

# 12.215 Modern Navigation

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# Review of Last Class

- Almanacs: Paper and electronics
  - Paper Almanacs: Nautical Almanac
  - Electronic: Available on many web sites
- Homework #1 solutions

# Today's Lecture

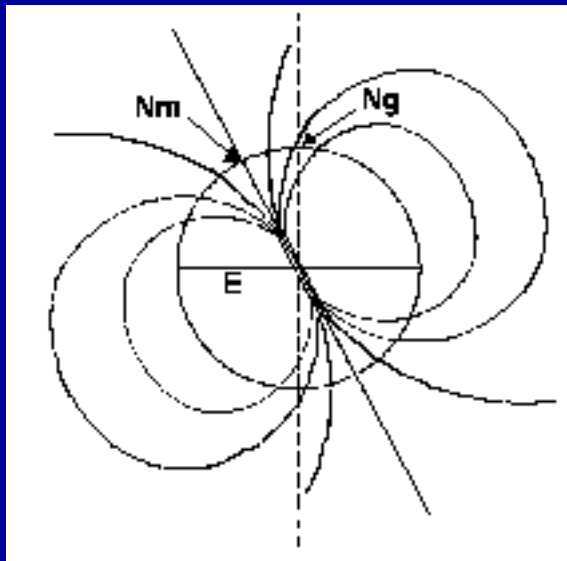
- Dead reckoning and conventional navigation
  - Magnetic North pole
  - Distance measurements
- Use of Sextant
  - Principles of instrument
  - Vernier Scale reading (ex. Pierre *Vernier* (1580?–1637), French mathematician.)
  - Corrections needed for sextant measurements
  - (Next class we make sextant measurements)

# Direction determination

- Before GPS it was difficult to determine direction of motion relative to true north.
  - From latitude and longitude determinations at two points, the direction between them could be determined.
  - Geodetic maps show the directions between monuments in the ground but these monuments need to be found.
  - Some geodetic monuments (triangulation stations have vanes on top that can be seen from a long distance).

# Magnetic North Pole

- For navigation, most common method of finding direction is relative to the magnetic North Pole
- The Earth magnetic field is largely a dipole field but it has higher order variations as well.

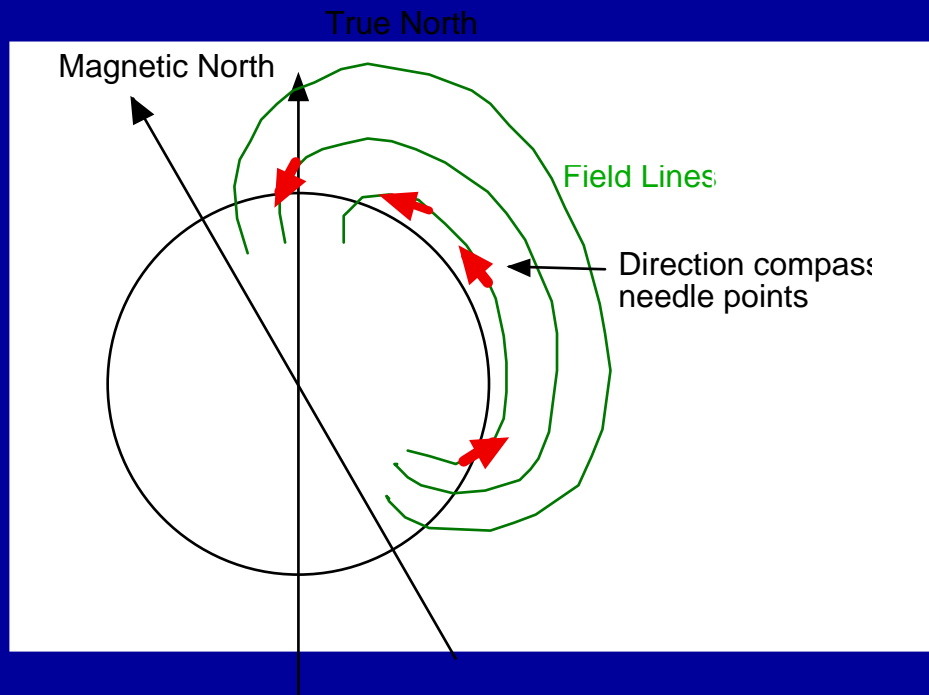


Notice that the direction of the dipole axis does not align with the rotation axis

A compass needle tries to align with the field lines

# Compasses

- Since a compass wants to align with the field lines it will point either up or down (relative to gravity) when it is away from the magnetic equator.



