Damietta University
Faculty of Science
Geology Department

Magnetic Exploration Course

For

First Year Geophysics Program

Code: 102 Geoph

Lecture 5: Measuring the Earth's Magnetic Field

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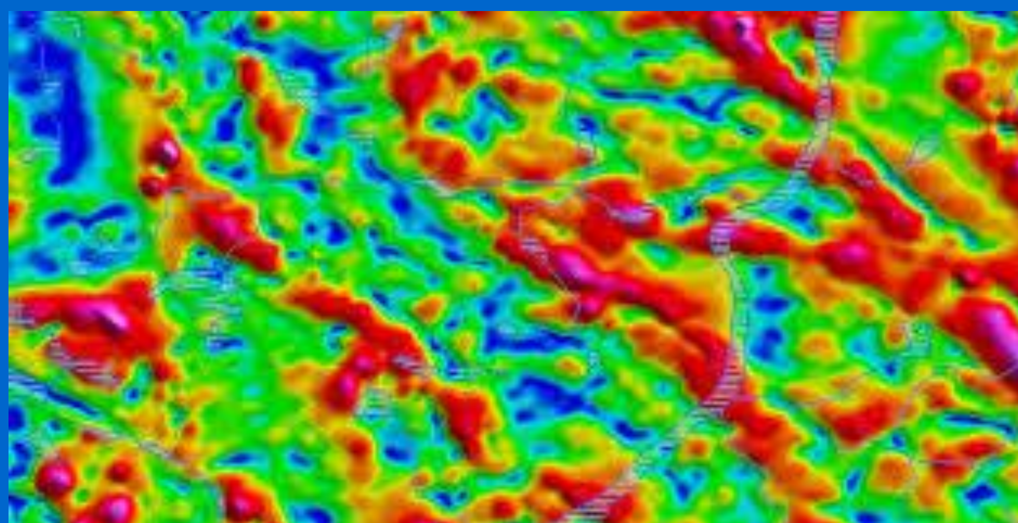
2020

Magnetic Exploration Method



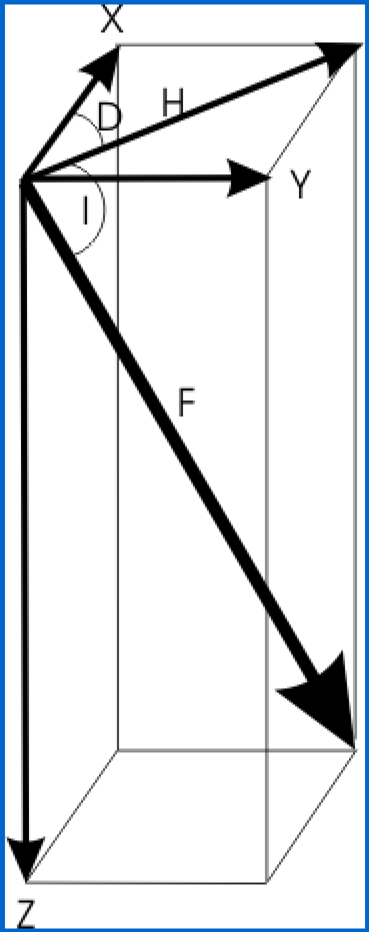
Measuring the Earth's Magnetic Field

Navigation (charts)

used for historical observations

Magnetic components

Component	Description
F	The total intensity of the magnetic field vector.
H	The horizontal intensity of the magnetic field vector.
Z	The vertical component of the magnetic field vector; by convention Z is positive downward.
X	The north component of the magnetic field; X is positive northward.
Y	The east component of the magnetic field; Y is positive eastward.
D	Magnetic declination, defined as the angle between true north (geographic north) and the magnetic north (the horizontal component of the field). D is positive eastward of true North.
I	Magnetic inclination, defined as the angle measured from the horizontal plane to the magnetic field vector; downward is positive.

