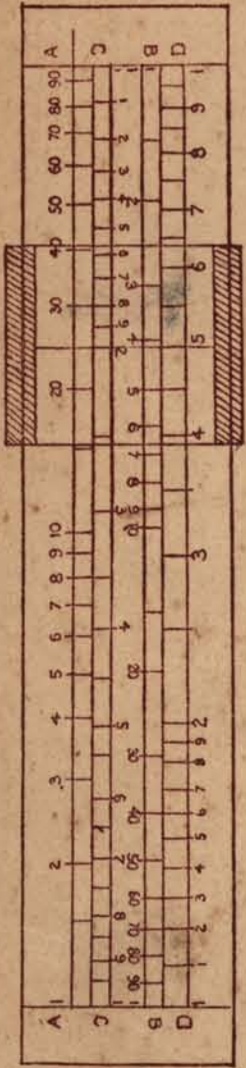

THE SLIDE RULE

FOR SHIPS' OFFICERS

A TREATISE ON SLIDE RULES FOR CARGO, NAVIGATION AND GENERAL USE ON BOARD A SHIP BOTH IN PORT AND AT SEA

BY

J. C. PODMORE

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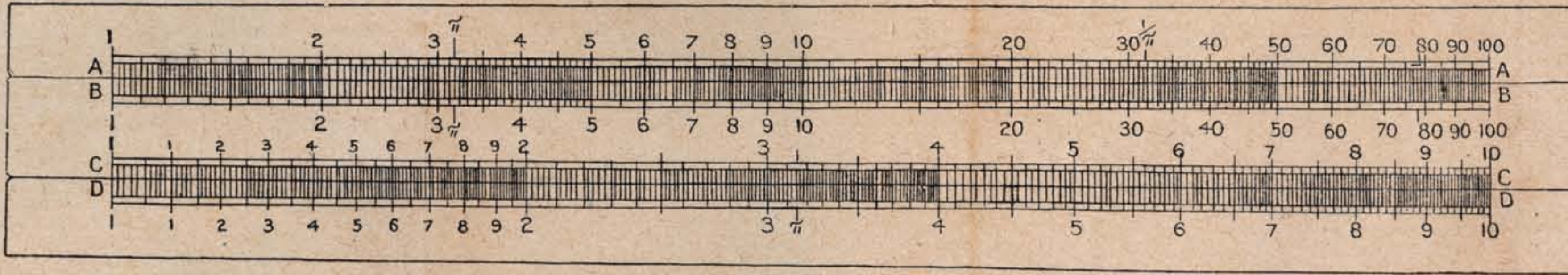
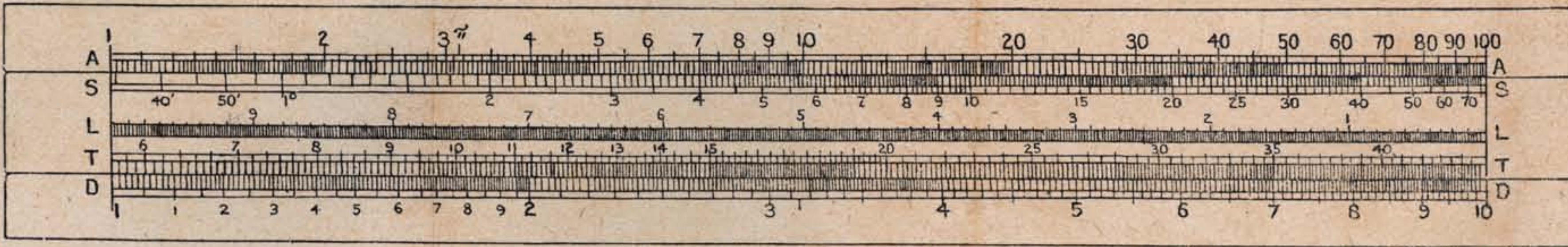
THE SLIDE RULE FOR SHIPS' OFFICERS

10-INCH SLIDE RULE.



Sketch of Mannheim Type Slide Rule showing A, B, C and D Scales.



Slide Reversed showing S, L and T Scales.

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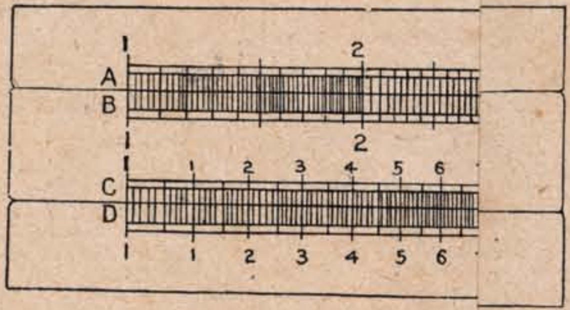

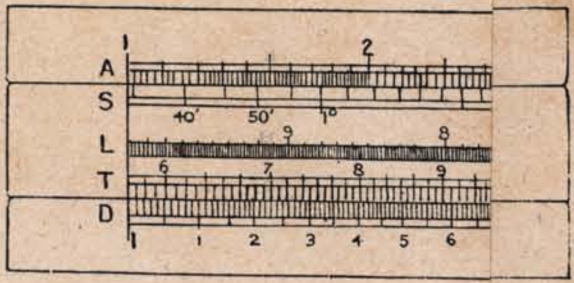

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INTRODUCTION.

It is really remarkable how very few sailors realise the simplicity of a slide rule, or how extremely useful it may be found on board a ship.

Calculations that waste valuable time may be worked on it in a few seconds.

So many people are under the impression that a slide rule is an engineer's instrument, and also that it is hard to understand how to use one, and that one must be continually practising to become proficient in its use. This is, in point of fact, far from the case, one does not need to practise continually any more than one does with a sextant.

In this book, I have endeavoured to show some of the many uses to which a slide rule may be put both in cargo working and navigation.

CONTENTS.

The Slide Rule for Ships' Officers

CHAPTER I.

THE RULE.

THE rule described in this book is an ordinary 10-inch rule, of the Mannheim type, such as may be borrowed from almost any ship's engineer, and not an article specially made for navigational problems and useless for any other calculations.

If we study the rule we find that there are four scales: two of them being on the rule itself and the other two on the slide. These are called for convenience A, B, C and D; A and D being the two scales on the rule itself and B and C the two on the slide.

There is also, attached to the rule, a small movable frame containing a piece of glass on which is drawn a fine hair-line. This is known as the runner, and when referred to, the hair-line on the runner is always meant. On some runners you will find more than one hair-line. It is best in that case always to use the same line, for ordinary calculations, to avoid confusion. The use of the other lines will be explained later.

Referring back to the rule, it will be noticed that whereas the two lower scales, C and D, extend the full length of the rule, the upper scales, A and B, are, in reality, each two similar scales placed end to end, the first reading from 1 to 10 and the second from 10 to 100. On some rules the second scale also reads from 1 to 10, but this does not affect the working in any way.

The first of these scales is known as the left-hand scale of A or B and the other as the right-hand scale. The end markings on these scales are known as the left index and right index respectively, and 10 (or 1) in the centre of the scales as the centre index.

Similarly with the C and D scales the end markings are known as the left and right indices of C and D.

How to Read the Scales.

If we look at the C and D scales, we see that the space between each of the main divisions decreases very considerably as we get further along the rule, and that, on that account, the rule cannot be as closely marked between, say, 7 and 8 as is the case between 1 and 2.

Between 1 and 2 the space is divided into ten major parts, numbered 1, 2, 3 etc., and each of these major parts is again divided into ten smaller parts. In other words, every hundredth part is marked; so

that if we call the left index 1 these major divisions will be 1·1, 1·2, 1·3 etc. and the smaller subdivisions 1·01, 1·02, 1·03 etc. To avoid confusion always remember that the small figures between the left index and 2, although marked 1, 2, 3 etc., are in reality 1·1, 1·2, 1·3 etc.

Between 2 and 4 there is only sufficient space to mark every other one of the smaller divisions. These then instead of representing ·01 will be ·02 and must be read as 2·02, 2·04, 2·06, 2·08, 2·10, 2·12 etc. Between 4 and the right index each space is divided into ten major parts, each of which is again halved. The smallest divisions must therefore represent ·05 and be read 4·05, 4·10, 4·15 etc.

We noticed previously that whereas C and D are each one scale, A and B are each two. From which we see that A and B are each just half of C and D. From which it will be obvious that they cannot be as closely marked.

In the A and B scales we find that, between the left index and 2, the scales are marked in the same manner as between 2 and 4 on the C and D scales. The smallest divisions therefore read 1·02, 1·04 etc. Between 2 and 5 the markings are similar to those between 4 and 10 on C and D, and will therefore read 2·05, 2·10, 2·15 etc. Between 5 and 10 only the major divisions are marked, so these must read 5·1, 5·2, 5·3 etc. On the right hand scale the markings are similar to those on the left hand scale, but have ten times their value; reading from the centre index on the smallest divisions 10·2, 10·4, 10·6 etc., up to to 20, then 20·5, 21, 21·5 etc. up to 50, and then on to the right index, 51, 52, 53 up to 100.

We will now take the three scales on the reverse side of the slide. These are lettered S, L and T, short for sines, logarithms and tangents.

Taking the L scale or scale of logarithms first. This is a simple way of taking out the logarithms of numbers to three figures. The L scale is on most rules the middle one, but the method used is the same in any case. At the back of the rule, at each end, you will find a notch cut out, and an index mark marked on it.

To find the logarithm of any number, pull out the slide, towards the right, till the left index of the C scale is exactly over that number on the D scale, then, turning to the back of the rule, read the logarithm on the L scale, where the index mark cuts it.

For example.—To find the logarithm of 3. Draw out the slide to the right till the left index of C is exactly over 3 on D. Then turn to the back of the rule and you will see that the index mark cuts the L scale at 477. So the log of 3 will be 0·477.

To take out an anti-logarithm. Set the logarithm on the L scale to the index mark at the back of the rule, then turning to the face of the rule

again, see where the left index of C cuts the D scale and this will be the anti-logarithm.

For example.—Given log $x = 0{\cdot}699$. Set 699 on the L scale to the index mark at the back of the rule, then turning to the face of the rule we see that the left index of C cuts the D scale at 5. So $x = 5$.

Next we will take the S scale or scale of Sines.

On studying this scale we see that it is marked, in degrees, from 0° 35′ to 90°. The right index of S being 90° and the left index 0° 35′, the first line to the left of the right index, or 90°, is 80°; then below 80°, between that and 70°, are five lines: these represent every other degree, below 70° every degree is marked, below 40° every half degree, below 20° every 10 minutes of arc and below 10° every 5 minutes of arc are marked.

Now the sine of 90° is 1. So we set the right index of S to coincide exactly with the right index of A, and call the right index of A, 1; then the centre index will be 0·1, and the left index 0·01.

To find the sine of any angle, we look along the S scale for the angle and immediately above it we find the sine on the A scale.

For example.—

Over 15° on S, we read 259 ∴ sin 15° = 0·259 right-hand scale of A.

Over 5° on S, we read 87 ∴ sin 5° = 0·087 left-hand scale of A.

B

Over 7° 15′ on S, we read 126 ∴ sin 7° 15′ = 0·126 right-hand scale of A.

Similarly, if we are given that sin θ = 0·25, we find 25 on the right-hand scale of A and under it 14° 30′ ∴ θ = 14° 30′; or if sin θ = 0·061, we find 61 on the left-hand scale of A, and under it 3° 30′ on the S scale ∴ θ = 3° 30′.

An alternative method can be used without reversing the slide. At the back of the rule at each end you will find an index mark, as was previously shown in describing the method of taking logarithms. Set the angle on the S scale to either of these index marks, then turning to the face of the rule again, under the index of the A scale, read the sine of the angle on the B scale.

For example.—Draw out the slide either way till one of the index marks, at the back of the rule, cuts the S scale at 20°; then turning to the face of the rule we see that the index of the A scale cuts the B scale at 342, and also that it is the right-hand scale, so that sine 20° must be 0·342.

Now taking the T scale, or scale of tangents, we see that it is marked in degrees from about 6° at the left index to 45° at the right index. Above 20° every 10 minutes of arc are marked and below 20° every 5 minutes of arc. This scale is read in the same manner as the S scale, except that now, instead of using the A scale, we must use the D scale, and that when using the alternative method

without reversing the slide we must always draw the slide towards the left.

As with the S scale, we call the right index 1; that is to say, that tan 45°=1. The left index must therefore be 0·1.

To find the tangent of 15°. We set the right and left indices of T exactly over the indices of D. Then under 15° on T we read 268 on the D scale. Tan 15° is therefore 0·268 or given tan θ=0·364. We find 364 on the D scale and immediately over it 20° on the T scale ∴ θ=20°.

To find the tangent of an angle of more than 45°, we have to bear in mind that tan A=cot (90° − A) or $\frac{1}{\tan(90° - A)}$. The method of finding the tangent being to draw the slide out to the left till (90° − the angle we require) on the T scale lies exactly over the left index of the D scale. Then under the right index of the T scale we read the required tangent on the D scale.

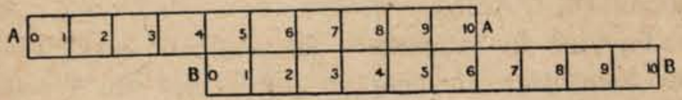
For example.—To find the tangent of 72°. Draw the slide to the left till 90° − 72° or 18° on T lies exactly over the left index of D, then immediately under the right index of T we find 308 on D; so tan 72°=3·08.

Always bear in mind that the tangent of an angle of less than 45° is less than 1, but that the tangent of an angle of more than 45° is more than 1.

As this scale is not marked below about 6°, it might be as well to mention here that the tangent of an angle of less than 6° is very nearly equal to the sine of the same angle.

In actual practice, when using a slide rule, the sine may be used instead of the tangent, when the angle is too small to be marked on the T scale.

The Principle of the Slide Rule.



The accompanying figure represents two Rules A and B of equal length each divided into ten equal parts.

If we set 0 on rule B to coincide with 4 on rule A, we find that over any number on rule B we have 4 plus that number on rule A.

For example.—Over 5 on rule B we find 4 + 5 or 9 on rule A, and over 2 on rule B we have 6 or 4 + 2 on rule A.

Similarly, to subtract, if we place 3 on rule B under 7 on rule A, we only have to see what number on rule A lies over 0 on rule B to find 7 − 3 or 4.

The slide rule is worked on exactly the same principle, the only difference being that instead of

all the spaces on the scales being equal, they are proportional to logarithms.

For instance, the logarithm of 3 is ·477 and the logarithm of 5 is ·699. If we have the curiosity to measure the space between the left index and 3 on the C or D scales, we shall find that this space is ·477 of the total length of the scale, and similarly that the space between the left index and 5 is ·699 of the length of the scale. From which it can easily be seen that the scales on a slide rule are in reality scales of logarithms.

Now we all know that to multiply by logarithms we have to add together the logarithms of the respective numbers, and to divide we subtract the logarithm of the divisor from that of the dividend. This is what the slide rule does for us mechanically, saving us the trouble of looking up logarithms and anti-logarithms.

Trigonometrical Equivalents.

Some slight knowledge of the relation between the different ratios in trigonometry, though not necessary when using the rule, will be found useful in working out certain problems. With its aid almost any triangle may be solved in a few seconds.

In the triangle ABC right angled at C—

We see that $\angle B = (90° - \angle A)$.

$$\text{Sin } A = \frac{a}{c} = \cos B \text{ or } \cos(90° - A)$$

$$\text{Sec } A = \frac{c}{b} = \text{cosec } B \text{ or cosec } (90^\circ - A)$$

$$\text{Cosine } A = \frac{b}{c} = \sin B \text{ or } \sin (90^\circ - A)$$

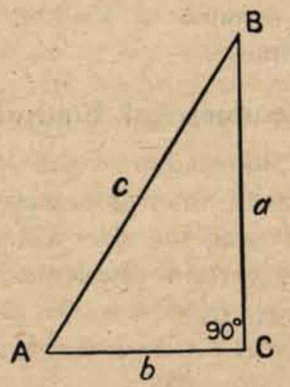
$$\text{Cosec } A = \frac{c}{a} = \sec B \text{ or } \sec (90^\circ - A)$$

$$\text{Tan } A = \frac{a}{b} = \cot B \text{ or } \cot (90^\circ - A)$$

$$\text{Cot } A = \frac{b}{a} = \tan B \text{ or } \tan (90^\circ - A)$$

From which we can see that—

$\text{Cosec } A = \dfrac{1}{\sin A}$, $\sec A = \dfrac{1}{\sin (90^\circ - A)}$, cosine $A = \sin (90^\circ - A')$, $\tan A = \cot (90^\circ - A) = \dfrac{1}{\cot A}$, $\cot A = \tan (90^\circ - A) = \dfrac{1}{\tan A}$.



