Directions, Courses, and Bearings: The Compass

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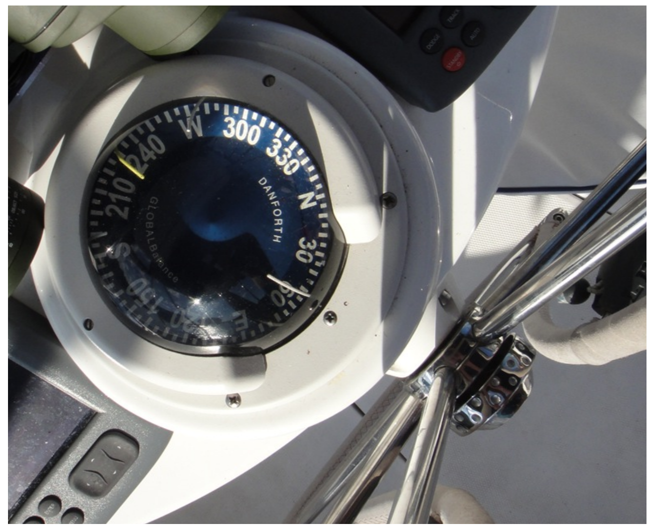
Ever since explorers and travellers have ventured beyond their familiar landscape, they have needed to know which way they were going. The need is particularly acute on the water where there are no paths to follow and often no landmarks on the horizon. Ancient civilizations such as the Polynesians were able to accomplish remarkable feats of navigation over many millennia by relying on their knowledge of stars, migratory bird movements, ocean swells, currents, trade winds, and faint signs of remote land such as clouds. More modern navigation has benefitted tremendously from the application of the magnetic compass for marine navigation in ancient China (approx 12th century), providing a simple way to determine orientation in reference to the compass needle.



Binnacle compass on a sailing yacht. The compass card (blue, with cardinal points and numerical headings marked) is free to rotate and keeps itself oriented towards compass north as the vessel turns. The lubber line (yellow) is fixed to the housing on the vessel and used to read the current heading.

What do we mean by "North"?

The answer is surprisingly tricky, and has evolved from ancient times to present. The briefest and easiest definition to understand is that it is the name given to one of the two ends (*poles*) of the axis around which the Earth rotates. Using a right-handed coordinate system, true north is the positive orientation for that rotation. At any point on or near the surface of the Earth then, (true) north is the direction towards the (true) north pole.

It may seem odd to start with such an abstract and scientific answer that predates knowledge that the earth is even round or rotating, but it makes sense historically.

In the mid latitudes of the Northern Hemisphere, true north can be found approximately using Polaris, the Pole Star ("North Star"). Of the stars bright enough to observe unaided, it conveniently happens to make the same angle with the plane of the ecliptic (in which the earth rotates around the Sun) as the Earth's rotation axis, within a few degrees. For that reason, it appears in a constant position with respect to the rotating earth, to the north of any observer on the planet. Or at least for the moment: the earth's spin axis undergoes axial precession meaning it travels in a circle like just like that of a spinning top over a 26,000 year cycle. That wandering of the spin axis causes the centre around which the stars appear to spin to move correspondingly. Over time, Polaris will trace out bigger and bigger circles as one of its


Long exposure image showing Polaris fixed in position as the other stars apparently turn around it.
by Ashley Dace, from Wikipedia: Polaris (CC 2.0)

neighbours becomes the centre. Various stars and constellations known since ancient times have been used for the purpose of determining at least rough visual orientation at night. The definition of true north-true south as the earth's axis of rotation, though, remains constant, as does its relationship to Earth's continents and any given point on them (plus or minus some tectonic drift).

In addition to providing orientation to anyone in the mid latitudes of the northern hemisphere, one can also use Polaris to determine latitude by measuring its altitude using a sextant (or one of its predecessors the quadrant or astrolabe) to measure its altitude over the horizon allows latitude (ie. how far north one is from the equator) to be determined to within a few degrees. After applying some corrections to account for the star's imperfect alignment with the spin axis, much better accuracy is possible. The centrality of celestial observations to our understanding of the earth, and particularly to our description of position, is the reason why True North is taken as the primary definition of "north".

While latitude has been easily measured for centuries, determination of longitude is different story. Since longitude deals with the direction in which the earth is rotating, determining it requires a precise time reference (how precise? turning through its equatorial circumference of about 21,700 nautical miles in a day means one nautical mile of position error at the equator for every four seconds of time error). The development of the marine chronometer in the eighteenth century was one of the most significant advances made in the entire history of nautical navigation. *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* by Dava Sobel (Hamilton Public Library, Amazon) tells the story of its invention. In short: due to the massive importance of the then-unknown ability to determine longitude at sea, Britain offered a prize of tens of thousands of pounds (modern equivalent, several million pounds) to whoever met certain performance standards in a sort of early precursor to the X Prize.

Celestial navigation is an art and science of its own. Its relevance to us here is both historical interest and as an explanation for the use of true north when determining courses and bearings in coastal navigation.

True North

Since it is the closest thing we have to an invariant orientation and corresponds most closely to celestial observations, nautical charts are drawn with a grid showing True North, with the conventional orientation showing True North up. Meridians of longitude run True North-South and so define a grid from which position may be read using latitude and longitude angles. Parallels of latitude intersect the meridians at right angles.

There are three notable exceptions to the True-North-Up orientation convention: strip charts of long, narrow waterways (canals, rivers, etc) are typically oriented for best efficiency in using the paper; and Small Craft Charts are generally drawn with magnetic north up, though the grid is still True and thus at an angle to the page orientation. Electronic chart plotters can generally be configured to show multiple different orientations including head-up, course-up and north-up. It goes without saying that knowing which is being displayed at a given moment is essential to understanding the situation.

Users such as surveyors, hikers, or military personnel may also be familiar with the Universal Transverse Mercator (UTM) projection and coordinate system (using metres easting and northing), which refers to Grid North. It is similar to True North at most scales and latitudes, but may differ by a few degrees because of the particular distortions used to simplify the coordinate system.

By convention, nautical chart work is done in terms of True North, with adjustments made as needed to convert to or from other representations.