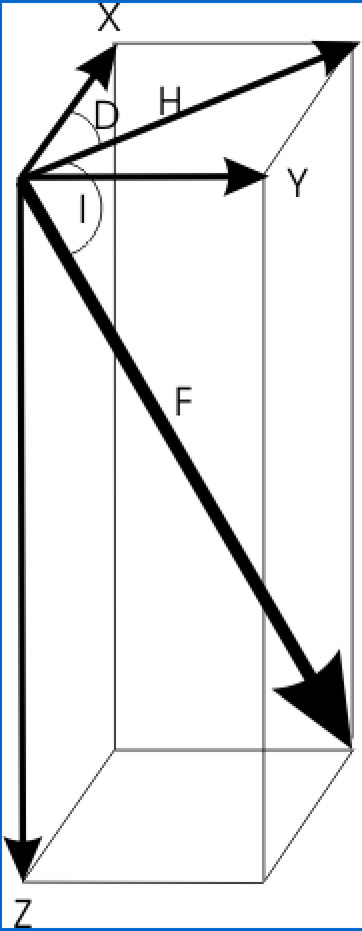


Magnetic components

The Earth's magnetic field is a vector quantity; at each point in space it has a strength and a direction.

To completely describe it we need three quantities. These may be:

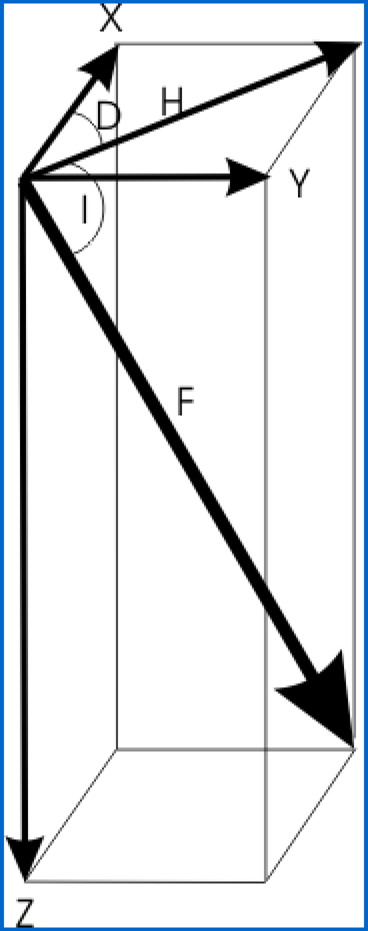
- three orthogonal strength components (X, Y, and Z);
- the total field strength and two angles (F, D, I); or
- two strength components and an angle (H, Z, D)



Magnetic components

The seven elements are related through the following simple expressions.