Studying this we notice that we can turn all the various ratios into either sines or tangents. On

the slide rule we have no secants, cosecants, cosines or cotangents marked, but only sines and tangents. Hence we see that if we wish to use any other ratio, we must first convert it to either a sine or a tangent.

For instance, if we wish to multiply by cosec A, we see that we must use $\dfrac{1}{\sin A}$, or in other words divide by sin A, or if we wish to divide by cosec A, we must multiply by sin A.

To use a cosine, we subtract the angle from 90° and use this angle thus found.

Or, again, to multiply by a secant, we divide by the sin of 90° − the angle, and to divide by a secant we multiply by the sin of 90° − the angle.

Similarly, with tangents and cotangents: instead of multiplying by a cotangent, we divide by the tangent.

But here we noticed before that the tangent scale only reads up to 45°, so that should we wish to use the tangent or cotangent of an angle greater than 45°, we must subtract the angle from 90°, and instead of multiplying, divide; or instead of dividing, multiply. For instance, $\tan 72^\circ = \cot (90^\circ - 72^\circ) = \cot 18^\circ$, but $\cot 18^\circ = \dfrac{1}{\tan 18^\circ}$ $\therefore \tan 72^\circ = \dfrac{1}{\tan 18^\circ}$.

As was shown earlier, the tan scale does not read below about 6°. But on small angles the sines and tangents are so nearly equal, that for practical purposes the sine may be assumed to be equal and used in place of tangents.

We have seen previously how to read sines on the slide rule. Now we will see how the value of the other ratios may be found. To read a cosine; set the right and left indices of the S scale coinciding with the right and left indices of the A scale. As with sines, we call the left index ·01, the centre index must therefore be 0·1 and right index 1. Subtract the angle from 90° and over this angle on the S scale you will find the cosine on the A scale. For example, cosine 58°. Cosine A we saw before is the same as sin (90° – A). So what we require here is sin 32° (90° – 58°). Over 32° on the S scale we find 53 on the right hand scale of A. So that cosine 58° = 0·53. Now we come to cosecants.

In this case we saw that $\text{cosec } A = \frac{1}{\sin A}$

So that now we pull out the slide either way till the angle on the S scale lies exactly under either the right or left index of the A scale. Then over the index of the S scale we find the cosecant on the A scale. In this case we call the left index of A, 1, and therefore the centre index 10, and the right index 100.

As an example we will find the cosec of 30°. Draw out the slide to the left till 30° on the S scale

lies exactly under the left index of the A scale. Now we see that exactly over the right index of the S scale is 2 on the left-hand scale of A, so that the cosec 30° = 2·0.

Next we come to secants. These are taken out in exactly the same manner as cosecants, except that now we use the complement of the angle or 90° – the angle.

For example.—Sec 67°. 67° = 90° – 23°. So we must use 23°.

Draw out the slide to the left till 23° on the S scale lies under the left index of the A scale. Then immediately over the right index of the S scale we find 256 on the left-hand scale of A, so that sec 67° = 2·56. Now we move on to the tangent scale again.

To find a cotangent all we have to remember is that cot A = tan (90° – A). We have seen previously how to read a tangent. So that now to read a cotangent, subtract the angle from 90° and look it up as a tangent.

For example.—Cot 65°. 90° – 65° = 35°. So that all we require is tan 35°.

Set the right and left indices of the T scale exactly over those of the D scale. Then immediately under 35° on the T scale read 7 on the D scale. Tan 35° = 0·7 ∴ cot 65° = 0·7.

CHAPTER II.

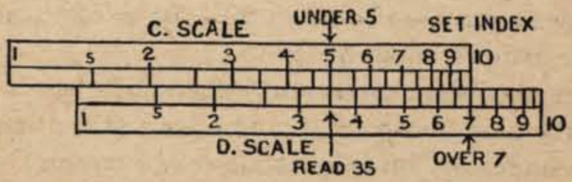
MULTIPLICATION.

Rule.—Set either index of C over the number to be multiplied on D, then under the multiplier on C read the answer on D.

This will be made much clearer by a few examples.

Example.—7 × 5.

First find 7 on the D scale, then draw the slide out to left till the right index of the C scale is exactly over 7 on the D scale. Now look along the C scale till you find 5 and set the hair-line of the runner to this and you will notice that it cuts the D scale exactly at 35·0. ∴ 7 × 5 = 35.



Example.—6 × 3.

Draw out the slide to the left till the right index of C is exactly over 6 on D, then move the runner

till the hair-line cuts the C scale at 3, and you will see that it cuts the D scale at 18. ∴ 6 × 3 = 18.

Example.—1·5 × 4.

Draw out the slide to the right this time till the left index of C is over 1·5 on D, move the runner till the hair-line cuts the C scale at 4. And you will see that it cuts the D scale at 6. ∴ 1·5 × 4 = 6.

Now we must have some means of telling where to put the decimal point.

The number of digits in a number is the number of figures before the decimal point or, if the number is less than 1, the number of digits will be the number of noughts after the decimal point and will of course be a minus quantity. For instance—

Number	3	number	of	digits	1.
,,	31	,,	,,	,,	2.
,,	340	,,	,,	,,	3.
,,	25789	,,	,,	,,	5.
,,	0·025	,,	,,	,,	−1.
,,	·000336	,,	,,	,,	−3.
,,	0·56	,,	,,	,,	0.

When multiplying together two numbers, if the slide projects to the left, add together the number of digits in the two factors, and the result will be the number of digits in the answer. If the slide projects to the right deduct 1 from this sum.

For example.—7 × 4.

Set the right index of C over 7 on D. Then under 4 on C you will find 28 on D.

The sum of the digits is $1+1=2$. The slide projects to the left, so there must be 2 digits in the answer. $\therefore\ 7\times 4=28{\cdot}0$.

Example.—16×5.

Set the left index of C over 16 on D, then under 5 on C read 8 on D.

The sum of the digits is $2+1=3$. The slide projects to the right, so we must subtract 1 from this sum, $3-1=2$. There are two digits in the answer. $\therefore\ 16\times 5=80$.

Example.—$5{\cdot}4\times 3{\cdot}7$.

Set the right index of C over 54 on D, then under 37 on C we read, 1998 on D.

The sum of the digits is $1+1=2$. The slide projects to the left. So there must be 2 digits in the answer. $\therefore\ 5{\cdot}4\times 3{\cdot}7=19{\cdot}98$.

In this case we find on placing the runner over 37 on C that it cuts the D scale at almost but not quite 2; in other words, somewhere between 1·99 and 2. We then judge that it is about ·8 of the distance between them and call the result 19·98. As a matter of fact one can often judge the last figure, as in this case, very simply. One can see at a glance that $5{\cdot}4\times 3{\cdot}7$ must end in an 8 as $4\times 7=28$. This gives us the last significant figure.

Now we come to the multiplication of more than two factors.

Example.—$6\times 3\times 8\times 26$.

Set the right index of C over 6 on D, now move the runner to 3 on C in the same manner as before, but in this case we do not read the D scale yet. Taking care not to move the runner, draw out the slide to the left till the right index of C lies exactly under the hair-line of the runner. Now move the runner to 8 on C, and again taking care not to move the runner, draw out the slide to the right till the left index of C lies exactly under the hair-line. Now move the runner up to 26 on C, and we find that it cuts the D scale at 374 and a little over. So we judge the last figure to be 4, making the answer 3744.

When multiplying by more than one factor at a time like this, the rule for placing the decimal point is slightly different. We still take the sum of all the digits, but now we subtract one for every time the slide projects to the right. In this case it was projecting to the left all the time until the last move. So we have only 1 to subtract. The sum of the digits will be $1+1+1+2=5$, subtract 1, $5-1=4$. There will therefore be 4 digits in the answer. $\therefore\ 6\times 3\times 8\times 26=3744$.

Example.—$2{\cdot}2\times 51\times 4\times 18$.

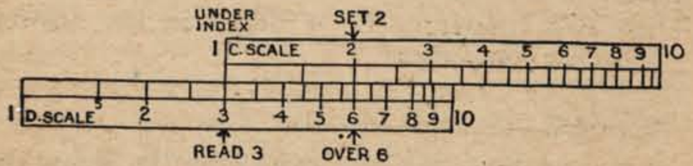
Set the right index of C over 22 on D, move the runner to 51 on C, and set the left index of C to the runner. Now move the runner up to 4 on C, and we notice that the slide is projecting to the right for the first time. Now set the left index of C to the runner and move the runner up to 18 on C, and we see that it cuts the D scale at 808, and also that for the second time the slide is projecting to the right. So to find the number of digits in the answer we must take the sum of the digits in the factors and subtract 2. This then will be $1+2+1+2-2=4$. There are therefore 4 digits in the answer which must then be 8080.

Division.

Rule.—Set the divisor on C over the dividend on D, then under the index of C read the quotient on D.

A few examples will illustrate this far clearer than a lengthy explanation. $6 \div 2$.

Set the runner to 6 on the D scale then draw out the slide to the right till 2 on the C scale lies exactly under the runner. Now looking at the left index of the C scale we see that it cuts the D scale at 3. $\therefore 6 \div 2 = 3$.



Example.—$8 \div 4$.

Set the runner to 8 on the D scale, then draw out

the slide to the right till 4 on the C scale lies exactly under the runner and then under the left index of the C scale we find 2. $\therefore 8 \div 4 = 2$.

Example.—$72 \div 12$.

Set the runner to 72 on the D scale, draw out the slide to the right till 12 on C is under the runner; this is known as setting 12 on C over 72 on D, then under the left index of C we find 6. $\therefore 72 \div 12 = 6$.

Example.—$15 \div 3$.

Set 3 on C over 15 on D and under the right index of C we read 5 on D. $\therefore 15 \div 3 = 5$.

To find the position of the decimal point or the number of digits in the answer.

If the slide projects to the left subtract the number of digits in the divisor from the number in the dividend. The result is the number of digits in the answer.

If the slide projects to the right add 1 to this difference.

For example.—$18 \div 72$.

Set 72 on C over 18 on D and under the right index of C we read 25. The slide projects to the left. There are 2 digits in 18 and 2 in 72. $2-2=0$. There are no digits in the answer therefore, and $18 \div 72 = 0{\cdot}25$.

Example—78 ÷ 65.

Set 65 on C over 78 on D and under the left index of C we read 12. There are 2 digits in 78 and 2 in 65 and the slide projects to the right. So we get $2-2+1=1$ digit in the answer. ∴ 78 ÷ 65 = 1·2.

When dividing by a series of numbers, in other words when we have more than one division, we proceed in the same way as before.

For example.— $\dfrac{14}{2\times4\times{\cdot}05\times1{\cdot}3}$

Set 2 on C over 14 on D, move the runner to the index of C, in this case the right index, and without moving the runner set 4 on C under the runner. Move the runner to the index of C again; this time it will be the left index, and set 5 on C under the runner; now move the runner to the index of C again, and set 13 on C under the runner, then under the index of C, the left index this time; we read the answer on D, 269.

We must now fix the position of the decimal point. The rule for this is: from the number of digits in the dividend subtract the sum of the number of digits in the divisor, adding 1 to his remainder for every time the slide projects to the right.

When we set 2 on C over 14 on D the slide projected to the left, but in the next move it projected to the right, the next time to the left again, and for the final move, to the right. Hence

we see that it projected to the right twice. So we have 2 to add. In the dividend 14, we have 2 digits. So we add our 2 to this making 4 in all. In the divisor, we have $1+1+(-1)+1=1+1-1+1=2$. $4-2=2$. There must be then 2 digits in the answer, which will be 26·9.

Example.— $\dfrac{252}{13\times22\times{\cdot}14\times{\cdot}06}$

Set 13 on C over 252 on D, the slide projects to the right; move the runner to the left index of C, and set 22 on C under the runner, the slide now projects to the left; move the runner to the right index of C, and set 14 on C under the runner, the slide again projects to the right; move the runner to the left index of C, and set 6 on C under the runner, once again the slide projects to the right, making three times in all. Now, under the left index of C, we read the anwer 105.

The slide projected to the right three times, so we have 3 to add to the number of digits. In the dividend, there are three digits, $3+3=6$. Now, in the divisor, we have $2+2+0+(-1)=4-1=3$ digits. This gives us $6-3=3$ digits in the answer.

$$\therefore \frac{252}{13\times22\times{\cdot}14\times{\cdot}06} = 105$$

Next we come to another case, a mixture of multiplication and division. There is no need to find the dividend and divisor separately and then

C

divide the former by latter, when using a slide rule, as may be made clear by a few examples.

To fix the position of the decimal we still stick to the same rules: if the slide projects to the right when multiplying subtract one from the sum of the digits, and if when dividing add one.

But now we say, that if the slide projects to the right more often when multiplying than when dividing *subtract* one from the total number of digits for each extra time. But if it projects to the right more often when dividing *add* one for each extra time.

Example.—$\dfrac{18 \times 24 \times 52}{23 \times 106}$

Set 23 on C over 18 on D and move the runner to 24 on C; we have now divided 18 by 23 and multiplied by 24 and the slide was projecting to the left all the time. Now set 106 on C under the runner and move the runner to 52 on C; we have now divided by 106 and multiplied by 52 and the slide projected to the right all the time, so that the slide has projected the same number of times for dividing as for multiplying. Thus the number of digits will be the number of digits in the dividend less the number of digits in the divisor.

In the dividend we have $2+2+2=6$, in the divisor $2+3=5$. So there will be 65 — = 1 digit in the answer.

Now if we look at the rule we see that the runner cuts the D scale at ·922. So the answer will be 9·22.

Example.—$\dfrac{6 \times 18 \times 13}{9 \times 14 \times 4}$

Set 9 on C over 6 on D and move the runner to 18 on C; so far for multiplying by 18 and dividing by 9 the slide has been projecting to the left. Now set 14 on C under the runner and then slide the runner to 13 on C, again we have both multiplied and divided with slide projecting to the left. Now set 4 on C under the runner and under the right index of C read the answer 278 on D.

As the slide did not project to the right at all the number of digits in the dividend less the number of digits in the division will be the number of digits in the answer.

In the dividend we have $1+2+2=5$ and in the divisor we have $1+2+1=4$, $5-4=1$. There will be 1 digit in the answer, which must then read 2·78.

Example.—$\dfrac{9 \times 7{\cdot}5 \times 40}{12 \times 11{\cdot}2}$

Set 12 on C over 9 on D and move the runner to 7·5 on C. At first sight this seems impossible, as the slide is projecting so far to the right that 75 on C is away outside the rule. So what we do is to set the runner to the left index of C, and then set the right index of C to the runner, now we move the runner to 75 on C. You will notice here that whereas the slide projected to the right in dividing by 12, now it projects left when we are multiplying by 75. So at present it has projected to the right for dividing but not for multiplying. Now set 112 on C under the runner, again it is projecting to the right for dividing by 11·2. Now to multiply by 40 we have to do the same as before: set the runner to the left index of C, set the right index under the runner and move the runner to 4 on C. Under the runner we read the answer, 201 on the D scale.

As the slide projected to the right twice when dividing, and did not project to the right at all for multiplying, we have to add 2 to the number of digits.

In the dividend we have $1+1+2=4$ digits, and in the divisor $2+2=4$ digits. So in the answer we must have $4-4+2=2$ digits. The answer then must be 20·1.

Powers of Numbers.