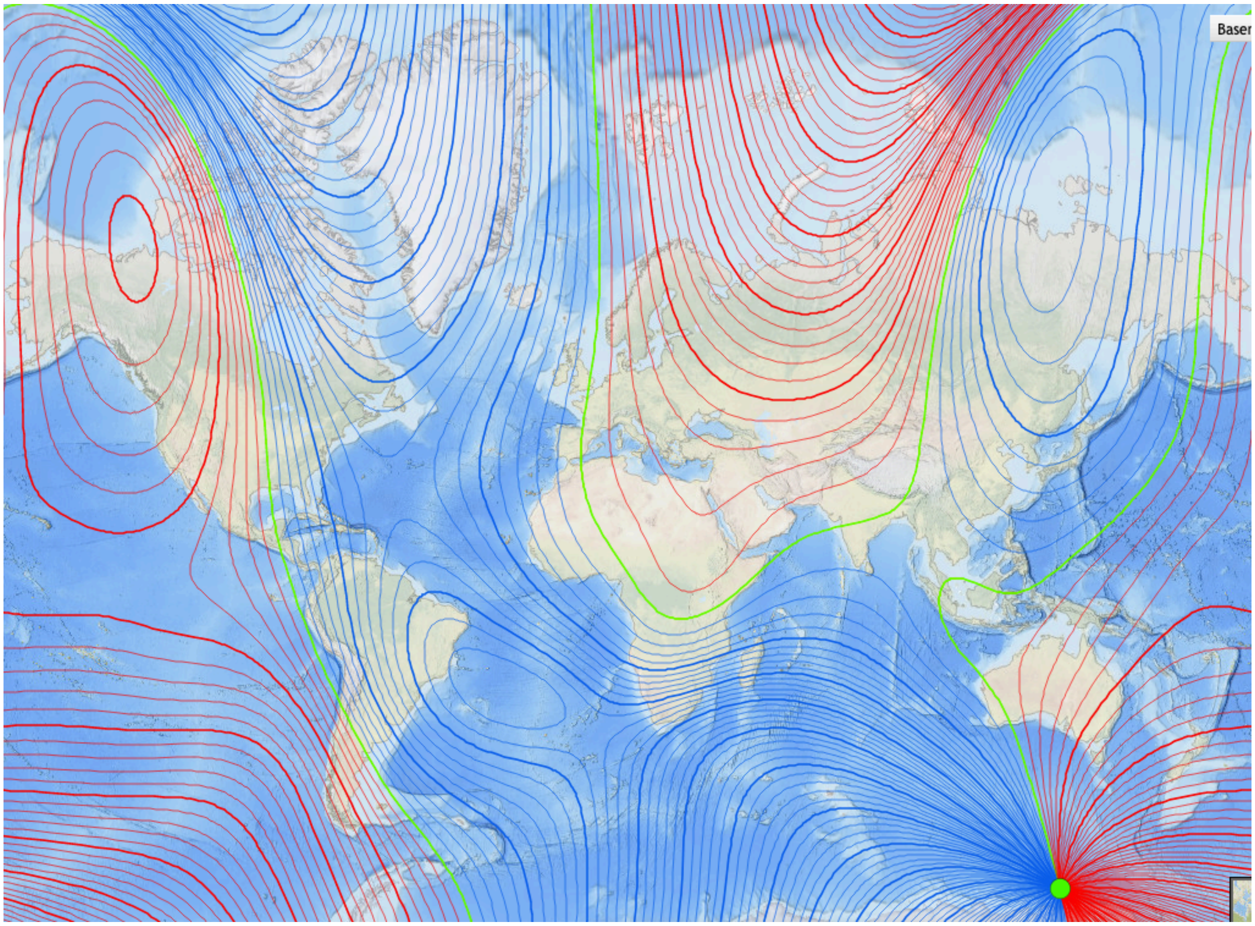
Magnetic North

While celestial observations have yielded some of the most important insights into the shape and motion of our planet, they are not very convenient to make on the move. Good astronomical observations require a significant amount of time, a stable platform, precision instruments, good weather, and extensive (non-trivial, time-consuming, error-prone) calculations.

Chinese compass, c. 1760
National Maritime Museum London
Wikipedia: History of the compass
Victoria C, CC BY-SA 4.0

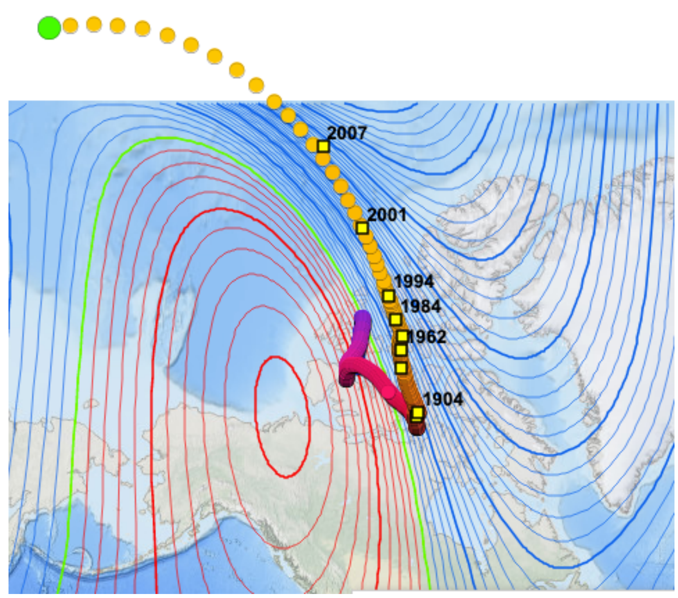
The ability to measure a ship's heading (the direction where it is pointing relative to some fixed reference) in real time is extremely important, and steering without terrestrial landmarks would be difficult if not impossible to do by celestial means alone. As noted earlier, the magnetic compass has been used for that navigational purpose since the 11th century.

Due to the concentration of iron in its core and its rotation, the Earth has a magnetic field that aligns roughly (though with some significant differences) with the True North-South axis. A compass is a small magnet which is free to move (eg. suspended by thread, attached to a pivot, or floating in a fluid) and thus tends to orient itself towards the Earth's Magnetic North Pole due to the very slight magnetic force exerted on it by the Earth. On board, the magnet is generally attached to a *compass card* with markings at regular intervals so that the card keeps a constant orientation to magnetic north while the vessel rotates around the card. It usually rests on a pivot to keep it centred, and immersed in fluid which helps damp the motion a bit. A *lubber line* fixed to the vessel (the yellow line in the image at top) allows the magnetic course to be read off the card.