To compensate for the tendency to point up or down, good compasses have weights to make the needle lay flat

# Dip or Inclination

- The angle that the needle wants to tilt to is called the dip or inclination of the needle.
- Normally, a compass designed for use in the Northern Magnetic hemisphere can not be used in the Southern hemisphere unless the weighting mass can be moved to opposite side of the needle.
- Magnetic dipole field equations:

$$H_r = -2m \cos \theta / r^3 \quad H_\theta = -m \sin \theta / r^3 \quad \theta \text{ is colatitude}$$

$$\text{Total Intensity } F = (m / r^3) \sqrt{1 + 3 \cos^2 \theta} \quad r \text{ is radius}$$

$$\text{Inclination } I = \tan^{-1}(2 \cot \theta) \quad m \text{ is field strength(Guass)}$$

# Declination or Variation

- The angle between true north and magnetic north is called the declination or variation (with variation being the marine term).
- This angle can be computed approximately from the location of the North magnetic pole.
- In 1994 North Magnetic Pole was located on the Noice Peninsula, southwest Ellef Ringnes Island, at  $78.3^{\circ}$  N,  $104.0^{\circ}$  W.
- The yearly motion of the pole is about 15 km per year.  
[http://www.geolab.nrcan.gc.ca/geomag/e\\_nmpole.html](http://www.geolab.nrcan.gc.ca/geomag/e_nmpole.html)