We noticed previously that the C and D scales are just twice the size of each part of the A and B scales and also that the scales are in logarithmic proportion. Hence we can see that if we set the runner to any number on the D scale, it will cut the A scale at a number whose logarithm is double that of the original number. But, if we double the logarithm of a number, we get the square of that number. So, from that, we see that if we set the runner to any number on the D scale, it will cut

the A scale at the square of that number. For example, if we set the runner to 4 on D, we see that it cuts the A scale at 16 or 4^2. Similarly, if we set the runner to 5 on D it cuts at 25 or 5^2 on the A scale.

To find a square root, we reverse this proceeding and set the runner to the given number on A, and where the runner cuts the D scale we find the square root.

For example, if we set the runner to 49 on A, we see that it cuts the D scale at 7 or $\sqrt{49}$.

To find the number of digits when taking out the square of a number, if the answer lies on the right-hand scale of A, double the number of digits in the given number, but if on the left-hand scale, subtract 1 from this.

When taking out a square root, if the original number is on the right-hand scale of A, halve the number of digits, but if on the left-hand scale, add 1 to the number of digits in the original number and halve the result; this will give the number of digits in the answer.

When finding a square root, if the number of digits in the original number is even, always use the right-hand scale of A or B, but if it is odd use the left-hand scale.

To find the cube of a number, set the index of C over the number on D, and then over the same number on B read the cube on A.

For example.—To find the value of 3^3.

Set the left index of C over 3 on D and over 3 on B, read 27 or 3^3 on A. It is possible to take out many other powers and roots on the slide with a single setting, but as it involves remembering different rules for each one, it is simpler in the long run to use logarithms for any others, as too many rules only make for confusion.

CHAPTER III.

PROPORTIONS AND PERCENTAGES.

The slide rule is primarily a proportional instrument, percentages being only a special case in proportions, all these can be worked very simply.

The simplest way to explain the method of working these will be to give a few examples.

Example.—A vessel steams 432 miles, while her log shows a distance of 448 miles. What is her log percentage? $448-432=16$.

Set 448, the log distance, on C over 16, the difference between the log distance and the true distance on D, then under the right index of C we read 3·57 on D.

Log reads 3·57 $^{\circ}/_{\circ}$ fast.

Example.—A ship's log reads 3·4 $^{\circ}/_{\circ}$ slow, what distance must it show for the ship to have run 247 miles? $100-3·4=96·6$.

Set 966 on C over 100 on D, then under 247 on C we read 256 on D.

Log must show 256 miles.

Example.—Distance shown by revolutions 345 miles, actual distance run 328 miles, required the slip $^{\circ}/_{\circ}$. $345-328=17$.

Set 345 on C over 17 on D, and under the right index of C read 492.

Slip $^{\circ}/_{\circ}$=4·92 fast.

Example.—A broker receives 7$^{\circ}/_{\circ}$ commission on a freight of £240.

Set right index of C over 7 on D, and under 240 on C read 16·8 on D.

Broker receives £16·8 or £16 16s.

Example.—A ship steams for 17 hours and burns 33 tons of coal, over a distance of 210 miles.

1. What is her daily consumption?
2. How much coal will she burn on a run of 670 miles?
3. How many miles can she run on 490 tons of coal?
4. What will be her day's run?
5. What is her speed?

1. Set 33 on C over 17 on D, and over 24 on D we read 46·6 on C.

Daily consumption 46·6 tons.

With the rule set like this, over any number of hours on D, we find the coal burnt in that time on C, and under any number of tons on C, we find the time taken to burn that amount on D.

2. Set 33 on C over 210 on D, then over 670 on D we read 105·2 on C.

In this case the slide is projecting too far to the left for us to read the required amount on C, so we

set the runner to the right index of C, and then set the left index under the runner. Now we can read the answer above 670 on D.

Ship burns 105·2 tons.

With this setting, we set tons on C over miles on D. So that under any number of tons on C we find the corresponding mileage on D, and over any miles on D the corresponding tons on C.

3. With rule still set the same as in the previous example. Under 490 on C we read 3120 on D.

Runs 3120 miles on 490 tons of coal.

4. Set 17 on C over 210 on D, and under 24 on C we read 296·5 on D.

Day's run 296·5 miles.

This time we set hours on C over miles on D, so that all numbers on C will be hours and below them the corresponding miles on D.

5. With the rule set as in the previous example under 1 or the left index of C we read 12·35 on D.

Speed 12·35 knots.

Example.—A steamer has a speed of 11·5 knots, how long will she take to run 7·4 miles?

In 60 minutes she runs 11·5 miles.

So we set 11·5 on C over 60 on D, and under 7·4 on C we read 38·6 on D.

Here again we have to set the runner to the left index of C and then set the right index under the runner before we can read off the required time.

Time taken 38·6 minutes.

Example.—A steamer runs 11 miles in 40 minutes. What is her speed?

Set 11 on C over 40 on D, and over 60 on D we read 16·5 on C.

∴ in 60 minutes or 1 hour she runs 16·5 miles.

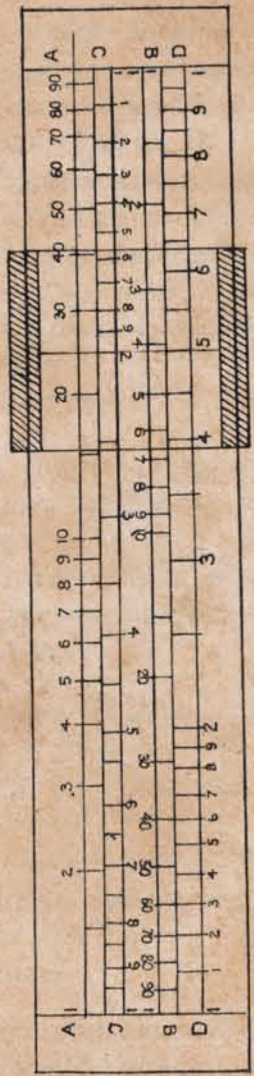
Here we set miles on C over minutes on D, so that all numbers on C must be miles and on D minutes.

Inverse Proportion.

In inverse proportion, when one of the parts increases, the other decreases. So, to do these problems, we must invert the slide; that is to say, turn it upside down, still leaving the B and C scales on the face of rule, but now the C scale lies along the A scale, and the B scale along the D scale, so that the order of the scales is now A, C inverted, B inverted, D.

In these problems, we have to use the runner all the time, both to set the rule and to read it afterwards.

The above sketch shows the slide rule with the slide inverted; and the runner set to 5 on D. It will be noticed that the runner cuts the inverted C at 2. $\frac{1}{5} = \cdot 2$. So that we see that with the slide set with indices coinciding, over any number on D, we find its reciprocal on C inverted and *vice versa*. The same thing, of course, applies to the A and B inverted scales.



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Example.—If 5 men do a job in 17 days, how long will 7 men take over the same job?

Set 5 on C inverted over 17 on D, and under 7 on C inverted read 12·14 on D.

To set 5 on C inverted over 17 on D, we have, first of all, to set the runner to 17 on D, then pull out the slide till 5 on the inverted C scale lies under the runner. Then we move the runner till it lies over the 7 on C inverted, and we see that it cuts the D scale at 12·14.

7 men take 12·14 days.

Example.—A ship steaming at 8 knots takes 67 hours to reach her destination, how long will she take at 12·5 knots?

Set 8 on C inverted over 67 on D, then under 12·5 on C inverted we read 42·9 on D.

Takes 42·9 hours.

Example.—A ship steaming at 12 knots will reach her destination in 23 hours. She does not wish to arrive before 27 hours, at what speed must she steam?

Set 12 on C inverted over 23 on D, move the runner to 27 on D, and we see that it cuts the C inverted scale at 10·2.

Speed 10·2 knots.

Example.—A vessel loads 92 tons of cargo at a distance of 72 feet forward of the tipping centre, how far abaft the tipping centre must she place 145 tons, to maintain the same trim?

Set 92 on C inverted over 72 on D, then under 145 on C inverted we find 45·6 on D.

45·6 feet abaft the tipping centre.

CHAPTER IV.

SLIDE RULES FOR CARGO WORK.

As a general rule the space in a ship's hold is measured on a basis of 40 cub. ft. to the ton measurement.

It often happens that the mate is told that he has so many tons weight of some commodity to load. He then wishes to know how much space it is going to occupy in the holds.

Say, for instance, he has 3700 tons of soya beans to load; 1 ton weight soya beans will stow in about 55 cub. ft. This is now simple proportion as described in Chapter III. What we wish to know may be set out as—40 : 55 :: 3700 : x. So we set 55 on C over 40 on D, then over any number of tons weight on D we find the tons space at 40 cub. ft. on C, and under any space at 40 cub. ft. on C we find tons weight on D.

In this case over 3700 on D we read 5090 on C.

Space required 5090 tons.

Or if he has, say, 480 tons space in a hold, and he wants to know how many tons of beans it will hold.

With rule still set as before under 480 on C we read 349 on D, 349 tons of beans.

To take another case. You have a deep tank that will hold, say, 872 tons of salt water. How many tons of molasses will it take?

Bulk molasses stow in about 27 cub. ft. to the ton weight; salt water in 35 cub. ft.

Set 35 on C over 27 on D, then over 872 on D read 1130 on C.

1130 tons of molasses.

When working with liquids like this, it is often better or simpler to use the specific gravity.

For example.—A certain tank will hold 420 tons of salt water; S.G. of salt water 1·025. How much linseed oil S.G. 0·94 will it hold?

Set 0·94 on C over 1·025 on D, then over 420 on D we read 385 on C.

385 tons of linseed oil.

In this case we have to set the runner to the right index of C, then set the left index to the runner before we can read off the result.

In certain ports instead of being told that you have so many tons space to load, you are told that you have so many cub. metres. You then wish to know how many tons space or cub. ft. that is.

At the end of the book there is a list of gauge points, turning to this we find for cub. metres, tons at 40 cub. ft., 17:15 and for cub. metres: cub. ft. 17:600.

So that now to convert say 624 cub. metres to tons at 40 cub. ft., we set 15 on C over 17 on D, then over 624 on D we read 550 on C.

624 cub. metres = 550 tons.

Or, if we set 600 on C over 17 on D, over 624 on D we find 22000 on C.

624 cub. metres=22000 cub. ft.

One of the handiest uses of a slide rule is for working out the space occupied or remaining in a compartment. We all know what a tedious business it is working out space after we have measured up. But with a slide rule the whole job can be done in a few seconds. It is simply a case of multiplication and division, as described in Chapter II.

Having measured the space, we simply set the index of C to the length on D, move the runner to the breadth on C, set 40 on C under the runner, move the runner to the height on C, and where the runner cuts the D scale we have the space at 40 cub. ft.

Or, if we are loading, say, the soya beans again which stow at 55 cub. ft., we set the index of C to the length on D, move the runner to the breadth on C, set 55 on C under the runner, and under the height on C we find the number of tons of beans the space will hold on D.

For example.—Length 28 feet, breadth 21 feet, height 11 feet.

the total sinkage. Set 49·3 on C over 520 on D, and under the left index of C read 10·5.

Sinkage 10½ inches.

520 tons × 85 feet ÷ 1230 (the I.T.M.) gives the change of trim. Set 1230 on C over 520 on D, and under 85 on C read 36 on D.

Change of trim 36 inches.

Original draft for'd	23′ 00″	Aft	23′ 00″
Sinkage	+ 10½		+ 10½
	23 10½		23 10½
½ change of trim	+1 6		−1 6
Final draft for'd	25′ 4½″	Aft	22′ 4½″

Remember that discharging a weight from aft has the same effect on the trim as loading one forward and *vice-versa.*

Change of Draft.

Having loaded a ship in fresh water you wish to know what her draft will be when you arrive in salt water. There are several ways of working this problem. Given here in the order of accuracy—

1. Displacement × ·025 ÷ T.P.I., or tons per inch immersion, gives the change of draft in inches.

2. On the load line certificate you will find the allowance for fresh water marked up. This allowance divided by the maximum draft of the vessel,

and multiplied by the draft at the time of the observation, gives the change of draft in inches.

3. The draft in feet multiplied by 0·25 gives the change of draft in inches.

To illustrate the accuracy of these formulæ we will work them out on the slide rule.

Taking actual figures again from the same ship as in the previous problem. We have displacement 12,000 tons, draft 23 feet, T.P.I. 49·3 tons, maximum draft 28 feet 3½ inches, fresh water allowance from load line certificate 7 inches.

1. Set 49·3 on C over 12,000 on D, and under ·025 on C we read 6·1 on D.

Change of draft 6·1 inches.

2. Set 28·3 on C over 7 on D, and under 23 on C we read 5·7 on D.

Change of draft 5·7 inches.

3. Set the left index of C over 23 on D, and under ·25 on C we read 5·75 on D.

Change of draft 5·75 inches.

For water of other densities.

Take the difference between the specific gravity (S.G.) of the water left and that of the water entered.

1. The displacement multiplied by the difference in S.G. and divided by the T.P.I. gives the change of draft in inches.

2. The allowance for fresh water from the load line certificate divided by the vessel's maximum draft, multiplied by the draft, divided by ·025 and multiplied by the change in S.G. gives the change in draft in inches.

3. The draft in feet multiplied by 10 times the change in S.G. gives the change of draft in inches.

Taking the same vessel as before and at the same draft. The S.G. of the water left was 1·008, and that of the water entered 1·025.

1·025 − 1·008 = ·017.

1. Set 49·3 on C over 12000 on D, and under 0·17 C we read 4·14 on D.

Change of draft 4·14 inches.

2. Set 28·3 on C over 7 on D, move the runner to 23 on C, set ·025 on C under the runner, and under ·017 on C we read 3·88 on D.

Change of draft 3·88 inches.

3. Set the left index of C over 23 on D, and under 0·17 on C we read 3·91 on D.

Change of draft 3·91 inches.

The safe working load of manila or hemp rope may be found by the formula $\frac{\text{circumference}^2}{7} = \text{S.W.L.}$ in tons.

On the slide rule this would be: set the runner to the size of the rope on the D scale, set 7 on the

B scale under the runner, and over the index of B read the S.W.L. on A in tons.

Example.—Find the S.W.L. of a $2\frac{1}{2}$-inch rope.

Set the runner to 2·5 on D, place 7 on B under the runner, and over the index of B read ·9 or very nearly ·9 on A.

S.W.L. of $2\frac{1}{2}$-inch rope 0·9 ton.

To find the smallest rope that may be used for a given strain.

Set either index of B under the load on A, move the runner to 7 on B, and on the D scale under the runner read the size of rope required.

For example.—Find the smallest rope required to lift $1\frac{1}{2}$ tons.

Set the left index of B under 1·5 on A, move the runner to 7 on B and we see that the runner cuts the D scale at 3·24.

Rope required $3\frac{1}{4}$ inch.

For the S.W.L. of steel wire we have the formula $\text{S.W.L.} = \frac{\text{circumference}^2}{3}$. So, in this case, we set the runner to the size of the wire on D, place 3 on B under the runner, and over the index of B read the S.W.L. on A.

For example.—Find the S.W.L. of a $2\frac{1}{4}$-inch wire. Set the runner to 2·25 on D, place 3 on B under the runner, and over the left index of B we read 1·7 on A.

S.W.L. = 1·7 tons.

To find the smallest wire required for a given load. Set either index of B under the load on A, then under 3 on B we read the size of wire required on D.

Example.—Find the smallest wire required to lift $2\frac{1}{4}$ tons. Set the left index of B under 2·25 on A, then under 3 on B we read 2·6 on D. Size of wire 2·6 inches or $2\frac{1}{2}$ inches would be sufficient to lift the weight.

To find the S.W.L of chains.

$$\text{S.W.L.} = \frac{(\text{diameter in } \tfrac{1}{8}\text{'s of an inch})^2}{10}$$

The diameter being the diameter of the metal forming the links, set the runner to the diameter in $\frac{1}{8}$'s on D, and where the runner cuts the A scale read the S.W.L.

Example.—Find S.W.L. of a $\frac{1}{2}$-inch chain. $\frac{1}{2} = \frac{4}{8}$. Set runner to 4 on D and under the runner read 1·6 on A.

