9. TRUE, MAGNETIC, AND COMPASS NORTH

Marine navigation, especially beyond the visible shores, requires a reference from which the boat direction can be measured. The True North has been used traditionally as this reference, but its direction was difficult to establish for centuries. At night, the Polar Star can be used in the northern hemisphere, if not hidden behind clouds. During the day, the sun is of some help, but its movement across the sky makes it difficult to use, except at noon when it is highest above the horizon: at that moment, south is exactly in the direction of the sun. Naturally, for navigators sailing in the southern hemisphere and south of the tropics, the sun at noon is due north.

By the year 1000, the Chinese had noticed the magnetic properties of certain metallic minerals, and had recorded their tendency to line up approximately towards the North Star (True North) when deposited on a small floating platform in a bowl of water. The Venetians, however, are usually credited with the practical application of these magnetic properties to determine direction at sea. In the 13th century, in Italy, the first floating compass roses used on ships were illustrated with the winds from all quarters. The dry compass was invented in Europe around the year 1300.

The magnetic compass points towards the Magnetic North, which happens to be fairly close to the True North. The difference of angle between the True North and the Magnetic North, as seen from where the navigator stands, is called the **"magnetic variation"** because it varies from year to year as well as with the position of the boat around the world. The magnetic variation is sometimes referred to as the magnetic declination, but the word "declination" is more properly used to indicate the latitude of a celestial object above or below the equatorial plane in celestial navigation.

Although the magnetic variation is close to zero around the center of Canada on one side of the Earth, and in Germany on the other side, it can be quite significant depending where the navigator is on Earth, and it is very important to correct for it. This is explained in the first part of this section.

On a boat, the compass is fixed on a pedestal, and is affected by metallic and magnetic masses as well as electric wires around it. The compass error from the Magnetic North, or **compass deviation**, is discussed in the second part of this section.

9.1 True North

True North and True South are the points through which the axis of rotation of the Earth runs. An observer at the North Pole (True North) sees the stars go around the sky at constant altitudes above the horizon. The Polar Star is pretty well right over the True North. All meridians on Earth, and on a sphere representing it, converge towards the True North (Fig. 9.1). Two or three compass roses pointing to the True North are printed on most Canadian charts (Fig. 6.2 p. 45).

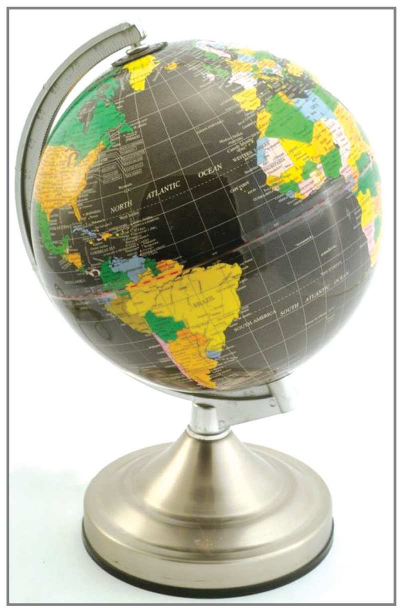


Fig. 9.1 Meridians converge at the True North (North Pole), at the point where the axis of rotation of the Earth passes.

9.2 Magnetic North

The movement of lava along loops above the iron core of the Earth causes a flow of electricity which, in turn, generates magnetic fields. The lines of force, in these magnetic fields, emerge from the Earth in the area called **Magnetic North (M)**; they diverge around the Earth, and return at the Magnetic South, not very far from the South Pole, at the edge of the Antarctic Continent nearest to Tasmania (Australia).

Since the loops of lava are fluid, the magnetic field varies slightly from year to year, and occasionally reverses itself. During the past few thousand years, the Magnetic North has been in Northern Canada. For the past few hundred years, it has been moving towards the NNW at the rate of about 50 km per year. In 1831, the Arctic explorer James Ross established its position along the central Canadian Arctic Coast, at the foot of the Boothia Peninsula. More recently, it was further north and slightly west, near Resolute Bay. By 2010, it was over the ice cap, some 400 km to the NW of Ellesmere Island (Fig. 9.2).