Isogonic lines (lines of equal magnetic variation) at 2-degree spacing as of 2020
Red is positive (easterly), green is zero, blue is negative (westerly).
The south magnetic pole is shown at bottom right where the lines converge.
US NOAA

For a variety of complex reasons relating to physical processes in the earth's core (some understood and some not), the magnetic field's north-south axis does not line up with the true axis of rotation. Since the Magnetic and True North Pole are not co-located, a compass pointing to Magnetic North will exhibit *variation* between its reading of "north" and True North. The direction and size of the difference depend on the relative positions of the two poles, and of the observer. Values become more extreme (to the point that compass navigation is largely useless) near the poles, and can attain large values (exceeding 10-15 degrees) even at more temperate latitudes.



Observed and projected track of the Magnetic North Pole, 1590-2020
US NOAA

The rate of change has recently been increasing as well (interesting article in Nature News: Earth's magnetic field is acting up and geologists don't know why). We will show below how to deal with that on short time scales of a few years. The US NOAA also has a fascinating interactive map that shows how magnetic declination (the landlubber's term for variation, where a positive number means easterly) changes in time and space and time, as well as a historical and projected track of the north pole showing the recently increased rate of change. As a result, magnetic north as printed on any given paper chart is necessarily out of date as time elapses.

In addition to global forces causing change, local magnetic anomalies due to large deposits of iron minerals can cause significant errors in the compass in some areas. These may be charted (see notation in Chart 1 below) or recorded in notes on the chart and related publications, but are hard to correct for. In affected areas, no magnetic compass (including the digital compass in an auto-helm, or included in a smartphone) should be relied on.

82.1

Local magnetic anomaly: Within the enclosed area the magnetic variation may deviate from the normal by the value shown
Anomalie magnétique locale : A l'intérieur de la zone, la déclinaison magnétique peut varier de la norme selon la valeur indiquée

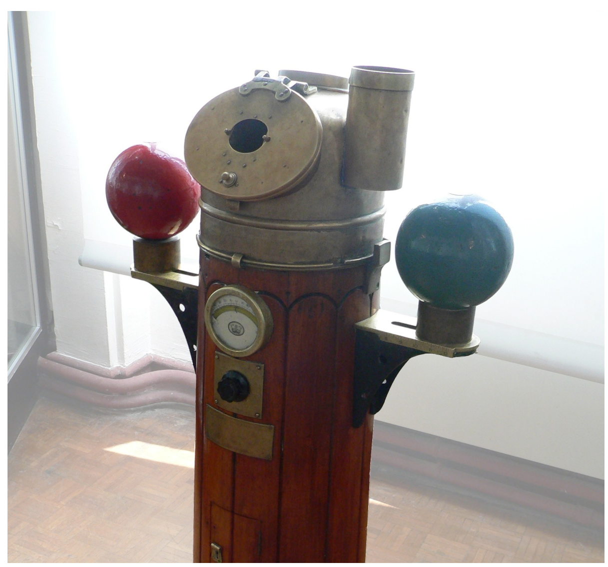
Local magnetic anomaly
CHS Chart 1 (2016) B82.1

Geomagnetic storms caused by solar flares can also exert some influence over magnetic compasses. They are usually associated with spectacular instances of the aurora borealis and can, in extreme cases, interfere with satellite navigation signals. Such events are generally short-lived and not likely to be announced on marine weather channels, though their effect can be measurable. Space agencies tend to be able to observe and predict such events a few days before the effects are felt.

Compass North

Magnetic North is an idealized notion that cannot be directly observed because of the interference of other nearby magnetic fields. Real vessels have their own magnetic fields which will cause the needle of any compass (or equally the digital readout from an electronic compass) on board or nearby to *deviate* from the value it would read in the same position with no other influences nearby.

Non-metallic materials (plastic, glass, wood, glass or carbon composites, fabrics) do not create magnetic fields and therefore do not influence the compass. Most metals, including brass, aluminum, tin, lead, and some formulations of steel (particularly some stainless grades) also do not cause magnetic fields. That, in addition to saltwater corrosion



Brass-mounted binnacle compass, showing iron spheres used for deviation compensation.
Musee de la Maritime, Paris
Wikipedia: Binnacle (User Rama, CeCILL license)

resistance, is one reason for the historical and enduring popularity of brass fixtures on board.

Iron is the most common magnetic material, and is also found in large amounts on board. An inboard engine block is usually several hundred pounds of iron. Other large masses such as the anchor, anchor chain, and dinghy engine may also have large associated magnetic fields. Motors such a fridge and AC compressors, fans, etc, will have residual magnetization in addition to the fields created during their operation. Some vessels have cast iron keels, in place of the denser but more expensive lead. Even large iron tools such as wrenches or swaging tools may contribute somewhat. They should be stored in a consistent location well away from any compasses, including digital readouts for autohelm.

Permanent magnets are also a serious concern for the steering compass. Some are obvious, such as fridge magnets. Others can be a little more subtle such as magnetized screwdrivers, small motors (eg. in your cell phone's vibrating-alert motor), magnetic clips for sunglasses, etc.

Electrical currents - both the wires powering domestic loads on board, and those within electronic devices - cause magnetic fields when powered on. If in doubt, you can check the effect by powering the device in question off and on while at dock and watching for movement of the compass (it may be slow or subtle, so watch carefully as even a few degrees can be quite meaningful over distance). New electrical and electronic equipment should be situated as far as possible from the compass, and its influence checked prior to relying on the compass. Properly-installed illumination for the compass will use twisted pairs of wire for current supply and return. With equal and opposite currents flowing in the two wires, the magnetic field is cancelled out.

Some components of deviation such as the engine block and keel are large, unavoidable, and mostly constant. Their total effect does not change much over time and can be calibrated in a *deviation card*. Since deviation is due to magnetic fields on the boat, the angle between the boat's magnetic field and the Earth's depends on the heading. On some headings, the vessel's field will pull (deviate) the compass card one way, on others the other way, and sometimes it will have no effect. Consequently, deviation depends on heading and so must be tabulated for a variety of headings. The exact mechanics of that are presented later.