Therefore S.W.L. 1·6 tons.

To find the smallest chain to use for a given load. Set the runner to the load A, then set 8 on C under the runner, and under the index of C read the size of chain on D.

Example.—Find the size of chain required for

a load of 12 tons. Set the runner to 12 on A, set 8 on C under the runner, and under the right index of C read 1·37 on D.

The diameter of the link must be not less than 1·37 inches.

To find the number of parts of a smaller rope required to equal the strength of a larger one. Set the size of the smaller rope on C over the larger on D, then over the left or right index of B we read the required number of parts on A.

Example.—How many parts of a 3-inch rope are required to equal a 7-inch rope. Set 3 on C over 7 on D, then over the left index of B read 5·45 on A.

6 parts would be required.

Stresses and Strains.—

When dealing with heavy lifts it is sometimes very important to know what is the strain on the topping tackle or the fall and the thrust on the derrick.

The best way to show how this may be found is by a diagram and an example.

In the figure we have—

AB the mast

BC the derrick

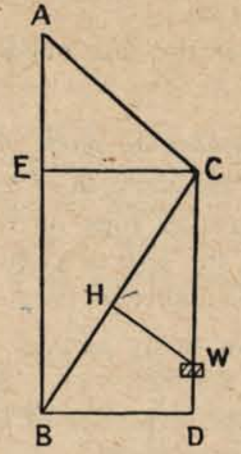
AC the topping tackle

W a weight suspended from C

BD the deck line

Draw EC parallel to BD

Make CW of a length proportional to the weight W
Draw WH parallel to AC



Now if CW represents the weight, CH represents the thrust on the derrick and HW the strain on the topping tackle.

We will take a derrick 60 feet in length with topping tackle made fast to a point on the mast 80 feet above the heel of the derrick. The derrick head plumbing a point 32 feet from the heel and a weight of 20 tons suspended from the head of derrick.

We now have to solve the triangle CHW.

We have already made CW equal to the weight or 20. Since HW is parallel to AC and AB is parallel to CW.

$\angle HCW = \angle ABC$, $\angle HWC = \angle BAC$ and $\angle CHW = \angle ABC$

We must now reverse the slide and use the sines and tangents.

Set the right index of S under 60 (the length of derrick) on A, then under 32 (BD or EC in the figure) on A read $32\frac{1}{4}°$ on S, and over $57\frac{3}{4}°$ $(90° - 32\frac{1}{4}°)$ on S we read 50·7 on A.

$\therefore \angle ABC = 32\frac{1}{4}° = \angle HCW$

and BE or CD = 50·7 feet. As AB = 80 feet and EB = 50·7 feet, we see that AE must be 80 − 50·7 or 29·3 feet.

Set the right index of T over 32 (EC) on D and over 29·3 (AE) on D we read $42\frac{1}{2}°$ on T.

As AE is less than EC, $\angle ACE$ must be less than $\angle EAC$.

$\therefore \angle ACE = 42\frac{1}{2}$ and $\angle EAC = 47\frac{1}{2}°$

$\angle EAC = \angle HWC \therefore HWC = 47\frac{1}{2}°$

In the triangle CHW we now know that $CW = 20$, $\angle HWC = 47\frac{1}{2}°$ and $HCW = 32\frac{1}{4}°$.

$\therefore CHW = 180° - (47\frac{1}{2}° + 32\frac{1}{4}°) = 180° - 79\frac{3}{4} = 100\frac{1}{4}°$

The sine scale on the slide rule only reads up to 90°, but as $\sin A = \sin (180° - A)$ we subtract $100\frac{1}{4}°$ from 180. $180° - 100\frac{1}{4} = 79\frac{3}{4}°$

Now under 20 (ton) on A we set $79\frac{3}{4}°$ on S, then over $32\frac{1}{4}°$ on S we read 10·8 on A and over $47\frac{1}{2}°$ on S we read 15 on A.

Thrust on derrick 15 tons.

Strain on topping tackle 10·8 tons.

If the height of the mast and length of the derrick are not known the angle may be judged by eye.

For example.—In the foregoing, if we judge the angle between the mast and the derrick to be 30° and that between the mast and topping tackle to be 45°, the remaining angle must be 180°−(30°+45°) =105°.

180°−105°=75°

Set 75° on S under 20 (tons) on A, then over 30° on S we read 10·4 on A and over 45° on S we read 14·7 on A.

Thrust on derrick 14·7 tons.

Strain on topping tackle 10·4 tons.

In the same way we can find the strain on the falls when using a span.

For example.—In handling a weight of 2 tons using a span, the angle between one fall and the vertical being 40° and the other 65°.

180°−(40°+65°)=180°−105°=75°.

Set 75° on S under 2 (ton) on A, then over 40° on S we read 1·33 (ton) the strain on the 2nd fall, and over 65° on S we read 1·88 (ton) the strain on the 1st fall on A.

If we increase these angles between the falls and the perpendicular to 80° and 60°.

180° − (80° + 60°) = 180° − 140° = 40°.

Set 40° on S under 2 (ton) on A, and over 80° on S, we read 3·06 (ton) the strain on the 2nd fall,

and over 60° on S, we read 2·69 (ton) the strain on the 1st fall.

To find the metacentric height for stability.

$$G M = \frac{w \times d}{W} \cot \theta.$$

Where G M is the metacentric height
W the displacement
w the weight applied or moved
d the distance moved or distance from the middle line of the vessel
θ the angle of heel

Example.—A weight of 10 tons was suspended from a derrick at a horizontal distance of 40 feet from the middle line of the vessel. A plumb line, 72 inches in length, moved a distance of 2 inches, displacement 5000 tons.

Set 5000 on C over 40 on D, move the runner to 72 on C, now set 2 on C under the runner, and under the left index of C we read 2·88 on D.

G M = 2·88 feet.

To find the weight of a consignment of timber, the measurement of which is given in board feet.

1 board foot=1 foot×1 foot×1 inch. In other words, 12 board feet are equal to 1 cub. ft.

At the end of this book you will find tables giving the weight per cub. ft. of various woods and metals.

The number of cub. ft. multiplied by the weight per cub. ft. will give the total weight in lbs. This divided by 112 gives the weight in cwts., or divided by 2240 the weight in tons. To find the weight of 14,500 board feet of American oak in tons. American oak weighs about 50 lbs. per cub. ft.

Set 12 on C over 14,500 on D, move the runner to 50 on C, then set 2240 on C under the runner, and under the left index of C we read 27 on D.

Weight is 27 tons.

To find the weight of a piece of timber, say, 40 feet long by 1 foot by 18 inches (18 inches = 1·5 feet), the wood being pitch-pine, weighing 38 lbs. per cub. ft.

$40 \times 1 \times 1{\cdot}5 \times 38$ gives weight in lbs.

Set the left index of C over 40 on D, move the runner to 1·5 on C, set the right index of C under the runner, and under 38 on C we read 2280 lbs. on D.

Weight 2280 lbs.

To find the space required to stow a consignment of timber in board feet.

The space required will, of course, vary considerably with the size of the pieces of timber and the method of stowage, but a good average approximation can be found by multiplying the board feet by 4 and dividing by 1000, the result being the space required in tons at 40 cub. ft. to the ton. For example, we previously found the weight of 14,500 board feet of American oak. Now to find the space it should

occupy in the hold. Set the left index of C over 14,500 on D, and under 4 on C we read 58 on D.

Space required 58 tons.

Or to reverse the proceeding. We have, say, 86 tons space in a hold and we wish to know how many board feet of timber it will hold. Set 4 on C over 86 on D, and under the left index of C we read 21·5 on D. This multiplied by 1000 gives the required number of board feet.

So the space will take 21,500 board feet of timber.

To find the volume or cubic contents of a round log. Set the index of C over the mean diameter on D, now move the runner to the length on the B scale, then set the right index of B under the runner, and over ·7854 $\left(\frac{\pi}{4}\right)$ on B we read the volume on A.

On some rules you will find this point, ·7854, marked on the rule.

Example.—Find volume of a log 25 feet in length, mean diameter 2 feet. Set the left index of C over 2 on D, move the runner to 25 on B. Set the right index of B under the runner, and over ·7854 on B we read 78·5 on A.

Volume of log 78·5 cub. ft.

If the mean circumference is given and not the diameter, we must first find the diameter by the formula, diameter = circumference $\div \pi$.

On the C scale you will find π marked at 3·1416.

Set π on C over the circumference on D, and under the index of C we read the diameter on D.

Example.—Find volume of a log length 30 feet, mean circumference 6 feet. Set π on C over 6 on D, and under the left index of C we read 1·91 on D.

Diameter = 1·91 feet.

In practice there is no need to read off the diameter at all. Simply set π on C over 6 on D, now move the runner to 30 on B. Set the right index of B under the runner, and over ·7854 on B we read 86 on A.

Volume of log 86 cub. ft.

To find the weight of the log we must multiply the volume by the weight per cub. ft. found in the appendix of this book and the result is the weight in pounds, which divided by 112 gives us the weight in cwts. or by 2240 the weight in tons.

Assuming the above log to have been of pitch-pine. We find in the table that pitch-pine weighs about 38 lbs. per cub. ft. Set the right index of C over 38 on D, and under 86 on C we read 3270 on D.

Weight = 3270 pounds (lbs.).

Or set 112 on C over 38 on D, and under 86 on C we read 29·2 on D.

Weight = 29·2 cwts.

Or set 2240 on C over 38 on D, and under 86 on C we read 1·46 on D.

Weight = 1·46 tons.

To find the weight of a pipe.

First we must find the volume of the metal forming the pipe. The formula for this is:—

$$\text{Volume} = \frac{\pi}{4}\,(D^2 - d^2)\,l.$$

Where D is the outside diameter, and d the inside diameter, l the length.

For example.—A pipe made of cast iron, length 24 feet, outside diameter 8 inches, inside diameter 6 inches.

Set 12 on C over 8 on D (this gives us the outside diameter in feet) now over the left index of B we read ·455 (the diameter in feet)² on A. Set 12 on C over 6 on D, and over the left index of B we read ·25 (the inside diameter in feet)² on A.

So $D^2 - d^2 = {\cdot}445 - {\cdot}25 = {\cdot}195$.

Set the left index of C over ·195 on D, move the runner to π (3·1416) on C, set 4 on C under the runner, and under 24 (the length) on C we read 3·67 on D.

Volume = 3·67 cub. ft.

Cast iron weighs 450 lbs. per cub. ft.

So set the right index of C over 450 on D, and under 3·67 on C we read 1652 on D.

Weight = 1652 lbs.

Or set 112 on C over 450 on D, and under 3·67 on C we read 14·75 on D.

Weight = 14·75 cwts.

Or set 2240 on C over 450 on D, and under 3·67 on C we read ·7375 on D.

Weight = 0·7375 tons.

On the use of multiple line runners.

As was mentioned in the description of the rule in Chapter I., one sometimes finds two or three hair-lines marked on the runner. The object of these extra lines is to simplify the working of problems dealing with the relation between the diameter and the area of a circle.

If we set the middle line of a three-line runner to the right index of the A or B scales, we see that the left hand line on the runner cuts the scale at ·7854 or $\frac{\pi}{4}$. On many rules you will find this point marked on the scales.

If we set the middle line of the runner, then, to any number on A, we find under the left-hand line that number $\times$ ·7854 or $\frac{\pi}{4}$.

Now the formula for finding the surface area of a circle is, area $= \frac{\pi}{4} d^2$, where d is the diameter.

So that to find the area of a circle with diameter, say, 2·5 feet, we set the middle line of the runner to 2·5 on D, when it will of course cut the A scale at $2{\cdot}5^2$; we then look to see where the left-hand line of the runner cuts the A scale and read the area 4·9 sq. ft.

Now though we do not very often require the surface area of a circle, what we do sometimes wish to know is the volume of a cylinder or a log, the formula for which is,

volume $= \frac{\pi}{4} d^2 l$, where d is the diameter and l the length.

So we set the index of C over d on D, then set the middle line of the runner to l on B, and under the left-hand line on the A scale we read the volume.

Example.—Length 37 feet, diameter 3·5 feet.

Set the right index of C over 3·5 on D, then set the middle line of the runner to 37 on B, and under the left-hand line we read 355 on A.

Volume 355 cub. ft.

When using a two line runner, substitute the words "right-hand line" for middle line of the runner.

CHAPTER V.

COASTING.

ONE of the most useful points about a slide rule is its handiness when coasting. There are times when for many reasons it is not convenient or even possible to slip into the chartroom to lay off bearings on a chart, etc. By the use of the slide rule many problems may be worked out in less time than it would take plotting on the chart, and by the light of the binnacle.

1. *To find the distance a vessel will pass off a light and the distance to run to bring it abeam.*

Set the right index of S under the range of the light on A, then over the angle on the bow on S read the distance the ship will pass off the light on A, and over (90° – angle on the bow) read the distance to run to bring it abeam.

Example.—Observed a light with a range of 18 miles, bearing 32° on the bow. Set the right index of S under 18 on A, then over 32° on S read 9·54 on A, and over 58° (90° – 32°) on S read 15·25 on A.

Passes 9·54 miles off the light. 15·25 miles to run.

2. *To find the course to steer to pass a given distance off a light.*

Set the right index of S under the range of the light on A, then under the distance you wish to pass off on A read the angle on the bow on S, and over (90° – angle on the bow) read the distance to run to bring the light abeam on A.

Example.—Observed a light, range 20 miles, bearing N. 40° E. What course must be steered to pass 6 miles to the southward of the light?

Set the right index of S under 20 on A, then under 6 on A read $17\frac{1}{2}°$ on S, and over $72\frac{1}{2}°$ ($90° - 17\frac{1}{2}°$) on S read 19·1 on A.

Angle on the bow $17\frac{1}{2}°$.

Distance to the beam bearing 19·1 miles.

Light bearing N. 40° E., angle on the bow $17\frac{1}{2}°$. As we wish to pass to the right of the light we add this angle to the bearing.

N. 40° E. + $17\frac{1}{2}°$ = N. $57\frac{1}{2}°$ E.

Course to steer N. $57\frac{1}{2}°$ E.

3. *To find the distance off by two bearings and the run between them.*

Subtract the first angle on the bow from the second angle on the bow.

Set this difference on S under the distance run on A, then over the second angle on the bow on S read the distance off at the first bearing on A, and over the first angle on the bow on S read the distance off at the second bearing on A.

Example.—Ship steering N. 60° E. First bearing N. 40° E. Second bearing N. 10° W. Run in the interval 7 miles.

N. 40° E. to N. 10° W. = 50°.

First angle on the bow 20°, second angle on the bow 70°.

Set 50° on S under 7 on A, then over 70° on S read 8·6 on A, and over 20° on S read 3·12 on A.

Distance off at first bearing 8·6 miles.

Distance off at second bearing 3·12 miles.

4. *To find the distance a vessel passes off abeam by a single bearing and the run to the beam.*

Angle from the beam less than 45°.

Set the angle from the beam on T over the distance run on D, then under the index of T read the distance off abeam on D.

Angle from the beam more than 45°.

Set the index of T over the distance on D, and under (90° − angle from the beam) read the distance off abeam on D.

Example.—A light was observed 30° forward from the beam; after running for 5 miles it was abeam.

Set 30° on T over 5 on D, then under the right index of T read 8·67 on D.

Passes 8·67 miles off.

Example.—A light was observed 75° forward of the beam; after running 22 miles it was abeam.

Set left index of T over 22 on D, and under 15° (90° − 75°) on T read 5·9 on D.

Passes 5·9 miles off.

Some may prefer to use the following method, as no matter how large or small the angle from the beam may be the setting is always the same.

Set the angle from the beam on S under the distance run on A and over (90° − angle from the beam) on S we read the distance off abeam on A.

Example.—Observed a lighthouse bearing N. 20° E. After running for 12 miles it was abeam. Ship steering N. 55° E.

N. 55° E. − N. 20° E. = 35°. ∴ angle from bow 35°, angle from the beam 55°.

Set 55° on S under 12 on A, and over 35° on S we read 8·4 on A.