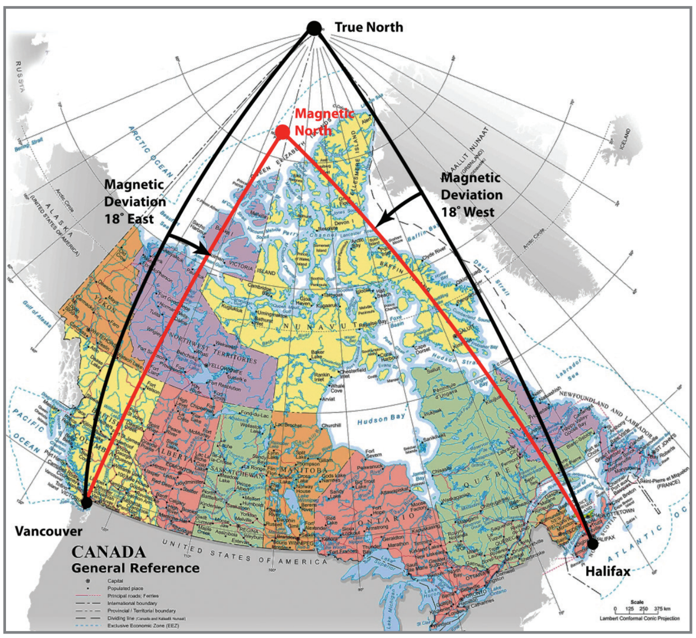


Fig. 9.2 The True and Magnetic poles.

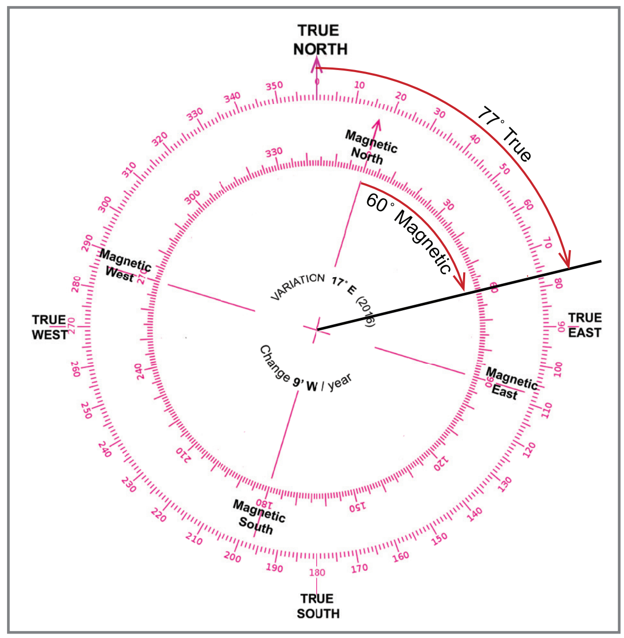


Fig. 9.3 The True and Magnetic Norths. Within each compass rose printed on a marine chart, the magnetic compass rose is a regular compass rose rotated until its zero points towards the Magnetic North. Any bearing measured with a hand bearing compass, i.e. off the magnetic north (i.e. 60º M), needs to be adjusted by the magnetic "variation" before it can be plotted on a chart, on which angles are measured off the True North (77º T). The variation, east or west, is the angle from the True North to the Magnetic North (17º E).

9.2.1 Conversions between True North and Magnetic North

On the chart, the navigator plots the tracks of the boat in **degrees True**, counted from the True North. The helmsperson, on the other hand, needs a direction in **degrees Magnetic**, counted from the Magnetic North, in order to be able to steer the boat by the magnetic compass. Conversely, the navigator takes bearings in degrees magnetic from landmarks with a hand bearing compass, and needs to convert these into degrees True in order to plot the lines of position on the chart and determine where the boat is (Fig. 9.3).