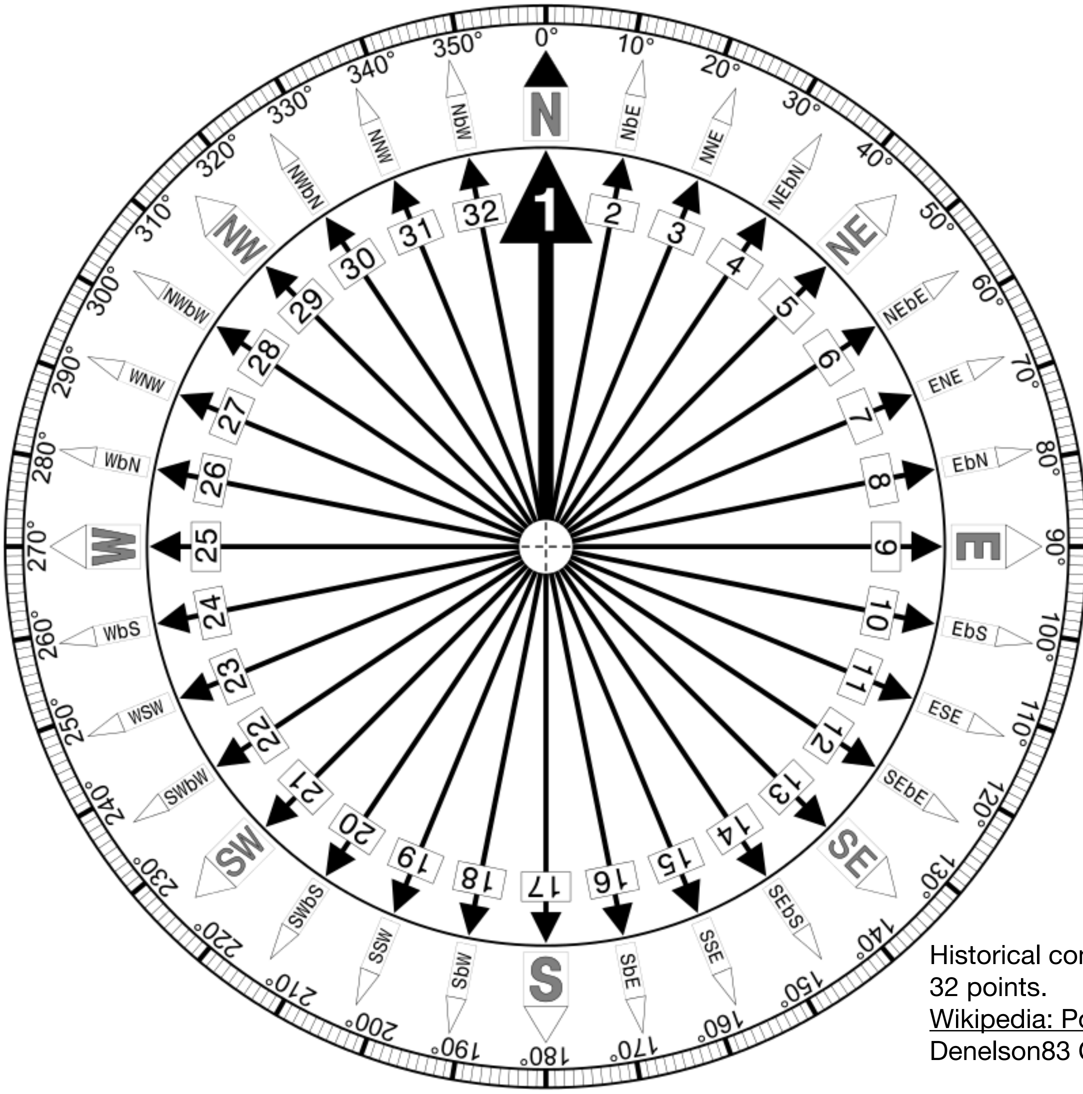
Other components of deviation are smaller and more variable. Their influence should be minimized by keeping anything with a magnetic field away from magnetic compasses (watch out for cell phones, tablets, belt buckles, tools, and flashlights). One should take particular care to note the location of the electronic magnetic-field sensor for the auto-helm, as they can be hidden in unusual places and magnets coming near may have unexpected effects!

If the compass, binnacle, or any of the large fixed contributors to deviation are changed (eg. engine hauled out for maintenance, major component replacement, etc), then the deviation card should be checked and possibly recompiled.

The Compass Rose

With a few different definitions of north now in hand, we can start talking about any other direction by its relation to north, conventionally in a clockwise direction.

In older times, the full circle was divided into 32 *points* of 11-1/4 degrees each. The influence persists in a few ways, notably that the international collision regulations still define overtaking



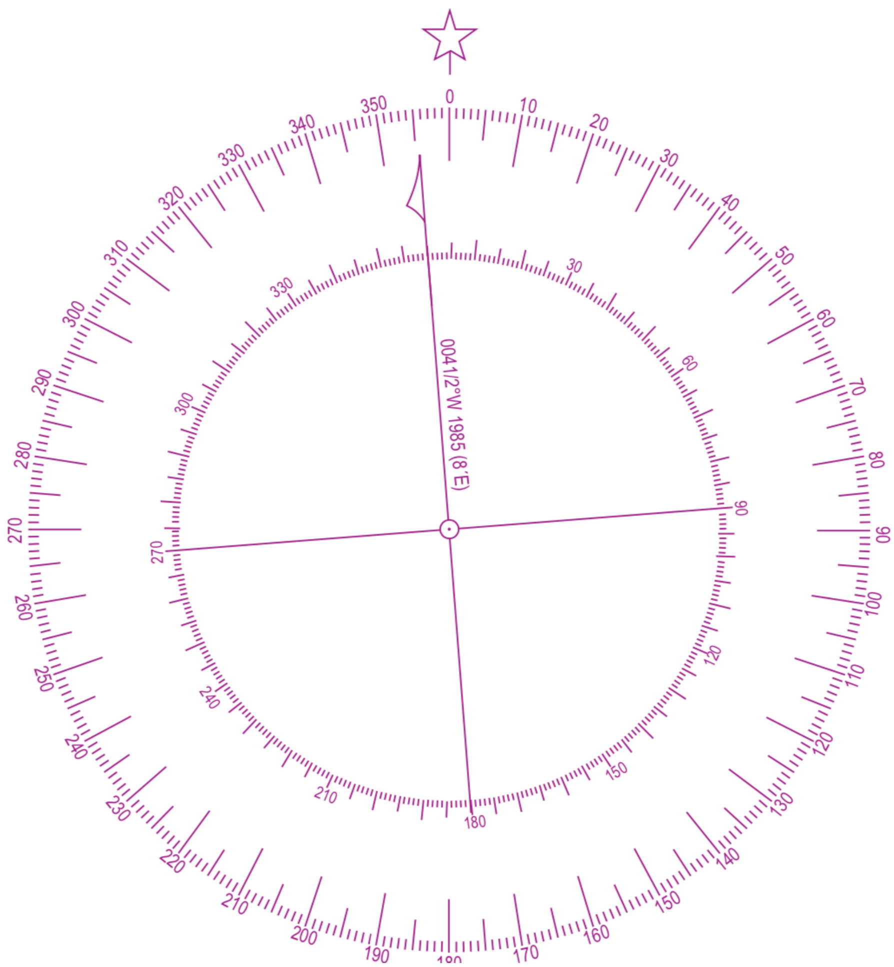
Historical compass rose, showing all 32 points.
Wikipedia: Points of the Compass
Denelson83 CC SA-3.0