Distance off abeam 8·4 miles.

5. *To find the distance to run to bring a light to a particular bearing, and the distance off at that bearing.*

Set the required angle on the bow (or quarter) on S, under the distance off on A, then over the original angle on the bow on S read the required distance off on A, and over the difference between the bearings read the distance to run on A.

Example.—A light bore 20° on the bow, distant

12 miles; when will it bear 55° on the bow and how far off will it then be?

Set 55° on S under 12 on A, then over 20° on S read 5 on A, and over 35° (55° − 20°) on S read 8·4 on A.

8·4 miles to run.

5 miles off the light.

6. *To fix the position by cross bearings without laying off on the chart.*

For this problem we must know the exact course and distance between the two points. We then proceed in the same manner as in fixing the position by two bearings and the run between them.

Under the distance between the two points on A. Set the difference between the two bearings on S, then over the angle between the bearing of the first point and the course between the points on S read the distance off the second point on A, and over the angle between the second bearing and course between the points on S read the distance off the first point on A.

Example.—The Mouse lightship bears N. 88° E. 4 miles from S. Shoebury buoy, and the lightship bore N. 43° E. and the buoy N. 10° W.

From N. 43° E. to N. 10° W. is 53°.

The angle at the lightship N. 88° E. to N. 43° E. = 45°.

The angle at the buoy N. 88° E. to N. 10° W. = 98°. 180° − 98° = 82°.

Under 4 on A set 53° on S, then over 45° on S read 3·54 on A, and over 82° on S read 4·94 on A.

Mouse lightship distant 4·94 miles.

S. Shoebury buoy distant 3·54 miles.

7. *To find the course to steer to counteract a current of known direction and strength.*

Set the angle between the ship's course and the direction of the current on S, under the speed of the ship on A, then under the speed of the current on A read the angle to counteract the current on S. Then if the current is a favourable one add this angle to the angle between the course and the current; or if it is adverse, subtract it, and over the resultant angle on S read the speed made good on A.

Example.—A ship steaming at 12 knots experiences a current setting S. 60° E. at 2 knots. What course must she steer to make good a S. 32° E. course?

From S. 32° E. to S. 60° E. is 28°. So the angle between the ship's course and the current is 28° and the current is favourable.

Set 28° on S under 12 (knots) on A, then under 2 (knots) on A read $4\frac{1}{2}$° on S, and over $32\frac{1}{2}$° (28° + $4\frac{1}{2}$°) on S read 13·7 on A.

The current is setting the ship to the left so we must steer more to the right.

S. 32° E. $-4\frac{1}{2}°=$ S. $27\frac{1}{2}°$ E.

Course to steer S. $27\frac{1}{2}°$ E. Speed made good 13·7 knots.

Example.—A ship steaming at 11 knots wishes to make good course N. 20° E., current setting S. 50° W. $1\frac{1}{2}$ knots.

From N. 20° E. to S. 50° W. is 150°. $180°-150°=30°$.

Angle between course and current 30°, current adverse.

Set 30° on S under 11 (knots) on A, then under 1·5 (knots) on A read 4° on S and over 26° (30° − 4°) on S read 9·64 on A.

The current is on the starboard bow. So we must steer more to starboard to counteract it.

N. 20° E. +4° = N. 24° E.

Course to steer N. 24° E.

Speed made good 9·64 knots.

8. *To find the distance off by vertical danger angle.*

In using this method the object should not be beyond the visible horizon. This may be worked with the slide either in the normal position or inverted.

For a single angle nothing is gained by inverting the slide, but for a series of angles of the same object it will be found handier to invert the slide.

The height of the object in feet multiplied by

0·565 and divided by the altitude in minutes gives the distance off in miles.

First method with the slide in the normal position. Set the altitude in minutes on C over the height of the object in feet on D, then under ·565 on C read the distance off in miles on D.

Second method with slide inverted. Set 0·565 on C inverted over the height in feet on D, then under the altitude in minutes on C inverted read the distance off in miles on D.

Example.—A lighthouse 210 feet high has an altitude of 45′.

Set 45 on C over 210 on D, then under ·565 on C read 2·64 on D.

Distance off 2·64 miles.

Example.—A lighthouse 352 feet high has an altitude of 33′ and later was found to have an altitude of 58′.

Required distance off at each observation. Set 0·565 on C inverted over 352 on D, then under 33′ on C inverted read 6·02 on D, and under 58′ on C inverted read 3·43 on D.

Distance at first angle 6·02 miles; distance at second angle 3·43 miles.

In using this method once we have set ·565 on C inverted over the height on D; we only have to move the runner to the altitude on C inverted to read off the distance on D. In this way any number of angles may be taken without having to reset the slide.

9. *To find the distance off by vertical angle of an object beyond the visible horizon.*

From the observed altitude subtract $\frac{1}{12}$ of the estimated distance from the object and the correction for dip from the accompanying table.

DIP OF THE SEA HORIZON.

Height of Eye. Ft.	10	15	20	25	30	35	40	45	50	55	60
Dip.	3·1′	3·8′	4·4′	4·9′	5·4′	5·8′	6·2′	6·6′	6·9′	7·3′	7·6′

Next correct the height of the observed object for the curvature of the earth. To do this multiply the square of the estimated distance by 0·885, and subtract the result from the height of the object in feet.

Now the corrected height × ·565 ÷ corrected altitude in minutes gives the distance off in miles.

Example.—The altitude of a hill, 6420 feet high, distant about 32 miles, was 1° 44′. Height of eye 40 feet.

Dip for 40 feet	6·2′	Observed alt.	1° 44′
32/12 =	2·7	Correction	−9
Corr. to altitude	8·9′	Corr. altitude	1° 35′ or 95′

To find the correction for the curvature of the earth.

Set the right index of C over 32 (miles) on D, and over ·885 on B we read 905 (feet) on A.

6420 − 905 feet = 5515 feet corrected height.

Now set 9·5 (altitude) on C over 5515 (feet) on D, and under ·565 on C we read 32·8 (miles) on D.

Distance from the hill 32·8 miles.

10. *To find distance to the visible horizon.*

Set the right or left index of B to the height on A, then under 1·15 on C we read the distance in miles on D.

Example.—Height of eye 38 feet. Observed, a light just dipping below the horizon. Height of light 240 feet. Find the distance from the light.

Set the left index of B under 38 on A and under 1·15 on C we read 7·1 (miles) on D. Set the left index of B under 240 on A, and under 1·15 on C we read 17·8 (miles) on D.

17·8 + 7·1 = 24·9 miles.

Light distant 24·9 miles.

11. *Conversion Angle. To convert a Radio Great Circle Bearing to a Mercatorial Bearing.*

Set the index of S to the ½ D long. on A ano over the middle latitude on S read the required conversion angle on A. This angle is always to be applied towards the Equatorial side of the Great Circle.

Example.—A ship in D.R. Lat. 39° 20′ N., Long. 12° 18′ W., receives a radio bearing 257° from a station in Lat. 40° 10′ N., Long. 7° 48′ W.

Ship Lat.	39° 20′ N.	Long.	12° 18′ W.
Station Lat.	40 10 N.	Long.	7 48 W.
	2)79° 30′	D. Long.	4° 30′
Mid. Lat.	39° 45′	½ D. Long.	2·25°

Set the index of S to 2·25° on A and over 39° 45′ on S read 1·44° on A.

∴ Conversion angle is 1½°.

257°−1½ = 255½.

Ship bore 255½ = S. 75½ W. (true) from the D.F. station.

12. *Reductions to Soundings.*

Having taken a cast of the lead and noted the time of the cast, find the difference between the time of the cast and the time of M.T.L. or mean tide level.

Turn this difference into degrees of arc assuming the tide to rise or fall through 180°. This is simple proportion.

Time taken to rise or fall : 180 : : difference . x°

Set the right index of S under the ½ range of the tide on A; then over the angle just found on S, read the correction to apply to the M.T.L. on A.

Example.—9.20 a.m., took a cast of the lead and found depth 18 feet.

High water 6.50 a.m. Height 18 feet.

Low water 1.20 p.m. Height 6 feet 6 inches.

H.W. -	6h 50m	H.W.	6h 50m	H.W.	18′ 00″	H.W.	18′ 00″
L.W. -	13 20	L.W.	13 20	L.W.	6 6	L.W.	6 6
Time falling	6h 30m	2)	20h 10m	2)	11′ 6″	2)	24′ 6″
		M.T.L.	10h 5m	½ range	5′ 9″	M.T.L.	12′ 3″

Time of M.T.L.	10h 5m
Time of cast	9 20
Before M.T.L.	0h 45m

6h 30m : 180° : : 45m : difference in degrees.

Set 6·5 (hours) on C over 180 on D, then under 0·75 (hours) on C we read 21 on D.

Difference of 45 minutes = 21°.

Set the right index of S under 5·75 (½ range) on A, then over 21° on S we read 2·06 (feet) on A.

Correction to M.T.L. = 2·06 feet, or nearly 2′ 1″.

M.T.L.	12′ 3″
Correction	+ 2 1
Correction to lead line	14′ 4″

So we must subtract 14′ 4″ from the sounding before comparing it with the depth shown on the chart.

Also, there will be 14′ 4″ more depth than is shown on the chart over any shallow patch.

Example.—At what time will there be 24 feet of water over a shoal where the chart shows 10 feet?

High water 2.15 p.m. Height 22 feet 6 inches.

Low water 8.35 p.m. Height 3 feet 6 inches.

H.W. -	2h 15m	H.W.	2h 15m	H.W.	22′ 6″	H.W.	22′ 6″
L.W. -	8 35	L.W.	8 35	L.W.	3 6	L.W.	3 6
Time falling	6h 20m		2)10h 50m		2)19′ 00″		2)26′ 00″
			5h 25m	½ range	9′ 6″	M.T.L.	13′ 00″

Required depth - -	24′ 00″
Chart depth - - -	10 00
Height above chart datum	14 00
M.T.L. - - -	13 00
Correction - - -	1′ 00′

Set the right index of S under 9·5 (½ range) on A, then under 1 (correction) or the right index of A we read 6° on S.

Required angle 6°.

Reverse the slide and set 6·33 (time falling) on C over 180° on D, then over 6 (the required angle) on D we read 0·21 on C.

Time from M.T.L. = 0·21 hours or 12½ minutes.

As the tide is falling and we require a depth greater than that at M.T.L., the required time must be before M.T.L.

M.T.L.	5h 25m
Correction	− 12½
Required time	5h 12½m

At 5·12½ p.m., there will be 24 feet of water over the shoal.

In actual practice, we can assume that the tide always takes 6 hours to rise or fall. In other words, that the duration of the tide is 6 hours. We then have the tide passing through 180° in 6 hours, or 30° in 1 hour; from which we see that we can allow 1° for every 2 minutes that the cast was taken before or after M.T.L.

For instance, in our first example, we had an interval of 45 minutes before M.T.L. This, then, we can call 22½°.

So we set the right index of S under 5·75 (the ½ range) on A, and over 22½° on S we read 2·2 on A.

The correction then is 2·2 feet or 2 feet 2½ inches.

This only differs from our previous result by 1½ inches; and as, even for B.O.T. examinations, we only have to work to the nearest "half foot or so," it will be seen that this difference is immaterial.

CHAPTER VI.

DEEP SEA NAVIGATION.

1. *To find the D. Lat. and departure.*

Set the right index of S under the distance on A, then over the course on S we read the departure on A, and over (90 − course) on S we read the D. Lat. on A.

Example.—Course S. 37° E. Distance 58 miles.

Set the right index of S under 58 on A, then over 37° on S we read 34·9 on A, and over 53° (90° − 37°) on S we read 46·3 on A.

D. Lat. 46·3 S. Departure 34·9 E.

2. *To convert departure to D. Long.*

Set (90° − latitude) on S under the departure on A, and over the right index of S we read the D. Long. on A.

Example.—Lat. 28° N. Departure 25 miles.

Set 62° (90 − 28°) on S under 25 on A, then over the right index of S we read 28·3 on A.

D. Long. 28·3′.

3. *To convert D. Long. to departure.*

Set the right index of S under the D. Long. on A, then over (90° − latitude) on S we read the departure on A.

Example.—Lat. 39° N. D. Long. 30′.

Set the right index of S under 30 on A, then over 51° (90° − 39°) on S we read 23·3 on A.

Departure = 23·3 miles,

4. *To find the course.*

If the course is less than 45°, in other words D. Lat. greater than departure.

Set the index of T over the D. Lat. on D, then over the departure on D we read the course on T.

Example.—D. Lat. 47′ S. Departure 35·2′ W.

Set the right index of T over 47 on D, then over 35·2 on D we read 36° 50′ on T.

Course S. 36° 50′ W.

If the course is more than 45°, in other words departure greater than the D. Lat.

Set the index of T over the departure on D, and over the D. Lat. on D we read (90° − course) on T.

Example.—D. Lat. 27° S. Departure 53·5′ E.

Set the right index of T over 53·5 on D, then over 27 on D we read 26° 47′ on T.

90° − 26° 47′ = 63° 13′.

Course S. 63° 13′ E.

If the course is less than 6° *or more than* 84°, we assume the sine to be equal to the tangent, and use the S scale and A, instead of T and D, and proceed in the same manner as before.

Example.—D. Lat. 60° N. Departure 2′ E.

Set the right index of S under 60 on A, then under 2 on A we read 1° 55′ on S.

Course N. 1° 55′ E.

Example.—D. Lat. 2·5′ S. Departure 132′ E.

Set the left index of S under 132 on A, and under 2·5 on A, we read 1° 5′ on S.

90° − 1° 5′ = 88° 55′.

Course S. 88° 55′.

5. *To find the distance.*

Set the course on S under the departure on A, or set (90° − the course) on S under the D. Lat. on A, and over the right index of S we read the distance on A.

It will usually be found better to use whichever is the greater of the D. Lat. or departure, but either can be used, the only reason for using the larger being that it is easier to set the slide accurately.

Example.—Course S. 60° W. D. Lat. 20·22′. Departure 35′.

Set 60° on S. under 35 on A, and over the right index of S we read 40·4 on A.

Distance 40·4 miles.

It will be noticed that under 20·2 on A we find 30° (90° − 60°) on S.

Example.—D. Lat. 38′ N. D. Long. 25′ E. Middle latitude 32°.

To find the course and distance.

Set the right index of S under 25 on A, and over 58° (90° − 32°) on S we read 21·2 on A.

Departure 21·2′

Now set the right index of T over 38 on D, and over 21·2 on D, we read 29° 10′ on T.

Course N. 29° 10′ E.

Next set 60° 50′ (90° − 29° 10′) on S under 38 on A and over the right index of S we read 43·5 on A.

Distance 43·5 miles.

6. *Mercator sailing.*

This is worked in the same manner as plane sailing, but now instead of using the D. Lat. and departure we use the Mer. D. Lat. and D. Long. Also, as we do not know the departure, we always use the D. Lat. and (90° − course) to find the distance.

Example.—To find course and distance.

From A, Lat. 36° 20′ N., Long. 25° 40′ E.

To B, Lat. 33° 25′ N., Long. 18° 30′ E.

Lat. A	36° 20′ N.	Mer. parts	2342·76	Long. A	25° 40′ E.
Lat. B	33 25 N.	Mer. parts	2129·41	Long. B	18° 30′ E.
D. Lat.	2 55 S.	Mer. D. Lat.	213·35	D. Long.	7 10 W.
D. Lat.	175′			D. Long	430′

Set the right index of T over 430 on D, and over 213·35 on D we read 26° 23′ on T.

Then set 26° 23′ on S under 175 on A, and over the right index of S we read 395 on A.

The D. Long. is greater than the Mer. D. Lat., so the course is greater than 45° ∴ 90° − 26° 23′ = 63° 37′.

Course S. 63° 37′ W. Distance 395 miles.

7. *To find the error in longitude caused by an error of 1′ in latitude.*

Set the azimuth on S under the index of A, move the runner (90° − azimuth) on S. Set (90° − latitude) on S under the runner, and over the index of S we read the required error on A.

Example.—Latitude 23°. Azimuth 59°.