Conversions between **true** and **magnetic** degrees are thus done frequently, and exact calculations are essential to avoid gross errors in position. Since navigators are often tired and frequently trying to work in a rather miserable environment, they are subject to human errors, and best rely on a mechanical and systematic method of calculations not requiring any profound thinking. Experience shows that by-passing the simple method described below in order to make full use of one's extended knowledge in mathematics and brilliant intelligence, leads to what the navigators themselves call "stupid errors", which can result in disaster.

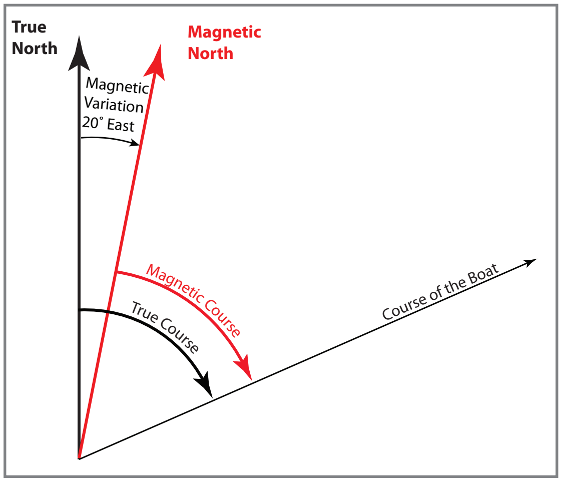


Fig. 9.4 Magnetic Variation East (least):
Magnetic Course = True Course - Variation.

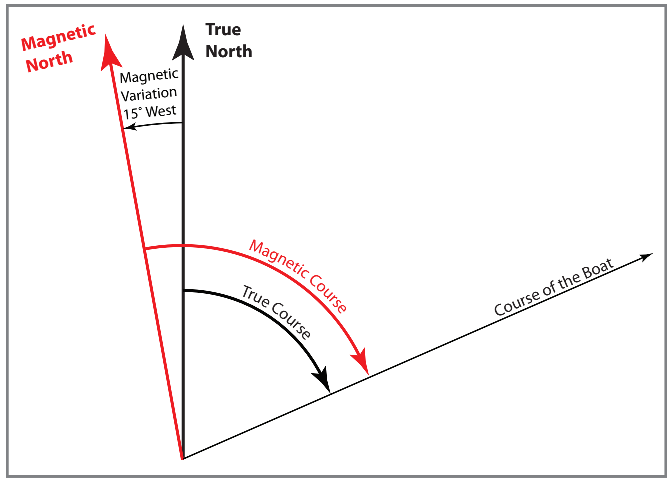


Fig. 9.5 Magnetic Variation West (best):
Magnetic Course = True Course + Variation.

- When Magnetic North **M** is **east** of the True North (Variation **V** is east; Fig. 9.4), as it is the case in Western Canada, the Magnetic Course **MC** of the boat can be calculated from its True Course **TC** measured on the chart, by applying the formula:

  MC = TC – Variation East (Fig. 9.4)

  i.e. Magnetic Course = True course **minus** the Variation East. In other words, when switching from True to Magnetic, and only when switching from True to Magnetic, **East is Least**.

- When Magnetic North **M** is **west** of the True North (Variation **V** is West; Fig. 9.5), as it is the case in Eastern Canada, the Magnetic Course **MC** of the boat can be calculated from its True Course **TC** measured on the chart, by applying the formula

  MC = TC + Variation West (Fig. 9.5)

  i.e. Magnetic Course = True Course **plus** the Variation West. In other words, when switching from True to Magnetic, and only when switching from True to Magnetic, **West is Best**.