as approaching in a direction 22.5 degrees (two points) abaft the beam. The lights displayed at night also follow that division. Points may also be encountered in historical documents or historical fiction. While the tradition may have anticipated computer engineering by centuries (computers work in powers of 2 such as 2, 4, 8, 16, 32, …), it can be a bit of a puzzling addition to counting in base-10 (normal math when you have a normal number of fingers), base-12 (feet and inches), base-60 (minutes of time and arc), and a 360-degree circle.

The four *cardinal points* of the compass are the simplest and most familiar division, with north, east, south, and west at 90-degree intervals clockwise from north. The *inter cardinal* points add another four directions (45-degree spacing) in between each of the cardinal points by specifying north or south first, then east or west (northeast, southeast, southwest, northwest). The subdivision can continue (to 22-1/2 degree spacing) by adding eight more *secondary intercardinal* points, two for each intercardinal, by saying first which cardinal point they are closest to: between north and northeast is called north-northeast (NNE); between northeast and east is east-northeast (ENE). This is all depicted in the compass rose below.

The final and largely historical subdivision into 32 points (11-1/4 degees) adds sixteen more points: one on either side of each cardinal or intercardinal point to give even coverage of the circle. Which side it is on is given by appending “by” and one of the cardinal or inter cardinal points. Just east of north is “north by east” (also said or heard “north, a point east”), while just south of southwest is “southwest by south” (yes, both Alfred Hitchcock and the culture festival got it backwards).

The modern, and much less confusing, convention is to use a number of degrees clockwise from north: positive values 0-359 with three digits including leading zeroes when speaking or writing bearings. North is 000, moving clockwise through 090 (east), 180 (south), 270 (west) back to north again at 360 (same as 000).



Example compass rose
CHS Chart 1 (2018) B70

Increasing course/bearing is always clockwise. Whichever way you are facing, to your right is the higher bearing or course (and naturally to the left is lower). This is why the “port/stbd” buttons on most auto-helm units also show “+10/-10” or “+1/-1”.

The Canadian compass rose above pays homage to Polaris by showing True North marked with a star. As noted earlier, plotting on the chart should always be done using the outer, True compass rose. The inner Magnetic rose should be mostly ignored.

Uses for the compass: course, bearing, heading

The main purpose of the compass is to measure directions relative to north. There are a few kinds of directions that have enough importance to have specific names. A *course* is a direction of travel: intended, actual, or historical. A *heading* refers specifically to the angle between the vessel's head (bow) and north at a given moment. A *bearing* is a direction between two objects (one of which is often but not always the vessel)

Course To Make Good (*CTMG*) is the True course between two waypoints (plotted positions forming part of a route). It describes the direction a navigator plans to go for a portion of the voyage.

Course to Steer (CTS) is the direction that the vessel needs to be pointed as it moves in order to arrive at the next waypoint. Typically it starts as the True CTMG, which is then adjusted to account for current and leeway to yield the True CTS. Adjustments for variation and deviation yield the Compass CTS that the helm actually tries to maintain on the steering compass, so that the True course is as planned and we arrive correctly at the waypoint.

Heading is where the vessel is pointing at a given moment. It may or may not be the same as the course to steer - the helm's job to keep it as close as possible, at least on average over time. Heading is typically measured by a steering compass which gives a Compass heading that can be corrected to True given a deviation card and known variation.

Course Over Ground (COG) is a measure of the actual direction travelled moment-to-moment. Typically this is only accessible via GPS as it requires taking position fixes in rapid succession (~once per second) and measuring the difference. COG will differ from heading by the amount of at least current and leeway. Said otherwise: heading is where we are <u>facing</u>, COG is where we are <u>going</u> in terms of change of position over time. Calculated from GPS, COG may be presented either True or Magnetic depending on settings. Recall that heading is measured by the steering compass, and needs to be corrected before comparing to True/Magnetic COG.

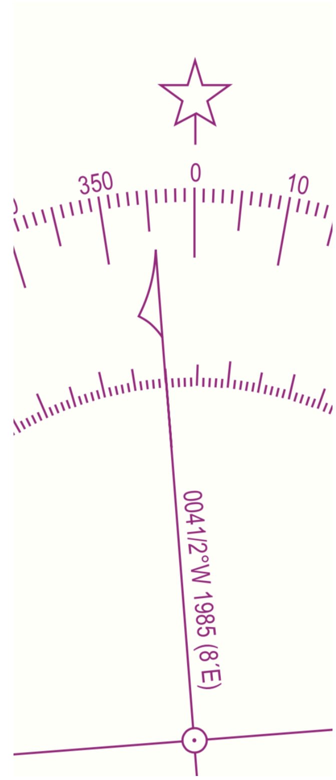
A vessel with no way (not moving through the water) subject to a current may have any heading, but the COG will be the direction of the current as the vessel is carried along over the bottom.