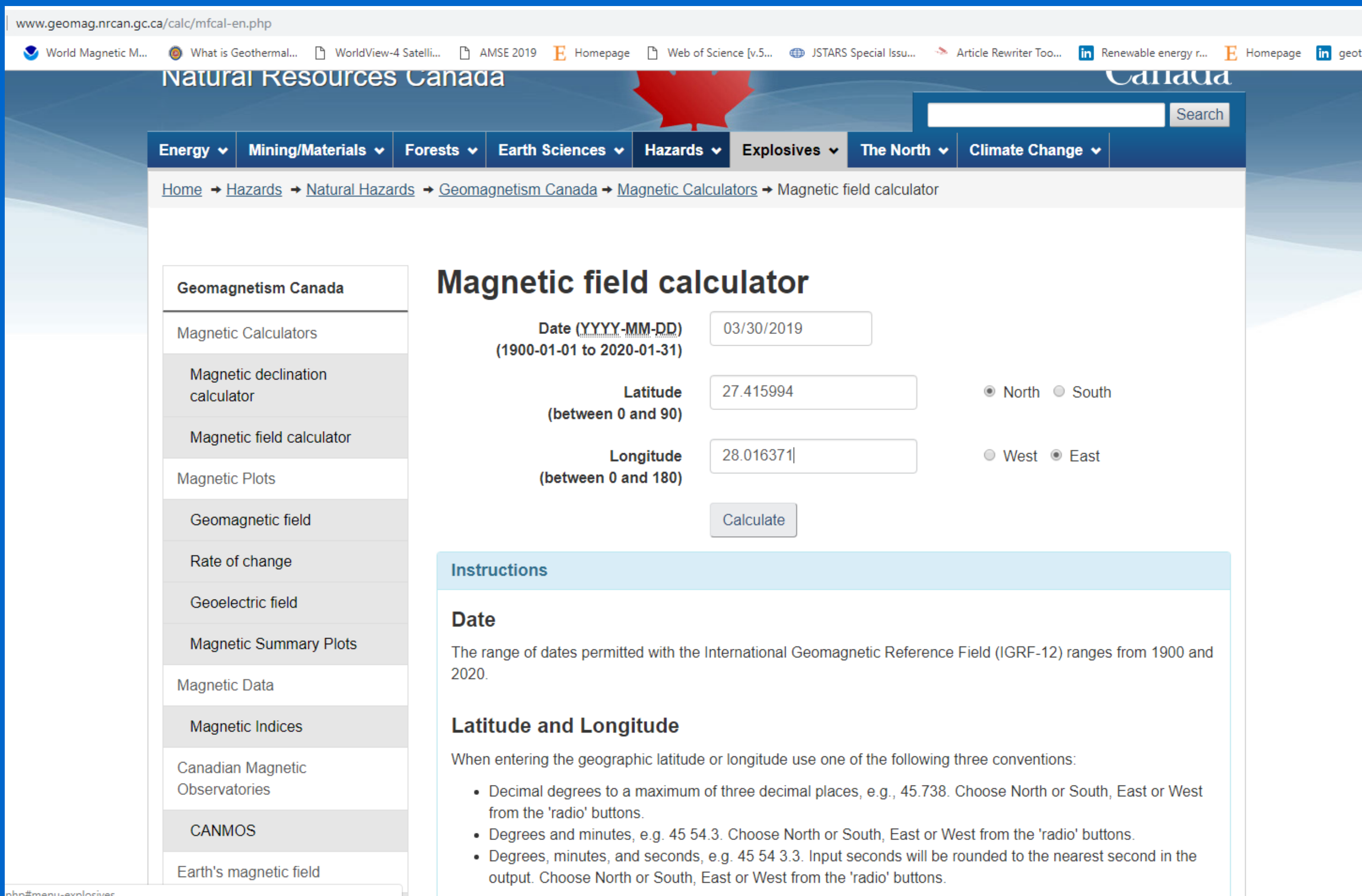
Declination (D)	$D = \tan^{-1}\left(\frac{Y}{X}\right)$
Inclination (I)	$I = \tan^{-1}\left(\frac{Z}{H}\right)$
Horizontal (H)	$H = \sqrt{X^2 + Y^2}$
North (X)	$X = H\cos(D)$
East (Y)	$Y = H\sin(D)$
Intensity (F)	$F = \sqrt{X^2 + Y^2 + Z^2}$



D and I are measured in degrees. All other elements are measured in nanotesla (nT; 1 nT = 10-9 Tesla).

Magnetic field calculator

Magnetic field calculator



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Geomagnetism Canada

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Magnetic field calculator

Date (YYYY-MM-DD) (1900-01-01 to 2020-01-31) 03/30/2019

Latitude (between 0 and 90) 27.415994 ◉ North ○ South

Longitude (between 0 and 180) 28.016371 ○ West ◉ East

Calculate

Instructions

Date

The range of dates permitted with the International Geomagnetic Reference Field (IGRF-12) ranges from 1900 and 2020.