- In summary:

TRUE (Course or Bearing) { - **VARIATION EAST** (East=Least) / + **VARIATION WEST** (West=Best) } = **MAGNETIC** (Course or Bearing)

9.3 Compass North

The boat compass should point to Magnetic North. However, it is affected by local metallic and magnetic masses as well as electric wires in the cockpit. This introduces small errors which vary depending on the heading of the boat. The error is the **compass deviation**, which vary from a few degrees east to a few degrees west of Magnetic North as the boat turns around.

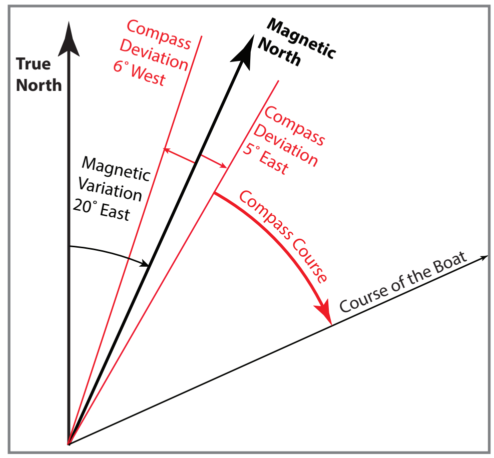


Fig. 9.6 Compass deviation, **east** or **west** of the Magnetic North depending on the orientation of the boat.

9.3.1 Conversions between Magnetic North and Compass North

The same calculations as in section 9.2.1 (conversion of True North to Magnetic North) apply to conversions from Magnetic North to Compass North:

- When the compass deviation is east of the Magnetic North (east deviation **D**), the Compass Course **CC** of the boat can be calculated from the Magnetic Course **MC** by applying the formula:

  CC = **MC** – **D**eviation East

  i.e. Compass Course = Magnetic Course **minus** the Deviation East of the compass. In other words, when switching from Magnetic to Compass, and only when switching from Magnetic to Compass, **East is Least**.

- When the compass deviation is west of the Magnetic North (West Deviation **D**), the Compass Course **CC** of the boat can be calculated from its Magnetic Course **MC** by applying the formula

  CC = **MC** + **D**eviation West

  i.e. Compass Course = Magnetic Course **plus** the Deviation West of the compass. In other words, when switching from Magnetic to Compass, and only when switching from Magnetic to Compass, **West is Best**.

- In summary:

MAGNETIC Course { - **DEVIATION EAST** (East=Least) / + **DEVIATION WEST** (West=Best) } = **COMPASS** Course

9.3.2 Compass Deviation Table and Graph

The compass deviation from Magnetic North depends on the boat's heading. As various metal parts such as winches, or magnetic masses such as loudspeakers, as well as electric cables such as the ones bringing lights to the cockpit, pass in front of the compass when the boat turns around, the compass needle is slightly deflected to the left or to the right of the Magnetic North.

Swinging of the compass consists of measuring the compass deviations as a function of its heading throughout a full rotation of 360°, and then minimizing these deviations through the use of small adjustment screws marked N-S and E-W on the sides of the compass. This procedure is best left to professionals. It is usually conducted in a quiet area of the harbour, and should be repeated whenever the cockpit configuration changes.

The compass deviation, is traditionally recorded as a function of the boat direction, either in a **compass deviation table** (Fig. 9.7), or in a **compass deviation graph** (Fig. 9.8):

COMPASS DEVIATION TABLE

Magnetic heading	Compass deviation	Compass heading
000	6° W	006
010	6° W	016
020	6° W	026
030	5° W	035
040	5° W	045
050	4° W	054
060	4° W	064
070	3° W	073
080	2° W	082
090	1° W	091
100	0°	100
110	2° E	108
120	3° E	117
130	3° E	127
140	4° E	136
150	4° E	146
160	5° E	155
170	5° E	165
180	5° E	175
190	5° E	185
200	4° E	196
210	4° E	206
220	3° E	217
230	2° E	228
240	1° W	241
250	3° W	253
260	3° W	263
270	4° W	274
280	4° W	284
290	5° W	295
300	5° W	305
310	5° W	315
320	6° W	326
330	6° W	336
340	6° W	346
350	6° W	356

Fig. 9.7 Compass Deviation Table.