Set 59° on S under the right index of A, move the runner to 31° (90° − 59°) on S.

Set 67° (90° − 23°) on S under the runner and over the right index of S we read 0·65 on A.

∴ an error in latitude of 1′ causes an error of 0·65′ in the longitude.

Example.—Latitude 30°. Azimuth 38°.

Set 38° on S under the left index of A, move the runner to 52° (90° − 38°) on S.

Set 60° (90° − 30°) on S under the runner, and over the right index of S we read 1·48 on A.

∴ an error in latitude of 1′ causes an error 1·48 in longitude.

8. *To find the error in latitude caused by an error of 1′ in longitude.*

Set the longitude correction on C over the right index of D, and under the left index of C we read the latitude correction on D.

Thus in the second example the longitude correction we found to be 0·65.

Set 0·65 on C over the right index of D, and under the left index of C we read 1·54′ on D.

An error of 1′ in longitude causes an error of 1·54′ in latitude.

9. *To find the error in longitude caused by an error of 1′ in the altitude.*

Set the azimuth on S under the left index of A, move the runner to the right index of S, then set (90° − latitude) on S under the runner, and over the right index of S we read the required error on A.

Example.—Azimuth N. 63° E. Lat. 52° N.

Set 63° on S under the left index of A, move the runner to the right index of S, then set 38° (90° − 52°) on S under the runner and over the right index of S we read 1·82 on A.

An error of 1′ in the altitude causes an error of 1·82′ in longitude.

10. *To find the change of altitude per minute of time.*

Set the right index of S under 15 on A, move the runner to the azimuth on S, then set the right index of S under the runner, and over (90° − latitude) on S we read the change in altitude on A.

Example.—Lat. 38°. Azimuth 62°.

Set the right index of S under 15 on A, move the runner to 62° on S.

Set the right index of S under the runner, and over 52° (90° − 38°) we read 10·4 on A.

Change in altitude 10·4′ per minute of time.

11. *To find the amplitude.*

Set the declination on S under either index of A, move the runner to (90° − latitude) on S, then set the right index of S under the runner and under the index of A we read the amplitude on S.

Example.—Latitude 22° N. Declination 18° S. Required the amplitude at sunset.

Set 18° on S under the left index of A, move the runner to 68° (90° − 22°) on S. Set the right index of S under the runner and under the left index of A we read 19° 30′ S.

Amplitude W. 19° 30′ S.

12. *To find the azimuth.*

Turn the hour angle into degrees of arc.

Set the hour angle on S under either index of A move the runner to (90° − altitude) on S. Set (90° − declination) under the runner, and under the index of A we read the azimuth on S.

Example.—Hour angle 3h 12m = 48°. Declination 21°. Altitude 38°.

Set 48° on S under the left index of A, move the runner to 52° (90° − 38°) on S, then set 69° (90° − 21°) on S under the runner, and under the left index of A we read 61¾° on S.

Azimuth 61¾°.

13. *To find the altitude to set the sextant for picking up a star.*

Turn the hour angle into degrees of arc.

Set the hour angle on S under either index of A, move the runner to the azimuth on S, then set (90° − declination) on S under the runner, and under the index of A we read (90° − altitude) on S.

Example.—Declination 22°. Azimuth 65°. Hour angle 2h 24m = 36°.

Set 36° on S under the left index of A, move the runner to 65° on S, then set 68° (90° − 22°) on S under the runner, and under the left index of A we read 37° on S.

90° − 37° = 53° altitude.

14. *To fix the position by double altitude without plotting on the chart.*

Work up the two observations using the same latitude in each case.

Take the D. Long. between the results thus obtained and turn it into departure.

Then under the departure on A, set the difference between the bearings of the objects on S and over the smaller bearing on S, we read the distance on A.

With this distance and the position line of the object having the greater bearing as course, correct the position found by the observation of that object.

If the objects are in the same or opposite quadrants, and the longitude obtained from the object with the greater bearing lies to the eastward of the other, the D. Long. will be easterly and *vice versa.* But if they are in adjacent quadrants the reverse is the case.

Example.—In D.R. Latitude 36° N.

Longitude by Markab 40° 28′ W., bearing N. 75° W.

Longitude by Castor 40° 21′ W., bearing N. 57° E.

N. 75° W. to N. 57° E.=132° 180°−132°=48°.

As sin A=sin (180°−A) we use 48° for our calculations.

40° 28′ W.−40° 21′ W.=7′ D. Long.

In Lat. 36°, D. Long. 7′=departure 5·66′.

Under 5·66 on A, set 48° on S, and over 57° on S we read 6·4 on A.

Distance=6·4′

Greater bearing=N. 75° W., position line N. 15° E.– S. 15 W.

Longitude from this observation lies to the westward of the other, and the bearings are in adjacent

quadrants, so the D. Long. will be easterly; our course, therefore, will be N. 15° E. Under 6·4 on A, set the right index of S, and over 15° on S read 1·66 on A, and over 75° (90°−15°) on S read 6·2 on A.

D. Lat. 6·2 N. Departure 1·66 E.

Under 1·66 on A, set 54° (90°−latitude 36°) on S, and over the right index of S read 2·05′ on A.

D. Long. 2·05 E.

Position from observation with greater bearing—

D.R. Lat.	36° 00′ N.	Obs. Long.	40° 28′ W.
D. Lat.	6·2 N.	D. Long.	2 E.
Latitude	36° 6·2′ N.	Longitude	40° 26′ W.

15. *To fix the position by Marcq St. Hilaire without plotting on a chart.*

Work up the first observation, and using the intercept as distance, and the bearing or bearing reversed as course, according to whether the intercept is away from or towards the object, correct the D.R. position used.

Then using the new D.R. position thus found, work up the 2nd observation.

Now, under the intercept found in the 2nd observation on A, set the angular difference between the bearings of the two objects on S, and over the right index of S we read X.

Now, with X as distance and the position line of the 1st observation as course, correct the 2nd D.R. position. The result is the position of the ship.

Example.—In D.R. Lat. 37° 20′ S., Long. 95° 14′ E.

Observations were taken of Venus and Sirius.

Venus, true altitude 31° 28′, bearing N. 40° E.

Sirius, true altitude 55° 42′, bearing N. 30° W.

From Venus, the intercept was found to be 6′ towards the planet. So with course N. 40° E., distance 6′, set the right index of S under 6 on A, and over 40° on S we read 3·85 on A, and over 50° (90° − 40°) on S we read 4·6 on A.

Now set 52° 40′ (90° − 37° 20′) on S under 3·85 on A, and over the right index of S we read 4·85 on A.

D. Lat. = 4·6 N. D. Long. 4·85 E.

Which applied to our original D.R. position gives Lat. 37° 15·4′ S., Long. 95° 18·8′ E.

Using this new D.R. position, we work up the observation of Sirius, and find an intercept of 5′ away from the star.

Bearing of Venus N. 40° E., bearing of Sirius N. 30° W., gives an angle of 70° between the bearings.

Set 70° on S under 5′ (intercept of Sirius) on A, then over the right index of S we read 5·32 on A.

Position line of Venus is 90° from N. 40° E., or S. 50° E.

Set the right index of S under 5·32 on A, and over 50° on S we read 4·07 on A, and over 40°

EX-MERIDIAN TABLE.

Lat. Dec.	A	Lat. Dec.	A	Lat. Dec.	A	Lat. Dec.	A
° ′		° ′		° ′		° ′	
0 30	0·27	20 30	11·43	40 30	26·09	60 30	54·02
1 00	0·53	21 00	11·73	41 00	26·57	61 00	55·14
1 30	0·80	21 30	12·04	41 30	27·04	61 30	56·29
2 00	1·07	22 00	12·34	42 00	27·52	62 00	57·48
2 30	1·33	22 30	12·66	42 30	28·01	62 30	58·71
3 00	1·60	23 00	12·97	43 00	28·50	63 00	59·97
3 30	1·87	23 30	13·29	43 30	29·00	63 30	61·29
4 00	2·14	24 00	13·61	44 00	29·51	64 00	62·65
4 30	2·41	24 30	13·92	44 30	30·04	64 30	64·07
5 00	2·67	25 00	14·25	45 00	30·56	65 00	65·53
5 30	2·94	25 30	14·58	45 30	31·10	65 30	67·05
6 00	3·21	26 00	14·90	46 00	31·64	66 00	68·63
6 30	3·48	26 30	15·24	46 30	32·20	66 30	70·28
7 00	3·75	27 00	15·57	47 00	32·77	67 00	71·99
7 30	4·02	27 30	15·91	47 30	33·35	67 30	73·77
8 00	4·30	28 00	16·25	48 00	33·94	68 00	75·63
8 30	4·57	28 30	16·59	48 30	34·54	68 30	77·58
9 00	4·84	29 00	16·94	49 00	35·15	69 00	79·61
9 30	5·11	29 30	17·29	49 30	35·78	69 30	81·73
10 00	5·39	30 00	17·64	50 00	36·42	70 00	83·96
10 30	5·66	30 30	18·00	50 30	37·08	70 30	86·29
11 00	5·94	31 00	18·36	51 00	37·74	71 00	88·74
11 30	6·22	31 30	18·73	51 30	38·42	71 30	91·33
12 00	6·50	32 00	19·10	52 00	39·12	72 00	94·05
12 30	6·78	32 30	19·47	52 30	39·82	72 30	96·92
13 00	7·06	33 00	19·85	53 00	40·56	73 00	99·95
13 30	7·34	33 30	20·23	53 30	41·30	73 30	103·2
14 00	7·62	34 00	20·61	54 00	42·06	74 00	106·6
14 30	7·90	34 30	21·01	54 30	42·85	74 30	110·2
15 00	8·19	35 00	21·40	55 00	43·64	75 00	114·0
15 30	8·48	35 30	21·80	55 30	44·47	75 30	118·2
16 00	8·76	36 00	22·21	56 00	45·31	76 00	122·6
16 30	9·05	36 30	22·61	56 30	46·17	76 30	127·3
17 00	9·34	37 00	23·02	57 00	47·05	77 00	132·4
17 30	9·64	37 30	23·45	57 30	47·97	77 30	137·8
18 00	9·93	38 00	23·88	58 00	48·91	78 00	143·8
18 30	10·23	38 30	24·31	58 30	49·87	78 30	150·2
19 00	10·52	39 00	24·75	59 00	50·86	79 00	157·2
19 30	10·82	39 30	25·19	59 30	51·88	79 30	164·9
20 00	11·13	40 00	25·64	60 00	52·93	80 00	173·3

(90° − 50°) on S we read 3·4 on A. Now set 52° 45′ (90° − 37° 15′) on S under 4·07 on A, and over the right index of S we read 5·12 on A.

From this, then, we get D. Lat. 3·4 S., D. Long. 5·12 E., which applied to our 2nd D.R. position gives us Lat. 37° 18·8′ S., Long. 95° 24′ E., the position of the ship at the time of the observations.

16. **Ex-Meridians.**

From the table take out A for the latitude and declination. If the latitude and declination are of the same name take the difference of these two quantities, but if of different names the sum. Then the square of the hour angle in minutes, divided by the number thus obtained, gives the reduction to add to the altitude.

Example.—Lat. D.R. 37° 20′ N. Declination 15° 15′ N. Hour angle 21m.

For Lat. 37° 20′ N. A = 23·31
For Dec. 15° 15′ N. A = 8·33
Same name subtract 14·98

Set 14·98 on B under the right index of A, then over 21 on C we read 29·5 A.

Reduction 29·5′

Example.—Lat. D.R. 12° 22′ N. Declination 36° 18′ S. Hour angle 42 minutes.

For Lat. 12° 22′ N. A = 6·70
For Dec. 36° 18′ S. A = 22·45
Different names add 29·15

Set 29·15 on B under the right index of A, then over 42 on C we read 60·5 on A.

Reduction 60·5′=1° 00½′.

When using the G.H.A. Almanac the Hour Angle in degrees or minutes of arc may be used as follows:—

Hour Angle in Degrees. Set A as obtained for the Latitude and Declination, on the B Scale to 16 on the A scale. Set the Cursor to the Hour Angle in degrees on the C scale and read the reduction on the A scale under the Cursor.

Hour Angle in Minutes of Arc.

Set A on the B scale to 444 on the A scale and over the Hour Angle in minutes of arc on the C scale read the reduction on the A scale.

Ex-Meridians—a further Method.

These may be worked without reference to any tables. To do so, set the right index of S to 32·72 on A. Move the runner to (90° – latitude) on S. Set the zenith distance on S under the runner, move the runner to (90° – declination) on S. Now reverse the slide and set the index of B to the runner.

Then over the hour angle, in minutes, on C we read the reduction to the meridian in minutes of arc on A.

Example.—D.R. latitude 28° N. Declination 18° 20′ S. Altitude 43° 31′.

∴ Zenith distance = 28° + 18° 20′ = 46° 20′.

Hour Angle 17 mins. 30 secs.

Set the right index of S under 32·72 on A, move the runner to 62° (90° – 28°) on S. Set 46° 20′ on S under the runner, move the runner to 71° 40′ (90° – 18° 20′) on S.

Now, without moving the runner, reverse the slide and set the right index of B under the runner, move the runner to 17·5 on C, and we find it cuts the A scale at 11·6.

Reduction = 11·6′ to add to the altitude.

T. Alt. - -	43° 31′ S.	Mer. zen. dist.	49° 17·4′ N.
Reduction -	+ 11·6	Declination -	18 20 S.
Mer. Alt. -	43° 42·6′ S.	∴ Latitude -	27° 57·4′ N.
	90 00		
Mer. zen. dist.	46° 17·4′ N.		

17. *To find the altitude of an object on the prime vertical.*

Set the declination on S under the left index of A, move the runner to the latitude on S, set the right index of S under the runner, and under the left index of A we read the altitude on S.

Example.—Lat. 24° N. Declination 16° N.

Set 16° on S under the left index of A, move the runner to 24° on S, then set the right index of S under the runner, and under the left index of A we read 42° 40′ on S.

Altitude 42° 40′.

18. *To find the hour angle of an object on the prime vertical.*

Set the declination on S under the left index of A, move the runner to (90° – declination) on S. Set (90° – latitude) on S under the runner, and move the runner to the latitude on S. Now set the right index of S under the runner and under the left index of A read (90° —hour) angle on S.

Example.—Latitude 24° N. Declination 16° N.

Set 16° on S under the left index of A, move the runner to 74° (90° —16°) on S. Set 66° (90° —24°) on S under the runner, and move the runner to 24° on S. Now set the right index of S under the runner and under the left index of A we read 40° on S.

Hour angle = 90 – 40° = 50° or 3h 20m.

19. *To find the hour angle at rising or setting of a celestial object.*

Set the declination on S under the index on A, move the runner to (90°— declination) on S. Set the latitude on S under the runner and move the runner to (90° —latitude) on S. Now set the index of S under the runner, and under the index of A read angle X on S.

If the latitude and declination are of the same name add angle X to 90° or 6 hours, but if of different names subtract it.

Example.—Latitude 22° N. Declination 33° S.

Set 33° on S under the left index of A, move

the runner to 57° (90° – 33°) on S. Set 22° on S under the runner and move the runner to 68° (90° – 22°) on S. Now set the right index of S under the runner, and under the left index of A we read $15\frac{1}{4}$°.

Latitude and declination are of different names, subtract, 90 – $15\frac{1}{4}$° = $74\frac{3}{4}$°, or 4h 59m.

Example.—Latitude 54° N. Declination 18° N.

Set 18° on S under the left index of A, move the runner to 72° (90°—54°) on S. Set 54° on S under the runner and move the runner to 36° (90° —54°) on S. Now set the right index of S under the runner, and under the left index of A we read $26\frac{1}{2}$° on S.

Latitude and declination are of the same name, add, 90° + $26\frac{1}{2}$° = $116\frac{1}{2}$° = 7h 46m.

$26\frac{1}{2}$° = 1h 46m. 6h + 1h 46m = 7h 46m.

20. *To find the time of the moon's meridian passage.*

Set the difference of time between the two consecutive passages, on C over 360 on D, then over the longitude on D read the correction on C.