Latitude and Longitude

When entering the geographic latitude or longitude use one of the following three conventions:

- Decimal degrees to a maximum of three decimal places, e.g., 45.738. Choose North or South, East or West from the 'radio' buttons.
- Degrees and minutes, e.g. 45 54.3. Choose North or South, East or West from the 'radio' buttons.
- Degrees, minutes, and seconds, e.g. 45 54 3.3. Input seconds will be rounded to the nearest second in the output. Choose North or South, East or West from the 'radio' buttons.

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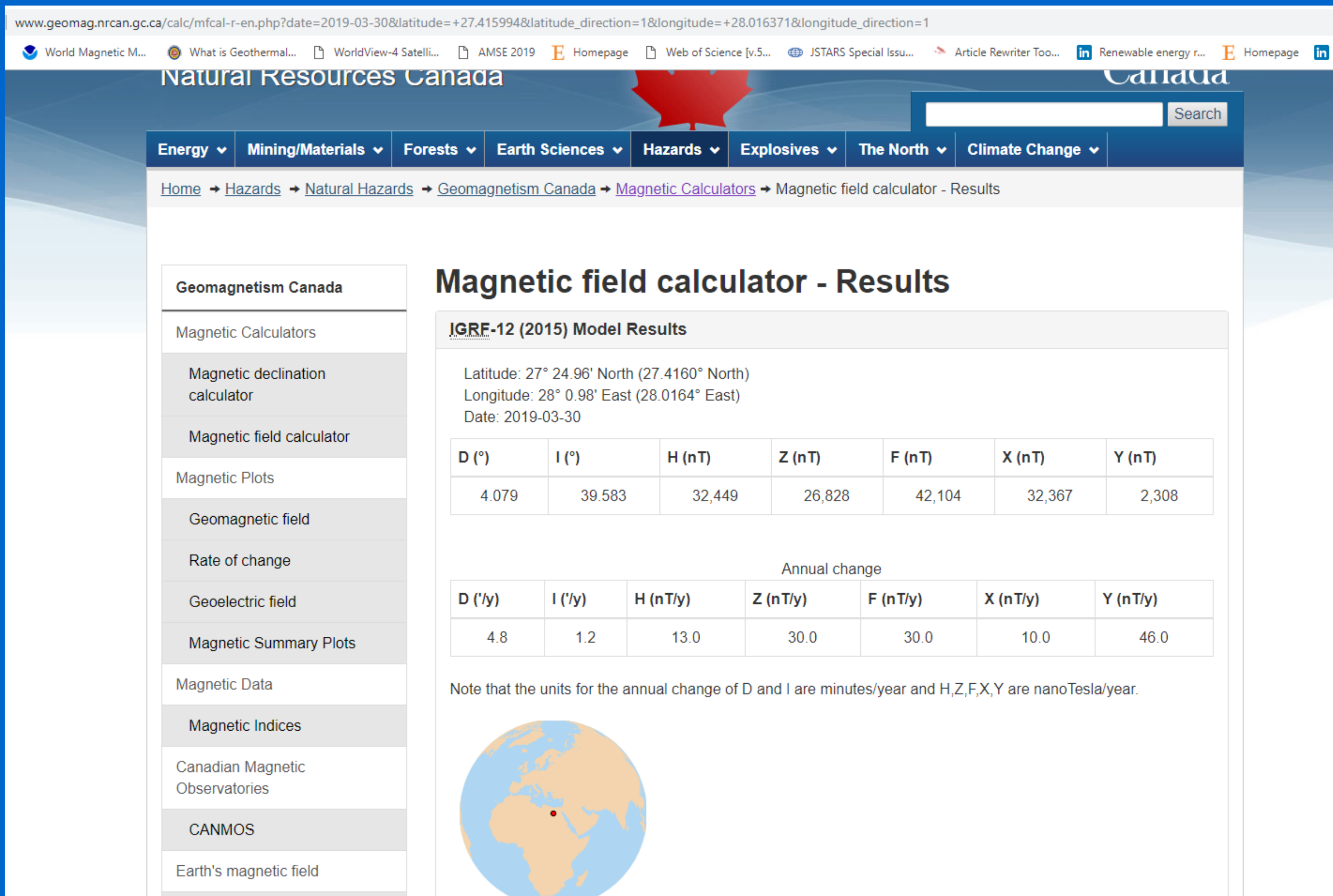
Magnetic field calculator



www.geomag.nrcan.gc.ca/calc/mfcal-r-en.php?date=2019-03-30&latitude=+27.415994&latitude_direction=1&longitude=+28.016371&longitude_direction=1