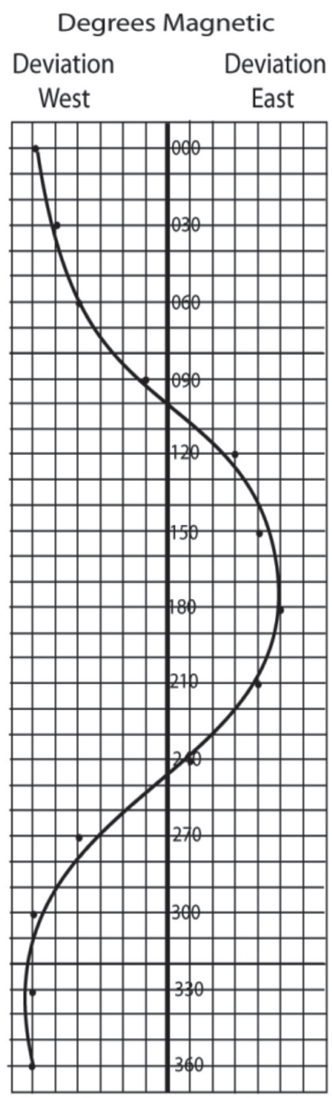


Fig. 9.8 Compass deviation graph, displaying identical information.

Note that, in the example given in Fig. 9.6 and 9.7, the swinging of the compass was not done very well: the overall deviation is mainly to the west. Some fine tuning is required, using the adjustment screws of the compass.

9.4 Mnemonics for conversions between True, Magnetic and Compass North

The process of conversion from any North to any other is straightforward, and yet most navigators make what they call "stupid errors", at least initially, adding degrees of variation or deviation instead of subtracting them, and vice versa. This is because they tend to blindly apply the phrase "East is Least and West is Best"; yet, the mnemonic sentence is valid **ONLY FROM TRUE TO MAGNETIC, AND ONLY FROM MAGNETIC TO COMPASS**, i.e. from **left** to **right** in the mnemonic relation given below. Hence all the arrows.

In other words, if one writes the letters **"TVMDC"** from **left** to **right**, as shown below, the mnemonic phrase "East is least and West is Best" only applies for the calculations from **left** to **right**.

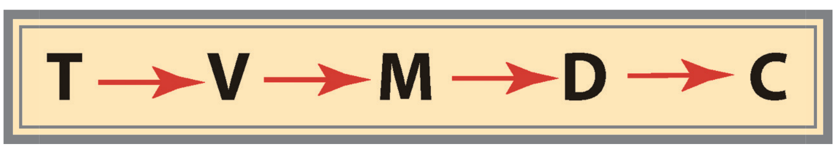
T (**T**rue course);

V (**V**ariation of the Magnetic North, either East or West);

M (**M**agnetic course);

D (**D**eviation of the compass, either East or West); and

C (**C**ompass course)



"East is Least (-) and West is Best (+)":

VALID ONLY FROM LEFT TO RIGHT

The sequence of calculations is easily remembered with the use of the mnemonic phrase:

"**T V M**akes **D**ull **C**hildren".

Other mnemonic phrases are used, usually by young sailors whose mind is affected by relatively high levels of testosterone, but these would be politically incorrect, and cannot be reproduced in such a conservative and traditional document.

Conversion of directions from True to Compass courses thus involves two steps:

1. Knowing the true course **T** to be followed by the boat, as measured on the chart from the True North, the navigator subtracts the magnetic variation **V** if it is east (**East is Least**) or adds it if the Variation is west (**West is Best**) to obtain **M**, the Magnetic course. This is the course which would be followed with a **perfect** compass, i.e. one not influenced by metal masses or electric wires around the cockpit.