A vessel not subject to current or leeway should have its COG and heading equal. This is one way to test for compass deviation: comparing GPS True COG with the True heading computed from the Compass course steered.

Course Made Good (CMG) is the direction of the vector from a start point to an end point over some length of time. Typically a CMG would be measured by plotting two position fixes from different times and measuring the course between them. Since it arises from chart plotting, CMG is normally measured and specified as True CMG.

Simply *Course* (C) is a bit imprecise as a term as it may refer to any of the terms listed above. Asking the helm "What's your course?" would generally mean "what has been your average heading over the last while?" or "what course to steer are you trying to maintain?". The former would be common when sailing upwind and the course depends on wind shifts.

Compass Correction



Example compass rose
CHS Chart 1 (2018) B70

As noted in the description above, our charts are laid out in reference to True North, but we have no direct means of measuring our True course. Our steering compass gives erroneous readouts due to magnetic variation (location-specific differences between Earth's magnetic field direction and True North) and compass deviation (compass- and heading-specific changes due to a particular vessel's own magnetic fields). What is a navigator to do?

The answer is to *correct* readings from the steering or hand-bearing compass to True, or to "*uncorrect*" True courses to their equivalent Compass reading for use with the steering compass. For both variation and deviation, the compass error is given as a number of degrees east or west. Let's take the example at right, showing both the True (outer, with star) and Magnetic (inner) compass rose from a Canadian chart. The notation near the centre shows a magnetic variation of 4-1/2 W: Magnetic North lies 4-1/2 degrees to the west (counter-clockwise) of True North. Equivalently, True North would read between 004 and 005 M. Since we measure bearings clockwise from north, a magnetic compass with westerly variation will measure bearings as numerically greater than they should be.

Imagine a True bearing of X degrees, meaning a direction that is X degrees clockwise from True North. If, like the example at right, the compass' north points 4½ degrees west (counter-clockwise) of True North, then to get from compass north to our bearing we need to turn 4½ degrees clockwise to get to True North, plus X degrees clockwise to get to the bearing of interest. The compass would indicate the bearing as X+4½ degrees, which corresponds to X degrees True. There is a handy rhyme for this:

Compass least, error east

meaning if the compass reading is less than the true reading, the compass error is easterly. In this case, the compass reading exceeds the True reading (X+4½ > X) meaning the compass error is not least (therefore not east), so west.

The sequence in which corrections are done or undone can also be remembered with one or more mnemonics:

***TV M**akes **D**ull **C**hildren, or*
***T**rue **V**irgins **M**ake **D**ull **C**ompany **A**t **W**eddings*

Which helps us remember

True + **V**ariation = **M**agnetic; **M**agnetic + **D**eviation = **C**ompass (**A**dding **W**est)

There is one gotcha to be careful of: when working with bearings near north, you need to remember that values "wrap around" when increasing past 359 or decreasing past 000. So even though 003 M is numerically less than 359 T (so we might be tempted to say "compass least") the difference represents a westerly variation of four degrees, which seems more sensible than saying an easterly deviation of 356 degrees. If it helps to subtract 360 and think of 359 as -1 in an intermediate step, go for it. Remember to always present a final course or bearing as a positive three-digit number 000-359.

There is a worksheet provided at the end of the document that helps structure this process. It looks like this:

	—> Add west —>				
	True	Variation	Magnetic	Deviation	Compass

You use it by filling in the information that you have (usually a True, Magnetic, or Compass course), deciding which information you want to get out, and then progressing from what you have to what you want column by column. You'll notice that the column headings spell out our earlier memory aid (TVMDC). The notation at top right reminds you whether to add or subtract westerly variation. If you are moving from the left to the right, you add westerly error and subtract easterly. If moving the opposite way, reverse. There are worked examples towards the end of the document.

Variation

The variation between the Earth's magnetic field and True North changes with position, and with time. Canadian charts are printed with an indication of the amount and direction of magnetic variation as of some base year, as well as an annual rate of change in the compass rose. Other charts might give the information in a slightly different form, or in notes in the title block. While (like any prediction) not perfectly accurate approximate, it allows a navigator to anticipate and correct some of the error over time.

This change over time is one of the reasons we prefer not to use the Magnetic compass rose printed on the chart: it's a snapshot valid for a single year only. Sometimes the annual change isn't that large, sometimes it can add up to degrees pretty quickly.

Example compass rose, rotated counter-clockwise and cropped to show detail of variation specification
CHS Chart 1 (2018) B70

Let's take a look at how it's presented on Canadian charts - the same compass rose as shown previously above, but turned on its side for ease of reading. In this case, it shows a variation of 4½° W as of the base year (1985) and an annual rate of change of 8' E.

Note it's not a degree sign but rather a single-tick in the annual change 8' E, which denotes units of arc minutes. An arc minute is 1/60th of a degree of angle (arc), just as a minute of time divides an hour into 60ths. That means that the variation at this location is expected to be 4½° W as of the base year (1985) and move 8/60 of a degree east annually.

To compute the present-year variation, take the difference in time from the current year back to the base year (2020-1985 = 35 years), multiply by the annual rate of change (35 years x 8/60 E per year = 280/60 = 4° 40' E), and apply it to the base-year variation (4½° W = 4° 30' W) to get a final result (10' E) which can be rounded to the nearest degree (0° E). Since it's hard enough to steer to the nearest degree, let alone a fraction of one, by convention the nearest degree is acceptable precision when plotting courses and dealing with compass error calculations.

Don't forget, half a degree is 30', just like 30 minutes of time is half an hour. That's 0.50 hours (or 0.50 degrees), not 0.30. It's a common mistake to mix up decimal fractions of degrees (0.XX) with arc minutes (YY'). Watch carefully for that tick versus a decimal point and a degree sign.

Deviation

Deviation works a little bit differently from variation. Instead of depending on your position on Earth and the year, it depends a particular compass on a particular vessel, on a particular heading. Consequently, we correct for deviation using a *deviation card* - a table that maps between Magnetic and Compass headings that has been compiled previously. A full sample deviation card is attached below for working examples. The first few lines look like:

To determine the deviation value that applies to a particular heading, you must look up that heading in the deviation card for the compass in use. Recall that Magnetic refers to what an ideal magnetic compass would read without any interference (ie. without your boat there), and Compass refers to what your compass actually reads when in its normal position given all the interference. If you are reading off the steering compass, you should look up using the Compass column. If you are converting a Magnetic course, use the Magnetic column to look up.

