bowditch's "Practical Navigator," but soon gave it up on account of its confusing technicality to one not having a mathematical foundation such as is provided in your Course. CARL I. OSTROM,

Quartermaster, U. S. Navy

MOST SATISFACTORY TREATISE ON THE SUBJECT

I have gone over the Lake Navigation Course very carefully, and will say that, without doubt, it is the most satisfactory treatise on the subject that could be compiled. The work reveals a master hand, and, as a whole, furnishes the most thorough and masterly education that could be devised for the mariner on the Great Lakes, who stands greatly in need of such an education, but to whom it has heretofore been inaccessible.

CAPT. FRANK HENRICH, Nautical Expert,
In charge Branch Hydrographic Office, 1001 Torry Bldg.
Duluth, Minn.

THOROUGH AND CONCISE

After thoroughly perusing the textbooks on Navigation and Nautical Astronomy of the International Correspondence Schools, I can conscientiously say that they are the most thorough and comprehensive work on the subject I have ever seen, and, therefore, I can and will recommend them to all my friends who desire to take a Course in Navigation. E. GRETHE,

Chief Mate S. S. "Francis H. Legget,"
Formerly Teacher of Navigation at San Francisco, Cal.

COULD NOT READ NOR WRITE ENGLISH

SEWERIN FALK, U. S. S. "Kentucky," care of Postmaster, New York City, enrolled in the I. C. S. Ocean Navigation Course while a seaman in the United States Navy and unable to read nor write English. He studied the Course with the aid of a dictionary. Now he not only can read and write English but has had his salary doubled, in a better position than when he enrolled. He holds a Diploma for the Ocean Navigation Course. In a letter to the Schools, Mr. Falk has written: "It is beyond my power to express my heartfelt gratitude toward the Schools for the thorough instruction and careful corrections given to me; and for the interest they have taken in helping me along. It is with great pleasure I recommend the I. C. S to every man and woman that desire to better their position."

REFERENCE VOLUMES OF GREAT VALUE

When I enrolled in the I. C. S., I had only a common-schoc education, and was a carpenter's mate, third class; but nov I am carpenter's mate, second class. The instruction an books supplied by the Schools are so thorough and clear tha the student cannot fail to succeed in his studies, particularl in the Navigation Courses. I therefore recommend the I.C.S to all seamen who wish to prepare themselves for a nautica examination. The Reference Volumes are of great value t me as a reference library. SVEN J. TROIN,

U. S. S. "Atlanta"

EASY TO LEARN NAVIGATION

THOMAS CHANTRE, U. S. S. "Des Moines," North Atlant Squadron, Sixth Division, Cap Cod Bay, in a letter to t Principal of the School of Navigation has written the following: "I take pleasure in saying that the Navigation Course the I. C. S. is the most simple and thorough method for an ambitious seaman to learn navigation. Having but a limit common school education to start with, I have received th I. C. S. Diploma with no help outside of the I. C. S. Instru tion Papers. This is a voucher of the Schools' guarantee teach any one that will study. It is my honest opinion the their Course in Navigation cannot be other than of grea benefit to any sailor trying to rise in his profession."

SALARY INCREASED 100 PER CENT.

PETER J. MILNE, 164 Bagot St., Kingston, Ontario, co hardly work division, in Arithmetic, when he enrolled in Marine Engineers' Course. Now he can master the m difficult problems and has advanced from the positior stationary fireman to that of chief engineer for the Cer Company, Kingston. By means of the Course he h secured a first-class engineer's certificate.

PASSED INSPECTOR'S EXAMINATION

JOHN H. FREDENBORG, 112 Seventh Ave North, Seatt Wash., by studying the Lake Navigation Course, has be able to pass the inspector's examination in Seattle for mat papers for steam vessels. When he enrolled he was a dec hand, soon securing a position as mate at a large increase i salary.

EDUCATION MUCH IMPROVED

J S. DEARWOOD, care of Steamer "Masaba," Marine P O Detroit, Mich., began studying the Lake Navigation Cours while working as a laborer. As a result of the increase knowledge Mr. Dearwood has, his income has been increasec He says: "I was only in the fourth grade when I left schoo and would not take for the I. C. S. Course twice what it cost me. I have much improved in my general education and certainly would recommend your Schools to any one seeking an education."