# Motion of North Pole

From <http://geo.phys.uit.no/articles.html>

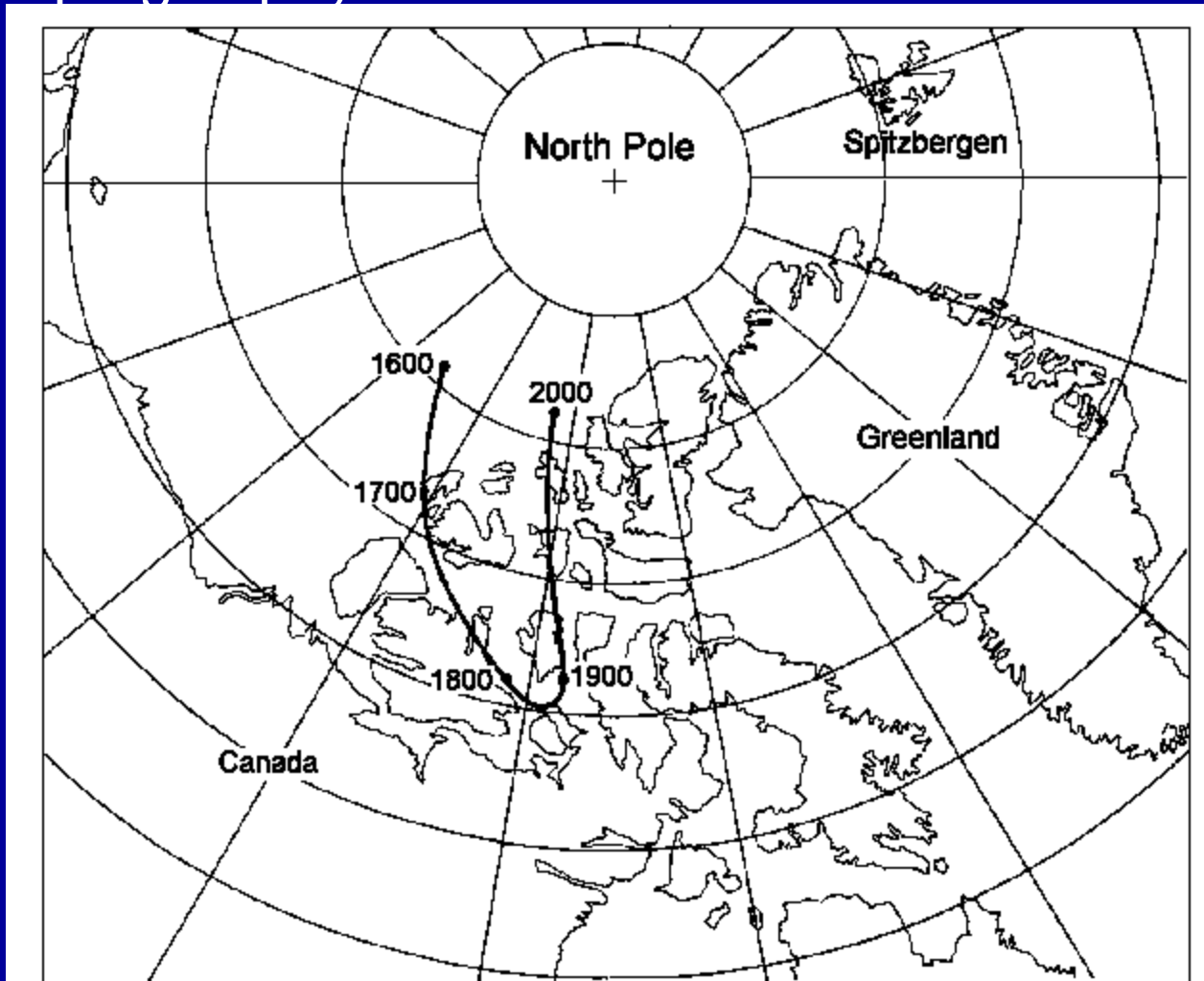
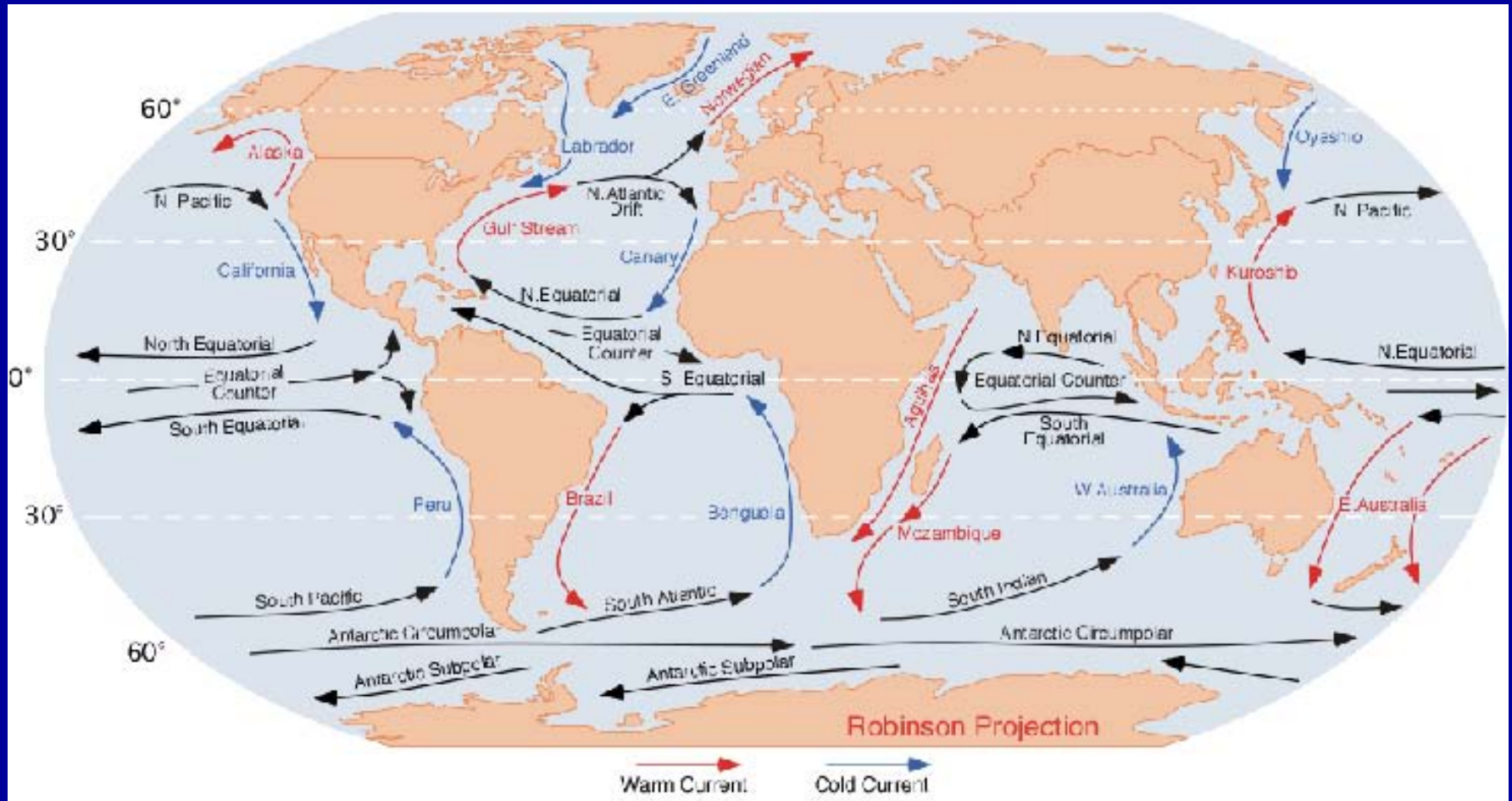