Magnetic	Compass	Deviation
000	353	7º E
015	013	2º E
030	033	3º W

So, if we are steering our very best close-hauled and the steering compass reads 353 C, a deviation of 7 E applies and we can say we're on course 000 M. If we then correct for variation, we'd have a True course to plot on a chart.

Similarly, if we have a True course to steer and have already uncorrected it to get a course of 015 M, then a deviation of 2 E applies and we should steer 013 C (error is east, so compass least).

Now what if we want to steer 006 M? It's not in the table. We need to interpolate, ideally to the nearest degree. Looking at the entries on either side of 006 M, the deviation changes by a (rather exteme) 5 degrees west over 15 degrees of M heading change. That's one degree less easterly deviation for every three degrees our course increases above 000. Let's do a quick check: by this rule we'd have 7 E at 000, 6 E at 003, 5 E at 006, 4 E at 009, 3 E at 012, and 2 E at 015. Seems reasonable. Yes, let's pick 5 E as our value. Turning our rhyme on its head: error east, so compass least: our compass course is 001 C (006 M - 5 E variation).

More often, deviation should change by just a few degrees in which case . If it's one degree, you just need to figure out which of the two tabulated values is numerically closer. If it's two, then the range is divided into thirds.

Working Procedures for Variation and Deviation

- There is Compass Worksheet below to structure your calculations, including the various steps and a helpful hint showing in which direction of calculation we should "—> Add West —>". Similar columns are often found on deck log sheets used to record voyages.
- When writing down a course or bearing use the suffix T, M, or C to make it clear which kind it is
- Always plot True on the chart. You may optionally reinforce this by writing T after courses and bearings on the chart. It is technically redundant (because everything on the chart should be True) but may be useful to jog your memory.
- Whenever writing variation and deviation values, always append E or W to indicate direction. Without knowing E/W the number is useless because you don't know which direction.
- Do not use the inner (Magnetic) compass rose on your chart. It is valid as of the base year only. Always read/plot True and convert to/from using the current-year variation to the nearest degree.
- Show your work clearly so that you can revisit it to check later

Example Deviation Card

Not for navigational use

These values are solely for illustrative purposes for this text and related example questions.

Magnetic	Compass	Deviation
000	353	7º E
015	013	2º E
030	033	3º W
045	052	7º W
060	070	10º W
075	086	11º W
090	099	9º W
105	109	4º W
120	119	1º E
135	130	5º E
150	142	8º E
165	156	9º E
180	173	7º E
195	193	2º E
210	213	3º W
225	232	7º W
240	250	10º W
255	266	11º W
270	279	9º W
285	289	4º W
300	299	1º E
315	310	5º E
330	322	8º E
345	336	9º E
360	353	7º E

Worked Examples

Compass course to steer

Having plotted a series of waypoints through safe water to arrive at our intended destination, we need to know what course to steer (using our steering compass) on each leg before setting out on our trip. All plotting on the chart is done using True courses. If we measure the first leg on the chart to be course 185 T, then what Compass course to steer (CTS) should we set to arrive at the first waypoint? Let's take the magnetic variation for Hamilton, given conveniently as 010 W 2018 (0').

In the year 2020, variation is 10° W + 0' W x (2020-2018) = 10° W + 0' W. Not a very exciting calculation.

Just steering the measured True course on the steering compass without "uncorrecting" would mean we'd be off course by the amount of variation and deviation, because the compass card would not be pointing to True North.

Leeway and current are adjusted for by changing the True course. Let's leave that aside for now, assuming that the True course plotted is the True course to steer. The process of converting True to Compass comes after current/leeway compensation and remains the same.

	—> Add west —>				
	True	Variation	Magnetic	Deviation	Compass
Start by filling in the information you have in the correct column. Courses, headings, and bearings should always be three digits, with leading zeroes.	**185**				
Identify which pieces of unknown information you want to produce. In this case, we need Compass Course To Steer (CTS) for the helm.	185				**?**
Start progressing one at a time from the known column(s) to the target columns. Here we need variation.	185	**?**			?
Consult the chart to determine the variation to the nearest degree based on position and updated to the current year. Always specify east or west.	185	**10 W**			
Apply the adjustment value, adding or subtracting as appropriate. Recall when moving rightwards in the table, we add westerly differences and subtract easterly. Since we are moving leftwards, do the opposite (subtract west)	185	10 W	**195**		

Use the Magnetic heading to look up the deviation in the deviation card that will apply when we're on course. Remember to always specify E/W. 195 M is in the table.	185	10 W	195	**?**	
Add or subtract as appropriate (see arrow in top row) to arrive at final answer. Here we're going left to right. Add west, subtract east.				2 E	193
Leave your work so you can re-check it later. Be sure to mark in your notes what the values mean! Are they a course to steer, a bearing, etc.?					

We should steer compass course 193 C to stay on our plotted true course line of 185 T. Good thing we calculated that, or we'd be off by 8° (after an eight-mile trip we'd be off track by a mile!)

Bearing to landmark

Suppose we take a visual bearing to a landmark using a hand-bearing compass and read 050. Since the hand-bearing compass is not fixed in location and not calibrated by a deviation card, we know that value is not a capital-C Compass bearing. We wouldn't know what deviation value to apply, so the best we can do is assume it is zero. We therefore call it a Magnetic bearing since that is the principle on which the hand-bearing (small-c) compass works. Since we always plot True bearings on the chart, we need to convert the Magnetic bearing to True. The table below illustrates the method step-by-step:

	—> Add west —>				
	True	Variation	Magnetic	Deviation	Compass
Known information first, three digits			**050**		
What do we want to know? True course to plot on chart.	**?**		050		
How to get there? Need variation.	?	**?**	050		
Determine variation to the nearest degree E/W based on position and updated to the current year. Value here is arbitrary for illustration.		**10 W**	050		
Apply the adjustment value, adding or subtracting as appropriate. Consult the top row arrow if unsure.	**040**	10 W	050		
Unneeded columns may be left blank.					

The magnetic bearing 050 M should be plotted on the chart as 042 T.