This correction is to be added to the meridian passage given in the *Nautical Almanac* for that day, when the ship is the west longitude and subtracted from it when in east longitude.

Example.—May 26, 1932 in Long 87° E., find time of moon's meridian passage.

From the *Almanac* moon's upper meridian passage

	May 26	5h 42m
Long. east use previous day moon's upper meridian passage	May 25	4h 44m
	Difference	48m

Set 48 on C over 360 D, and over 87 on D we read 11½ on C.

Correction 11½ minutes to subract.

May 26	5h 32m
Correction	— 11½m
Meridian passage	5h 20½m

21. *To find the parallax in altitude of the moon.*

Set the right index of S under the moon's horizontal parallax on A, and over 90° — altitude on S, we read the parallax in altitude on A.

Example.—Altitude 71° 30′. Horizontal parallax from the *Almanac* 59·9′.

Set the right index of S under 59·9′ on A, and over 18° 30′ (90° — 71° 30′) on S we read 19 on A.

Parallax in altitude 19′.

22. *To find the dip of the sea horizon.*

Set the right index of B under the height of eye on A, and under 0·98 on C we read the dip in minutes of arc on D.

Example.—Height of eye 42 feet.

Set the right index of B under 42 on A, and under ·98 on C we read 6 35 on D.

Dip for 42 feet = 6·35′ or 6′ 21″.

23. *To find the mean refraction.*

Barometer 29·6. Temperature 50° Fahrenheit.

Altitude less than 45°.

Set the altitude on T over 56·7 on D, and under the index of T we read the mean refraction in seconds on D.

Or set the altitude on T over 0·946 on D, and under the index of T we read the mean refraction in minutes on D.

Altitude more than 45°.

Set the index of T over 56·7 on D, and under (90° — altitude) on T we read the mean refraction in seconds on D.

Or set the index of T over 0·946 on D, and under (90° — altitude) on T we read the mean refraction in minutes on D.

Example.—Altitude 28°.

Set 28° on T over 56·7 on D, and under the left index of T we read 107 on D.

Mean refraction for 28° = 107″ or 1′ 47″.

Example.—74°.

Set the index of T over 0·946 on D, and under 16° (90° — 74°) on T we read 0·27 on D.

Mean refraction for 74° = 0·27′ or 16·2″.

The results obtained in this manner are a very close approximation of the actual refraction, at 15° altitude being only 2″ more than that given in the tables. Provided that the altitude be not less than 10°, they may be assumed to be correct.

CHAPTER VII.

VARIOUS SETTINGS.

Coal consumption.

Over a given period of time the consumption varies as the cube of the speed of the engines.

Example.—A vessel steaming at a speed of 12 knots burns 50 tons of coal a day, what will be her daily consumption if the speed is reduced to 9 knots?

$12^3 : 9^3 :: 50$: required consumption.

$12^3 = 1728$. $9^3 = 729$.

So we set 1728 on C over 729 on D, and under 50 on C we read 21·1 on D.

Consumption at 9 knots, 21·1 tons per day.

Example.—A vessel steaming at 11 knots burns 35 tons a day, what will she burn at 13 knots?

$11^3 : 18^3 :: 35$: required consumption.

$11^3 = 1331$. $13^3 = 2197$.

Set 1331 on C over 2197 on D, and under 35 on C we read 57·75 on D.

Consumption at 13 knots, 57·75 tons per day.

Over a given distance the consumption varies as the square of the speed of the engines.

Example.—A vessel steaming at 12 knots burns 420 tons of fuel to cover a certain distance. What would she burn at 10 knots?

We noticed earlier that any number on the C and D scales coincides with its square on the B and A scales respectively.

We now have $12^2 : 10^2 :: 420$: required consumption. Set 12 on C over 10 (the left index) of D, and over 420 on B we read 291·6 on A.

Consumption over the same distance at 10 knots = 219·6 tons.

Example.—A vessel steaming at 14 knots covers a certain distance on 530 tons of fuel. At what speed must she steam to cover the same distance on 275 tons?

Set 530 on B under 275 on A, then under 14 on C we read 10·08 on D.

Speed 10·08 knots.

Example.—A vessel steaming at 12 knots covers a distance of 2900 miles on 620 tons of coal. How much will she burn if she steams at 8 knots for 2200 miles?

Set the right index of B under 620 on A, move the runner to 8 on C. Set 12 on C under the runner, move the runner to 2200 on B, and set 2900 on B under the runner, then over the left index of B we read 209 on A.

Burns 209 tons.

Example.—A vessel steaming at 13 knots burns 580 tons of fuel over a distance of 2120 miles. To what speed must she reduce to cover 1800 miles on 340 tons of fuel?

Set 1800 on B, under 2120 on A, move the runner to 340 on B, and set 580 on B under the runner, then under 13 on C we read 10·8 on D.

Speed 10·8 knots.

To find the speed for a given number of revolutions per minute.

Set 15·2 on C over 15 on D, move the runner to the pitch of the propeller in feet on C. Set the index of C under the runner, and under the number of revolutions per minute on C we read the speed in knots on D.

Example.—Pitch 18 feet. Revs. per minute 62.

Set 15·2 on C over 15 on D, move the runner to 18 on C, set the right index of C under the runner and under 62 on C we read 11 on D.

Speed for 62 revs. per minute is 11 knots.

To make allowance for, say, 4% slip. Set the right index of C to this speed, 11 knots, on D, and under 96 (100—4) on C we read 10·55 on D.

Allowing for 4% slip the speed will be 10·55 knots.

To find the revolutions per minute required to give a certain speed.

Set 15·2 on C over 15 on D, move the runner to the pitch of the propeller on C. Set the index of

C under the runner, then over the speed in knots on D we read the required revs. per minute on C.

Example.—Pitch 18 feet 6 inches. Required speed 12 knots.

Set 15·2 on C over 15 on D, move the runner to 18·5 on C. Set the right index of C under the runner and over 12 on D we read 65·7 on C.

65·7 revs. per minute required for a speed of 12 knots.

To allow for slip.—Set (100 — slip%) on C over the number of Revolutions thus found, and under the index of C read the required revolutions on D.

Thus in this case to allow for 6% slip.

Set 94 (100—6) on C over 65·7 on D and under the index of C read 69·9 on D.

∴ 69·9 revs. per minute will be required.

To find the distance run by the revolutions.

Set the pitch of the propeller on C, over 6080 on D, and under the given number of revolutions on C we read the distance on D.

Example.—Pitch 19 feet. Engines turned 14,600 revolutions.

Set 19 on C over 6080 on D, and under 14,600 on C we read 46·7 on D.

Engine distance 46·7 miles

To make allowance for slip.

Set the right index of C over the engine distance on D, and under 100 − the slip on C we read the distance made good on D.

Example.—Pitch 18 feet 6 inches. Engines turned 12,450 revolutions.

Required distance made good allowing for 4·5% slip.

Set 18·5 on C, over 6080 on D, move the runner to 12,450 on C. Set the right index of C under the runner, and under 95·5 (100 − 4·5) on C we read 38·05 on D.

Distance run 38·05 miles.

To find the increase of draft due to heel.

Set the right index of S under half the vessel's beam on A, then over the angle of heel on S we read the increase of draft on A.

Example.—Beam of vessel 56 feet. Heel 8°.

Set the right index of S under 28 ($\frac{56}{2}$) on A, then over 8° on S we read 3·9 on A.

Increase of draft 3·9 feet or 3 ft. 11 ins.

To find the distance off an object by the angle of depression.

With the sextant measure the angle between the horizon and the waterline of the object. To this angle add the correction for dip for the height of eye.

Now set this corrected angle on T over the height of eye on D, and under the index of T we read the distance off on D.

Example.—Observed angle 20° 40′. Height of eye 45 feet.

The dip for 45 feet is 6·6′. Which added to 20° 40′ gives us 20° 47′.

Set 20° 47′ on T over 45 on D, then under the left index of T we read 118·6 on D.

Distance off 118·6 feet.

Should the angle of depression be less than 6°, instead of using the T and D scales we use S and A.

Example.—Height of eye 34 feet. Observed angle 4° 50′.

The dip for 34 feet is 6′, which added to the observed angle gives us 4° 56′.

Set 4° 56′ on S under 34 on A, then over the left index of S we read 395 on A.

Distance off 395 feet.

To find the diameter of the turning circle of a ship.

This is found in exactly the same manner as in finding the distance off an object by the angle of depression. In fact, it is really a particular case of the angle of depression.

Turn the ship through about 20 points of the compass, and measure the angle between the horizon and the ship's wake. Add the correction for dip to this angle and proceed in exactly the same manner as in finding the distance off an object in the water.

Example.—Height of eye 38 feet. Observed angle 4° 25′.

The dip for 38 feet is 6′. Corrected angle 4° 31′.

Set 4° 31′ on S under 38 on A, then over the left index of S we read 482 on A.

Diameter of turning circle 482 feet.

To find the pressure on a tank top when testing with a head of water.

In the list of gauge points at the end of the book we find :—

Feet of water : pounds per sq. inch : : 60 : 26.

So we set 60 on C over 26 on D, then under any number of feet of head of water on C we read the corresponding pressure in lbs. per sq. inch on C, which multiplied by 144 gives us pressure per sq. foot in pounds.

Example.—Find the pressure per sq. foot on a tank top, the head of water being 18 feet above the tank top.

Set 60 on C over 26 on D, move the runner to 18 on C, set the right index of C under the runner, and under 144 on C we read 1122 on D.

Pressure = 1122 lbs. per sq. foot.

To mark a hand log line.

Set 180 on C over 304 on D, and under the number of seconds in the second glass on C read the length of line required for each knot on D.

Example.—28 second glass.

Set 180 on C over 304 on D, and under 28 on C read 47·3 on D.

47·3 feet or 47 feet 3½ inches of line will be required for each knot.

To find the speed on the measured mile.

Set the time taken in seconds on C, over the index of D, and under 36 on C read the speed in knots on D.

Example.—A vessel takes 4m 18s to cover the measured mile.

4m 18s = 258s.

Set 258 on C over the left index of D, and under 36 on C read 13·95 on D.

Speed 13·95 knots.

APPENDIX.

APPENDIX.

Approximate Weight per Cubic Foot of Various Metals.

	lbs.		lbs.
Wrought Iron	480	Aluminium	167
Cast Iron	450	Gun Metal	531
Cast Steel	490	Gold	1204
Copper	550	Mercury	849
Brass	525	Platinum	1344
Lead	710	Silver	654
Tin	462	Antimony	420
Zinc	449	Bronze	513
White Metal	456	Nickel	560

Approximate Weight per Cubic Foot of Various Woods.

	lbs.		lbs.
Ash	47	Deal U.K.	30
Beech	45	Ebony	74
Birch	45	Elm, Canadian	45
Boxwood	61	Elm, English	35
Cedar, American	35	Fir, Douglas	38
,, Lebanon	30	Fir, Spruce	34
,, W. Indies	47	Larch	34
Chestnut	38	Greenheart	71
Cork	15	Hornbeam	47
Cottonwood, Green	46	Ironwood	71
,, Dry	24	Junglewood	57
Cypress	27	Lignum Vitae	83
Deal, Norway	43	Lime	35

Approximate Weight per Cubic Foot of Various Woods.—cont.

	lbs.		lbs.
Mahogany, Honduras	35	Pine, Yellow - -	32
„ Spanish	53	Redwood, Green -	60
Maple - - -	42	Redwood, Dry - -	27
Oak, African - -	62	Sycamore - -	37
„ American -	50	Teak, Africa - -	60
„ English -	52	„ Burma - -	54
Pine, Red - -	34	„ India - -	46
„ Norway - -	34	„ Philippine -	48
„ Pitch - -	38	Yew - - -	50
„ White - -	29		

Approximate S.G. of Various Oils.

	S.G.		S.G.
Aniseed - - -	1·00	Palm - - - -	0·91
Castor - - -	0·97	Paraffin - - -	0·91
Coconut - - -	0·93	Petrol - - - -	0·76
Colza - - -	0·92	Petroleum, Crude -	0·85
Cottonseed - -	0·93	Pine - - - -	0·85
Linseed - - -	0·94	Poppyseed - - -	0·92
Neatsfoot - - -	0·92	Rapeseed - - -	0·91
Kerosene - - -	0·80	Soya Bean - - -	0·92
Olive - - -	0·92	Turpentine - - -	0·87
China Wood - -	0·94	Seal - - -	0·93
Lardine -- - -	0·97	Sperm - - -	0·88
Nigerseed - - -	0·93	Tallow Oil - - -	0·91
Palm Nut - -	0·95	Whale - - -	0·93

Approximate number of Cubic Feet required to Stow 1 Ton of Various Grains and Seeds.

	Cu. ft.		Cu. ft.
Aniseed - - -	120	Caraway - -	62
Barley - - -	60	Castor - - -	72
Bushwheat - -	66	Cloves - - -	48

Approximate number of Cubic Feet required to Stow 1 Ton of Various Grains and Seeds.—cont.

	Cu. ft.		Cu. ft.
Coriander - - -	130	Oats, Clipped - -	74
Corn - - -	54	Oats, Unclipped - -	83
Cotton - - -	75	Onion - - -	65
Croton - - -	80	Paddy - - -	65
Fennel - - -	95	Peas - - - -	50
Flax - - -	57	Poppy - - -	71
Guinea Maize - -	80	Rapeseed - - -	60
Hemp - - -	68	Rice - - - -	52
Kernels - - -	48	Rye - - - -	55
Linseed - - -	58	Sesame - - -	60
Locust Beans - -	78	Soya Bean - - -	55
Maize - - -	54	Spinach - - -	70
Millet - - -	50	Sugar Beet - - -	135
Mirobolans - -	70	Sunflower - - -	105
Mustard - -	60	Vetch - - -	50
Negro Corn - -	53	Turkish Millet - -	53
Niger - - -	64	Wheat - - -	52

The figures given above are an approximation for cargo in bags. For bulk cargo decrease these figures by about 10 per cent.

Weights and Measures.

12 inches	=1 foot	5280 feet	=1 land mile
3 feet	=1 yard	6080 feet	=1 sea mile
5½ yards	=1 rod or pole	1760 yards	=1 land mile
40 poles	=1 furlong	608 feet	=1 cable
8 furlongs	=1 land mile	10 cables	=1 sea mile
100 links	=1 chain	220 yards	=1 furlong
10 chains	=1 furlong		

Weights and Measures.—cont.

144 sq. ins.	=1 sq. foot	40 roods	=1 acre
9 sq. feet	=1 sq. yard	4840 sq yds.	=1 acre
30¼ sq. yds.	=1 sq. rod, sq.pole or perch	640 acres	=1 sq. mile
40 perches	=1 rood		

1728 cu. ins.	=1 cu. foot	100 cu. feet	=1 ton register
27 cu. feet	=1 cu. yard	35 cu. feet	=1 ton displacement
40 cu. feet	=1 ton cargo measurment		

AVOIRDUPOIS.

16 drams	=1 ounce	4 quarters	=1 cwt.
16 ounces	=1 pound	20 cwts.	=1 ton
14 pounds	=1 stone	112 pounds	=1 cwt.
28 pounds	=1 quarter	2240 pounds	=1 ton

2000 lbs. =1 short ton American
100 lbs. =1 short cwt American

LIQUIDS.

4 gills	=1 pint	36 gallons	=1 barrel
2 pints	=1 quart	54 gallons	=1 hogshead
4 quarts	=1 gallon	72 gallons	=1 puncheon

CORN MEASURE.

2 pints	=1 quart	4 pecks	=1 bushel
4 quarts	=1 gallon	8 bushels	=1 quarter
2 gallons	=1 peck	5 quarters	=1 load

METRIC SYSTEM.

10 millimetres	=1 centimetre	10 metres	=1 decametre
10 centimetres	=1 decimetre	10 decametres	=1 hectometre
10 decimetres	=1 metre	10 hectometres	=1 kilometre

METRIC SYSTEM.—cont.