Image courtesy of Prof. Truls Lynne Hansen, University of Tromsø, Auroral Observatory.

# Dead Reckoning

- Full book on subject available at:  
<http://www.irbs.com/bowditch/>
- Basic problem with dead reckoning is that measurements are made relative to the water and the water can be (usually is) moving with respect to the land beneath
- Knowledge of ocean currents is necessary for accurate dead reckoning:
  - Cross currents will have motion of vessel not in direction that it is pointed
  - Along-track currents will make speed relative to water (“knots”) different from speed relative to ocean bottom.
- General character of ocean currents remains fixed, but frequent celestial fixes are needed to compensate for variations.

# Basic ocean currents



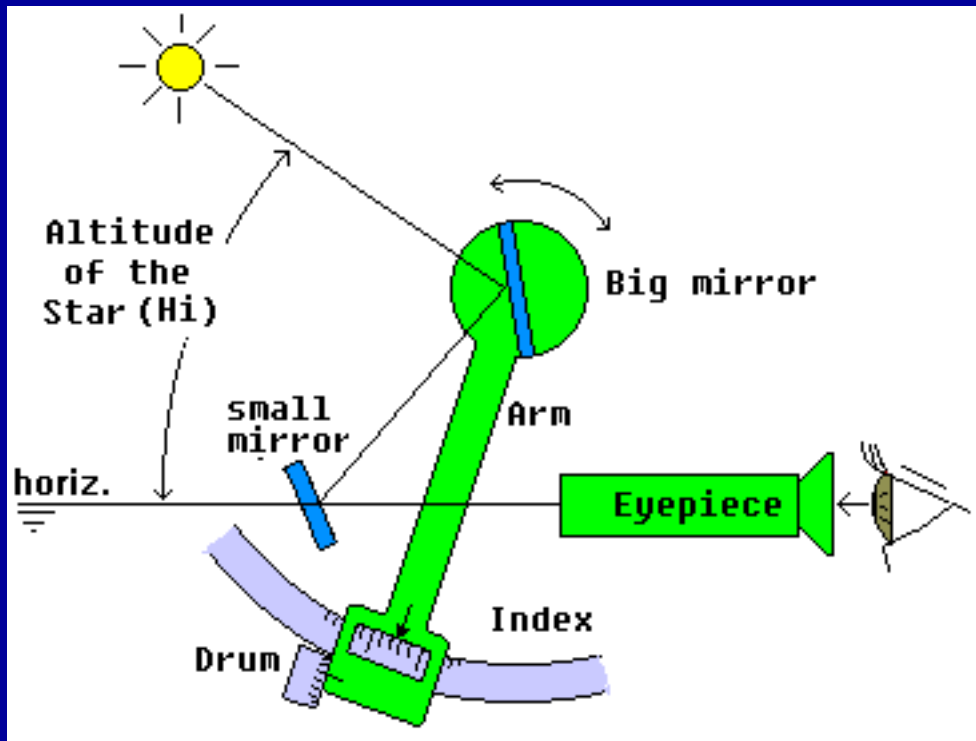
From [http://www.physicalgeography.net/fundamentals/8q\\_1.html](http://www.physicalgeography.net/fundamentals/8q_1.html)