Correcting compass course

While sailing to our next waypoint, suppose that we've had an unfavourable wind shift. The helm reports they are only able to steer a course of 123 C. How did they measure that? From the steering compass, which is fixed in place and calibrated via a deviation card. That means they've read a capital-C Compass course. To plot our dead reckoning on the chart we need to correct that to True, as follows.

First we need deviation. 123 C isn't in the table. It falls between 119 C (1° E) and 130C (5° E). Let's interpolate by math this time. (123-119) x (5-1) / (130-119) = 1.45° E -> round to 1° E.

	—> Add west —>				
	True	Variation	Magnetic	Deviation	Compass
Fill in known information, identify goal	**?**				**123**
Use the deviation card for the compass the helm is using to look up the deviation value specific to the compass heading, and apply. Going right-to-left against the arrow: add east.	?		**124**	**1 E**	123
Use the variation marked on the chart for the current position, corrected to the current year.	**114**	**10 W**	124		

The current course of should be plotted on the chart as 114 T.

Compass Correction Worksheet

	Compass least, error east				
	—> Add west —>				
Notes	True	Variation	Magnetic	Deviation	Compass
Example: compass course to steer (CTS) given plotted course 353 T, charted variation 12 W, and deviation from the example deviation card.	353				?
Fill in one-by-one:	**353**	12 W	005		

Need to know

The listing below gives Performance Objectives from Sail Canada courses that are related to the material discussed here. Navigation standards are classroom-only, while Cruising courses are on-water instruction that includes application and evaluation of theoretical skills. See www.sailing.ca or contact jeff@steelcitysailing.ca for more information.

Sail Canada Basic Coastal Navigation (2017/03 revision)

PO 6. List and describe or demonstrate the use of tools required for prudent navigation including:
a) Hand-bearing compass;
b) Steering compass and deviation table;
[…]

- Know that hand-bearing compass produces Magnetic bearings (not Compass because no deviation card can be compiled for a portable compass)
- Know that steering compass is used to steer/read Compass course
- Relationship of each deviation card to one specific compass in one specific location on board

PO 9. Convert courses, headings and bearings between true, magnetic, and compass.

- Compute current-year variation on chart from base-year variation and annual rate of change
- Use deviation card to look up deviation value for a given Magnetic or Compass heading
- Interpolate deviation readings where needed to nearest degree
- Variation and deviation to be presented to nearest degree, E/W always specified
- Always show and keep calculations for later review
- Always use True course/bearing and compass rose when plotting on chart
- Always use Compass course for steering compass in use
- Multiple compasses (eg. port/stbd wheel, auto-helm, etc) each needs its own deviation card

PO 13. Use charts and publications to prepare a basic pilotage plan for a daytime trip including:
[…]
b) Waypoints, rhumb line course, heading (in compass), distance, and ETA;
[…]

- CTMG between waypoints using True
- Passage plan includes Compass CTS converted from True for helm to steer

PO 15. Describe the types of information that may be included in a vessels log.

- Bearings (Magnetic & True) with time, landmark, and correction calculations shown
- Changes of course with time, speed, and course
- Course noted both True & Compass, conversion calculations shown

PO 16. Use Sail Canada Uniform Navigation Symbols and Terms for plotting and labelling.

- Terms: Course (C), heading (HDG), bearing, CTS, CTMG, CMG

- Chart work to be done with True course/bearing
- Course/bearing written as three digits using leading zeroes
- Course/bearing value followed by T, M, or C to mark True/Magnetic/Compass

Sail Canada Basic Cruising (2017/03 revision)

Ashore PO 4. List from memory:

a) Transport Canada (TC) required items for the candidate's boat (Safe Boating Guide), […]

Ashore PO 11. Describe the precautions taken to prevent undue magnetic influences to the vessel's compass;

- Keep electronics, tools, magnets, and large pieces of iron away
- Electrical wire near compass should be run in twisted pairs
- Deviation card to be checked/recompiled if major changes made to onboard equipment

Sail Canada Intermediate Cruising (2019/01 revision)

Ashore PO 36. Convert directions between true, magnetic and compass, using the compass rose on a current chart;

Afloat PO 20. Lay off a course and determine compass heading and Estimated Time of Arrival (ETA) (assuming no current or leeway);

Afloat PO 21. Plot and determine your position using deduced reckoning (DR) methodology;

Afloat PO 22. Plot a fix using bearings taken on objects visible at the same time;

- Calculation of current-year variation from base-year variation and annual rate
- Hand-bearing compass produces Magnetic bearings
- Steering compass reads out Compass heading, to be corrected using deviation card
- Conversion between True/Magnetic/Compass course, use of log sheet / worksheet
- True course to be plotted on chart

Sail Canada Intermediate Coastal Navigation (2017/03 revision)

Most objectives of the Intermediate Coastal Navigation standard require a thorough understanding of True, Magnetic, and Compass including:

sources and ways of correcting for variation and deviation
habits of using the deck log or worksheet and showing calculations
plotting True on the chart

understanding uses of the hand-bearing compass for Magnetic bearings
using Compass course and accounting for deviation with the steering compass

PO 4. Describe:

a) How to check compass deviation by means of a transit bearing and process for building a deviation card;

[…]

- Deviation card construction by comparing GPS True COG with steering compass while under power on clear, calm, current-free day
- Deviation card construction by comparing Magnetic with Compass
- Deviation check using transit (known True bearing) to compare with True heading computed from Compass

PO 9. Demonstrate sound planning of an overnight coastal passage exceeding 20 miles using all relevant sources of information to include the following components:

[…]

d) Pilotage techniques including transits, lead/back bearings and danger/clearing bearings;

[…]

- Application of variation
- Increasing course means turning to starboard
- To increase bearing to an object, the object must "move" clockwise (starboard), which means vessel must turn counter-clockwise (move to port)

PO 11. Use Sail Canada Uniform Navigation Symbols and Terms for plotting and labelling.

Sail Canada Advanced Cruising (2019/01 revision)

Afloat PO 17. Determine deviation of the ship's compass using a transit;

Afloat PO 19. Stand a navigation watch of 20 miles by day and 20 miles by night, keeping a full navigation log including the following:

a) Danger bearings,

b) Clearing bearings,

[…]

e) Plot course upwind including 3 tacks and resulting dead reckoning (DR) position,

[..]