10 centimetres	=1 decilitre	10 dekalitres	=1 hectolitre
10 decilitres	=1 litre	10 hectolitres	=1 kilolitre
10 litres	=1 dekalitre		

10 milligrams	=1 centigram	10 hectograms	=1 kilogram
10 centigrams	=1 decigram	10 kilograms	=1 myriagram
10 decigrams	=1 gramme	10 myriagrams	=1 quintal
10 grammes	=1 dekagram	10 quintals	=1 tonne
10 dekagrams	=1 hectogram		

Equivalents.

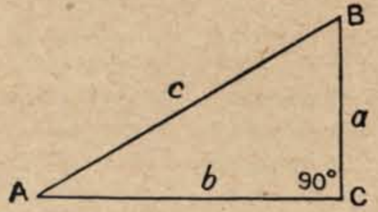
π	=3·1416	1 cu ft of fresh water	=62·36 lbs.
1 inch	=2·54 cm.	1 cu ft of salt water	=64·1 lbs.
1 metre	=1·0936 yds.	1 gal. of fresh water	=10 lbs.
1 mile	=1·6093 km.	1 gal. of salt water	=10·27 lbs.
1 knot	=1·1528 m.p.h.	1 ton of fresh water	=35·94 c.ft.
1 pint	=34·659 cu. ins.	1 ton of salt water	=35 cu ft.
1 litre	=1·7608 pints	1 ton of fresh water	=224 galls.
1 gramme	=15·432 grains	1 ton of salt water	=218·7galls.
I.H.P.	=33·000 ft lbs.	1 gallon	=277 cu ins.
1 kg	=2·204 lbs.		

Absolute Zero= −273° Centigrade or −459·4 Fahrenheit

1 board ft	=1 ft × 1 ft × 1 in	1 coil of rope	=112 fathoms
1 bolt of canvas	=42 yds	1 cord of wood	=128 cu ft.

Useful Formulae.

IN THE TRIANGLE ABC. RIGHT ANGLED AT C.



$a = c \sin A = b \tan A = c \cos B$

$b = c \cos A = a \tan B = c \sin B$

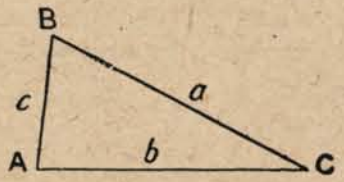
$c = a \operatorname{cosec} A = b \operatorname{cosec} B = b \sec A = a \sec B$

$\frac{a}{b} = \tan A = \cot B \qquad \frac{b}{a} = \tan B = \cot A$

$\frac{a}{c} = \sin A = \cos B \qquad \frac{c}{b} = \operatorname{cosec} B = \sec A$

$\frac{c}{a} = \operatorname{cosec} A = \sec B \qquad \frac{b}{c} = \sin B = \cos A$

IN THE TRIANGLE ABC.



$a = c \sin A \operatorname{cosec} C = b \sin A \operatorname{cosec} B$

$b = a \sin B \operatorname{cosec} A = c \sin B \operatorname{cosec} C$

$c = a \sin C \operatorname{cosec} A = b \sin C \operatorname{cosec} B$

$$\operatorname{Sin} A = \frac{a \sin B}{b} = \frac{a \sin C}{c}$$

$$\operatorname{Sin} B = \frac{b \sin A}{a} = \frac{b \sin C}{c}$$

$$\operatorname{Sin} C = \frac{c \sin A}{a} = \frac{c \sin B}{b}$$

IN THE SPHERICAL TRIANGLE ABC.

$$\frac{\operatorname{Sin} a}{\operatorname{Sin} A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}$$

$\operatorname{Sin} a = \sin b \sin A \operatorname{cosec} B = \sin c \sin A \operatorname{cosec} C$

$\operatorname{Sin} b = \sin a \sin B \operatorname{cosec} A = \sin c \sin B \operatorname{cosec} c$

$\operatorname{Sin} a = \sin a \sin C \operatorname{cosec} A = \sin b \sin C \operatorname{cosec} B$

$\operatorname{Sin} A = \sin B \sin a \operatorname{cosec} b = \sin C \sin a \operatorname{cosec} c$

$\operatorname{Sin} B = \sin A \sin b \operatorname{cosec} a = \sin C \sin b \operatorname{cosec} c$

$\operatorname{Sin} C = \sin A \sin c \operatorname{cosec} a = \sin B \sin c \operatorname{cosec} b$

IN RIGHT ANGLED OR QUADRANTAL SPHERICAL TRIANGLES.

By Napier's circular parts.

Sin middle part=tan adjacents=cos opposites

Navigational Formulae.

IN PLANE SAILING.

$$\text{Tan course} = \frac{\text{Departure}}{\text{D. Lat.}} \qquad \text{Cot course} = \frac{\text{D. Lat.}}{\text{Departure}}$$

D. Lat. =distance cos course =Departure cot course

Departure=distance sin course =D. Lat. tan course

Distance =D. Lat. sec course =Dep cosec course

Departure=D. Long. cos middle latitude

D. Long. =Dep sec middle latitude

Mercator's Sailing.

Tan course $= \dfrac{\text{D. Long.}}{\text{mer D. Lat.}}$ Distance = D. Lat. sec course

Sin azimuth =sin hour angle cos declination sec altitude
Cos altitude =sin hour angle cos declination cosec azimuth

Observations of a Body Rising or Setting.

Sin amplitude =sec latitude sin declination
Cos hour angle=tan latitude tan declination

Observations of a Body on the Prime Vertical.

Sin altitude =sin declination cosec latitude
Cos hour angle=cot latitude tan declination
Sin hour angle=cos declination sec altitude

Radio Bearings.

Sin convergency=sin latitude sin D. Long

Miscellaneous.

Dip in minutes $=\sqrt{\text{height of eye in ft.}}\times 0{\cdot}98$
Distance to horizon in miles $=\sqrt{\text{height of eye in ft.}}\times 1{\cdot}15$
Mean refraction in seconds = 56·7 cot altitude
Mean refraction in minutes = 0·946 cot altitude

Ex-Meridians.

A=the reciprocal of the change of altitude, expressed in minutes of arc, in the first minute of time before or after the meridian passage.

Areas and Volumes.

Area of a triangle$=\sqrt{S\ (s-a)\ (s-b)\ (s-c)}$
where a, b, c, are the sides of the triangle and $S=\frac{1}{2}(a+b+c)$
Area of parallelogram=length × height
Area of trapezoid=half the sum of the two parallel sides × height

Area of circle $=\frac{\pi}{4}d^2$ or πr^2
where d=diameter, r=radius
Circumference of circle=πd or $2\pi r$
Surface area of cylinder = $\pi d l$+area of ends
where d=diameter and l=length

Volume of cylinder $=\frac{\pi}{4}d^2 l$ or $\pi r^2 l$

Surface area of sphere=πd^2
Volume of sphere $=\frac{1}{6}\pi d^3$
Surface area of cone $=\frac{1}{2}\pi d h$+area of base
where d =diameter of base, h=slant height

Volume of cone$=\frac{1}{3}\times\frac{\pi}{4}d^2 l$
where d =diameter of base, l=length
Surface area of a round tapered log=$\pi d l$+area of ends

Volume of a round tapered log $\frac{\pi}{4}d^2 l$
where d=mean diameter and l=length

Gauge Points.

The use of these can best be shown by a few examples; for instance:

To convert yards to metres.
In the table we find—
Yards : metres 82 : 75
So we set 82 on C over 75 on D.

Then under any number of yards on C we find the corresponding number of metres on D and over any number of metres on D we find the corresponding yards on C.

For example, under 40 on C we find 36·6 on D
40 yards=36·6 metres
And over 16 on D we find 17·5 on C
16 metres=17·5 yards

To convert imperial gallons to U.S. gallons.

We have the gauge points 5 : 6.

Set 5 on C over 6 on D, then under any number of imperial gallons on C we find the corresponding number of U.S. gallons on D and *vice versa.*

For instance, under 6 on C we find 7·2 on D.

6 imperial gallons=7·2 U.S. gallons

And over 90 on D we find 75 on C.

90 U.S. gallons=75 imperial gallons.

Distances and Speeds.

Sea miles	:	Land miles	33 : 38
Land miles	:	kilometres	87 : 140
Sea miles	:	kilometres	138 : 256
Yards	:	metres	82 : 75
Inches	:	centimetres	26 : 66
Feet	:	metres	82 : 25
Chains	:	metres	43 : 865
Links	:	feet	100 : 66
Links	:	inches	12 : 95
Feet per second	:	miles per hour	44 : 30
Yds per minute	:	miles per hour	88 : 3
Metres per sec.	:	miles per hour	80 : 179
Feet per second	:	knots	304 : 180

Areas.

Square inches	:	square centimetres	31 : 200
Square feet	:	square metres	140 : 13
Square yards	:	square metres	61 : 51
Acres	:	hectares	42 : 17
Square miles	:	square kilometres	22 : 57

Cubes.

Cubic inches	:	cubic centimetres	5 : 82
Cubic feet	:	cubic metres	600 : 17
Cubic yards	:	cubic metres	85 : 65
Cubic metres	:	tons at 40 cu. feet	17 : 15
Cubic metres	:	tons at 100 cu. feet	17 : 6

Weights.

Ounces	:	grammes	6 : 170
Pounds	:	kilograms	75 : 34
Imperial tons	:	metric tonnes	62 : 63
Grains	:	grammes	108 : 7
Cwts.	:	kilograms	63 : 3200
Tons	:	kilograms	62 : 63,00
Fresh water	:	salt water	38 : 39
Cu. ft. of fr. wa.	:	pounds	5 : 312

Capacities.

Imperial gallons	:	U.S. gallons	5 : 6
„ „	:	litres	55 : 150
„ „	:	cubic inches	22 : 6100
„ „	:	cubic feet	430 : 69
„ „	:	pounds of fresh water	1 : 10
„ „	:	tons of fresh water	224 : 1
U.S. gallons	:	pounds of fresh water	3 : 25
„ „	:	cubic feet	800 : 107
„ „	:	cubic inches	1 : 231
„ „	:	litres	14 : 53
Litres	:	cubic feet	170 : 6
Litres	:	pints	25 : 44
U.S. gallons	:	short tons of fresh water	240 : 1
U.S. gallons	:	long tons of fresh water	3760 : 14

Pressures.

Inches of mercury	:	feet of water	15 : 17
Inches of mercury	:	pounds per square inch	57 : 28
,, ,,	:	millibars	22 : 745
,, ,,	:	millimetres of mercury	26 : 660
Feet of water	:	pounds per square inch	60 : 26
Feet of water	:	tons per square foot	600 : 167
Mi'metrs of mercury	:	millibars	45 : 60
Atmospheres	:	pounds per sq. inch	34 : 500
Pounds per sq. inch	:	k'grms per sq c't'metre	640 : 45

Temperatures.

Fahrenheit	:	Centigrade	9 : 5
Centigrade	:	Reaumur	5 : 4
Fahrenheit	:	Reaumur	9 : 4

The freezing point on the Fahrenheit scale is 32° above zero. So when converting from Fahrenheit to any other scale, first deduct 32° from the Fahrenheit reading, and when converting from any other scale to Fahrenheit add 32° to the result obtained.

CONVERSION TABLES.

Pence as Decimals of a Shilling Inches as Decimals of a Foot				
Pence or Ins.	0	¼	½	¾
0	·000	·021	·042	·063
1	·083	·104	·125	·146
2	·167	·188	·208	·229
3	·250	·270	·291	·312
4	·333	·354	·375	·395
5	·416	·437	·458	·478
6	·500	·520	·541	·562
7	·583	·604	·625	·645
8	·667	·687	·708	·729
9	·750	·770	·791	·812
10	·833	·854	·875	·895
11	·917	·937	·958	·979

16ths as Decimals	
$\frac{1}{16}$	·0625
$\frac{2}{16}$	·125
$\frac{3}{16}$	·1875
$\frac{4}{16}$	·25
$\frac{5}{16}$	·3125
$\frac{6}{16}$	·375
$\frac{7}{16}$	·4357
$\frac{8}{16}$	·5
$\frac{9}{16}$	·5625
$\frac{10}{16}$	·625
$\frac{11}{16}$	·6875
$\frac{12}{16}$	·75
$\frac{13}{16}$	·8125
$\frac{14}{16}$	·875
$\frac{15}{16}$	·9375

Hours and Minutes as Decimals of a Day

Hrs.	Minutes				Hrs.	Minutes			
	0	15	30	45		0	15	30	45
0	·000	·010	·021	·031	12	·500	·510	·521	·531
1	·042	·052	·063	·073	13	·542	·552	·563	·573
2	·083	·094	·104	·114	14	·583	·594	·604	·614
3	·125	·136	·146	·156	15	·625	·636	·646	·656
4	·167	·177	·188	·198	16	·667	·677	·688	·698
5	·208	·219	·229	·240	17	·708	·719	·729	·740
6	·250	·260	·271	·281	18	·750	·760	·771	·781
7	·292	·302	·312	·323	19	·792	·802	·812	·823
8	·333	·344	·354	·365	20	·833	·844	·854	·865
9	·375	·385	·396	·406	21	·875	·885	·896	·906
10	·417	·427	·438	·448	22	·917	·927	·938	·948
11	·458	·469	·479	·490	23	·958	·969	·979	·990

Minutes of Time as Decimals of an Hour
Minutes of Arc as Decimals of a Degree

Min. ′	Hours °	Min ′	Hours °	Min ′	Hours °	Min ′	Hours °	Min ′	Hours °
1	0·017	13	0·217	25	0·417	37	0·617	49	0·817
2	·033	14	·233	26	·433	38	·633	50	·833
3	·050	15	·250	27	·450	39	·650	51	·850
4	·067	16	·267	28	·467	40	·667	52	·867
5	·083	17	·283	29	·483	41	·683	53	·883
6	·100	18	·300	30	·500	42	·700	54	·900
7	·117	19	·317	31	·517	43	·717	55	·917
8	·133	20	·333	32	·533	44	·733	56	·933
9	·150	21	·350	33	·550	45	·750	57	·950
10	·167	22	·367	34	·567	46	·767	58	·967
11	·183	23	·383	35	·583	47	·783	59	·983
12	·200	24	·400	36	·600	48	·800	60	1·000

DATA SLIPS.

π	= 3·1416	1 Land mile	= 5280 feet
$\frac{\pi}{4}$	= 0·7854	1 Sea mile	= 6080 feet
Area of circle	= $\frac{\pi}{4}d^2$ or πr^2	10 Cables	= 1 sea mile
Circ of circle	= πd or $2\pi r$	100 cu. ft.	= 1 ton register
Vol of cylinder	= $\frac{\pi}{4}d^2 l$ or $\pi r^2 l$	35 cu. ft.	= 1 ton displacement
Ex. Mer. constant	= 32·72	2240 lbs.	= 1 ton weight
Dist. to horizon	= $\sqrt{\text{ht.}} \times 1{\cdot}15$	2000 lbs.	= 1 short ton
Dist. by danger angle	= ht. × ·565 ÷ Alt.	2204 lbs.	= 1 metric tonne

Scale C	Scale D	C	D	Scale C	Scale D	C	D
Sea miles	Land miles	33	38	Cu. ft.	Cu. metres	600	17
Land miles	Kilometres	87	140	Cu. yds.	Cu. metres	85	65
Sea miles	Kilometres	138	256	Cu. metres	Tons @ 40 cu. ft.	17	15
Feet	Metres	82	25	Cu. metres	Tons @ 100 cu. ft	17	6
Ft. per sec.	Miles per hour	22	15	Lbs.	Kilograms	280	127
Ft. per sec.	Knots	304	180	Imp. tons	Metric tonnes	62	63
Metres per sec.	Miles per hour	80	179	Imp. tons	Short tons	100	112

These slips may be cut out and stuck on the back of the Slide Rule. They will be found to contain information of more practical use to the seaman than those already there.

SIN = $\frac{\text{opp}}{\text{Hyp.}}$ $\frac{O}{H}$

COS = $\frac{\text{adj}}{\text{Hyp.}}$ $\frac{a}{H}$

TAN = $\frac{\text{opp}}{\text{adj}}$ $\frac{O}{a}$