# Magnetic variations

- For dead reckoning variations in the magnetic field and compass also need to be accounted for
- Major changes:
  - For compass: Deviation is a local correction to compass because of nearby objects (important on a ship)
  - Magnetic field:
    - Diurnal variations (tendency to point towards Sun) — 2-5'
    - Annual variations — 1'
    - Secular variation (due to changes in dipole field) — 5-10'/yr
    - Local attractors (potential problem on land)

# Sextant

- Basic instrument for measuring altitude or elevation angle to celestial bodies.
- Schematic of sextant:  
[http://www.tecepe.com.br/nav/inav\\_c12.htm](http://www.tecepe.com.br/nav/inav_c12.htm)

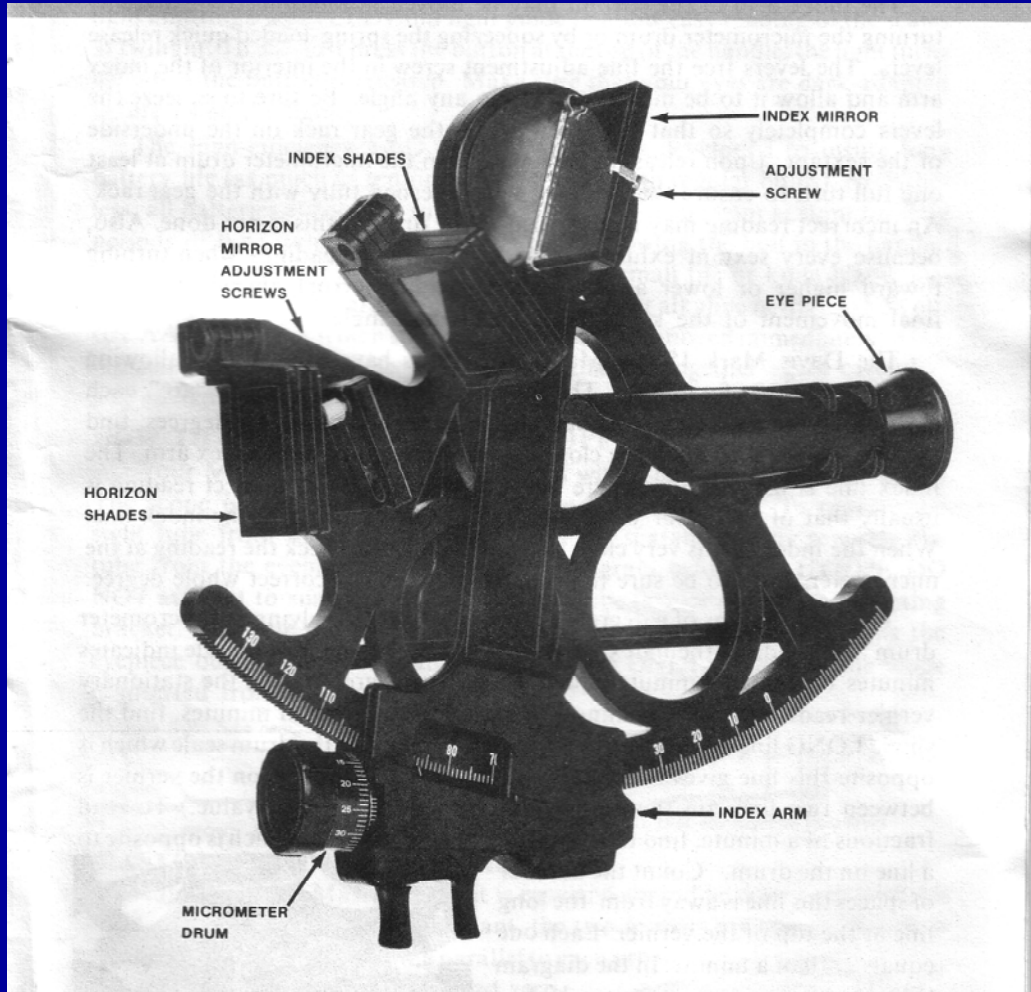


Small mirror is half a mirror so that direct ray and reflected rays are both visible.