2. Since the boat compass always has some error, i.e. a small deviation, further calculations must be made to correct for compass deviation. Having calculated the magnetic course of the intended track by applying the local magnetic variation, the navigator subtracts the compass deviation **D** if it is east (**East is Least**) or adds it if it is west (**West is Best**) to obtain **C**, the Compass course. This is the course to be followed on the boat compass.

Example 1:

A skipper wishes to follow a course of 240° True (T=240), along the West Coast where the Magnetic North is 17° to the east of the True North (V=17 east). What is the compass course to follow, given the compass deviation table given in Fig. 9.7.

We place the numbers which we know under to letters TVMDC:

T	V	M	D	C
240	17E (-)			

Since we are doing the calculation from **left** to **right**, the Variation of 17° east must be subtracted (**East is Least** from **left** to **right**). The Magnetic course M is 240° – 17° = 223° (column **M**):

T	V	M	D	C
240	17E (-)	223		

When the boat follows a magnetic heading of 223° M, the deviation table (Fig. 9.7) shows a compass deviation of 3° E. We write the deviation **3° E** in the column D:

T	V	M	D	C
240	17E (-)	223	3E (-)	

Again, since we are doing the calculation from **left** to **right**, the deviation of 3° east must be subtracted (**East is Least** from **left** to **right**):

T	V	M	D	C
240	17E (-)	223	3E (-)	220

The compass course C is 223° - 3° = 220° (column **C**). The helmsperson needs to follow a course of 220° on the boat compass to maintain a true course of 240°.

Example 2:

Sometimes, we follow a compass heading **C** and wonder what the true course **T** of the boat might be. More frequently, we take a bearing with the **hand bearing compass**. We assume that we keep our hand bearing compass away from ferrous masses and electric wires or magnets so that it has no deviation: our measure of the angle between the Magnetic North and a landmark is thus in degrees magnetic, **M**.

If we want to plot this bearing on a chart, we need to convert it to degrees true, **T**. For example, we take a magnetic bearing of 060° on a landmark in Newfoundland, where the local magnetic variation is V = 20° W. We want to plot the corresponding line of position (Chapter 10, p. 63).

In order to apply the same mnemonics (**East is Least** and **West is Best**), we need to make sure our calculations are done from **left** to **right**. In other words, we need to **guess** at the number T which, given our known local Variation V of 20º W, will give us the hand compass bearing M.

T	V	M	D	C
?	20W (+)	060		

The process involves two steps.

1. We take an educated **guess** at the number which we think, in column T, would result in a Magnetic heading of 60° if we did the calculation from **left** to **right**, and added the Variation W (**West is Best**) of 20° to T. We think that **T** should be 40°.
2. We verify, from **left** to **right**, that our guess was right, especially its sign:

T	V	M	D	C
40	20W (+)	060		

40° + 20° W = 060° indeed. Our educated guess was right. This verification is necessary given the traditional frequency of erroneous guesses. The most common mistakes are either a wrong sign, or a guessed number off by 10°. Experience with hundreds of students over some 15 years shows that guesses are wrong about half the time at sea, as would be expected with sailors who are stressed and tired, and who thus do not have full use of their vast knowledge and sharp mind. Guesses in class are a little better. It is thus essential to carefully verify the guess, and in particular its sign.

Example 3:

We might know our true course, for instance by following a range marked in degree True on the chart, and also know our magnetic heading, for instance from our hand bearing compass which has no deviation error. We can then measure the local magnetic variation:

T	V	M	D	C
245	?	228		

Looking at the data from left to right to use the rule "West is Best and East is Least," we can calculate the magnetic variation as 245º - 228º = 17º E. Similarly, knowing M and C, we could calculate the compass deviation D. If we read, for example, C = 230º on the boat compass, we can tell that D = 2º W since 228º M + 2º W = 230º C.