# Student Sextant

This is the sextant we will be using for making measurements.

Scales are read through a combination of a micrometer wheel and a vernier.



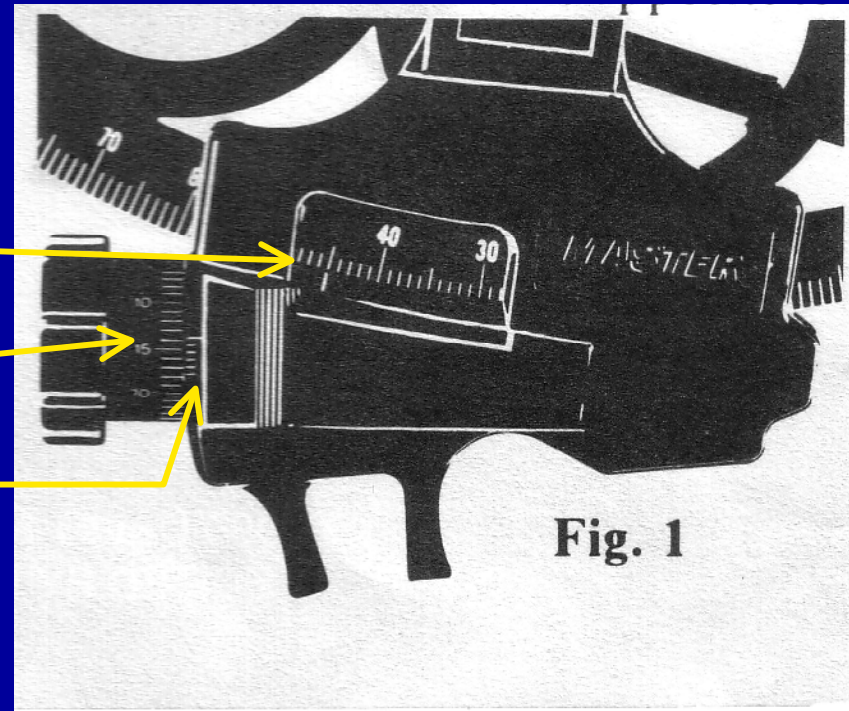
# Scale reading

Reading on sextant is  
45 deg 13.6 minutes

45 degs (main scale)

13' (micrometer)

0.6' (venier)



# Scales

- Micrometer scale is a method a turning rotation in to small displacements (basically a screw drive). One full turns moves scale a set amount. The amount of the turn (angle between 0-360deg) can then be used to interpolate between graduations
- Vernier scales provide another method of interpolating between graduations.
- Example JAVA program:  
<http://www.phy.ntnu.edu.tw/java/ruler/vernier.html>



# Vernier scales

- The idea of a vernier scale is to make a scale that has  $N$  markings in the same distance as  $N-1$  markings on the original scale. The fractional difference between the scales sets the scale that the vernier reads:

So if  $N=10$ , then 10 graduations on the vernier take up 9 markings on the original (see note)

From <http://www.tpub.com/math1/7e.htm>

# Corrections needed for sextant measurements

- Basic sextant measurement is to measure the elevation angle of the sun at its highest elevation and to note the time this occurs.
- Generally, this is done as series of measurements across the transit of the sun and the highest point is interpolated.
- Corrections that need to be applied:
  - Atmospheric refraction (already covered)
  - Index error in sextant (does not read zero when direct and reflected signal are parallel)
  - Sun's diameter if measurement made to lower limb on horizon (diameter is about 16')
  - Height of eye correction if horizon used and standing above level of sea: Correction is  $\sim 0.3'$  per foot of height

# Summary and Next class

- Today we covered:
  - Dead reckoning and use of magnetic field direction
  - Currents and magnetic variations need to be accounted for
- Sextants
  - Basic principles of the sextant and its scales
  - Corrections that need to be applied
- Next class: weather permitting we will make sextant measurements.