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Geomagnetism Canada

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Magnetic field calculator - Results

IGRF-12 (2015) Model Results

Latitude: 27° 24.96' North (27.4160° North)
Longitude: 28° 0.98' East (28.0164° East)
Date: 2019-03-30

D (°)	I (°)	H (nT)	Z (nT)	F (nT)	X (nT)	Y (nT)
4.079	39.583	32,449	26,828	42,104	32,367	2,308

Annual change

D ('/y)	I ('/y)	H (nT/y)	Z (nT/y)	F (nT/y)	X (nT/y)	Y (nT/y)
4.8	1.2	13.0	30.0	30.0	10.0	46.0

Note that the units for the annual change of D and I are minutes/year and H,Z,F,X,Y are nanoTesla/year.

Example

Lat	Long	D	I	H	Z	F	X	Y
23.991705	34.178017							
30.159015	33.960227							
22.719782	57.112819							
42.738233	-96.237695							

Types of magnetic instruments

Magnetic instruments can be classified into two types:

- Mechanical Instruments
- Magnetometers

Mechanical Instruments

These are instruments that are mechanical in nature that usually measure the attitude (its direction or a component of its direction) of the magnetic field.

The most common example of this type of instrument is the simple compass.

Magnetometers

- Magnetometers are measurement instruments, usually operating non-mechanically.
- Magnetometer capable of measuring the magnetization of a magnetic material like a ferromagnet or to measure the strength and direction of a magnetic field at a point in space.
- Magnetometer are specifically used to measure very low (< 1nT) magnetic filed.

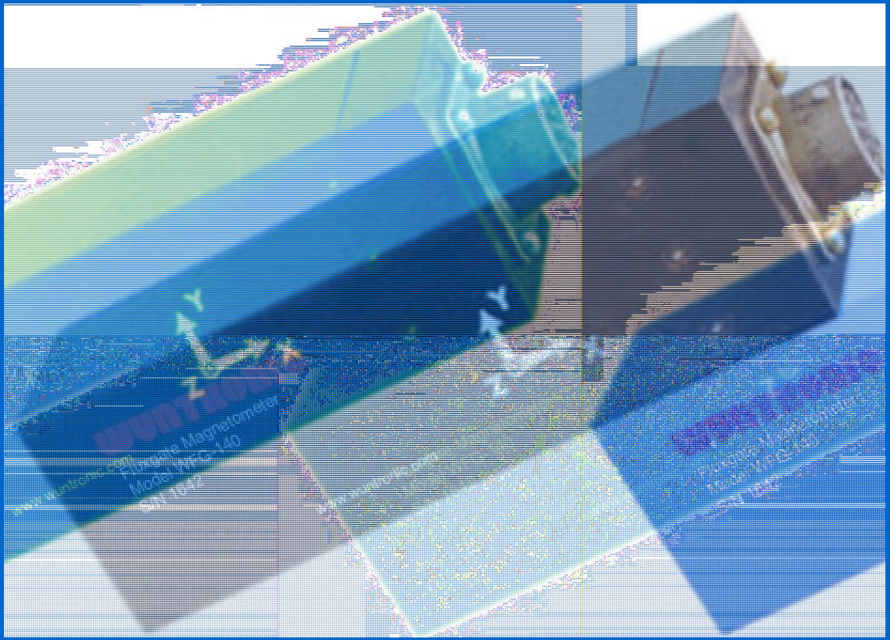
Types of Magnetometer

Magnetic field sensors can be divided into two components.

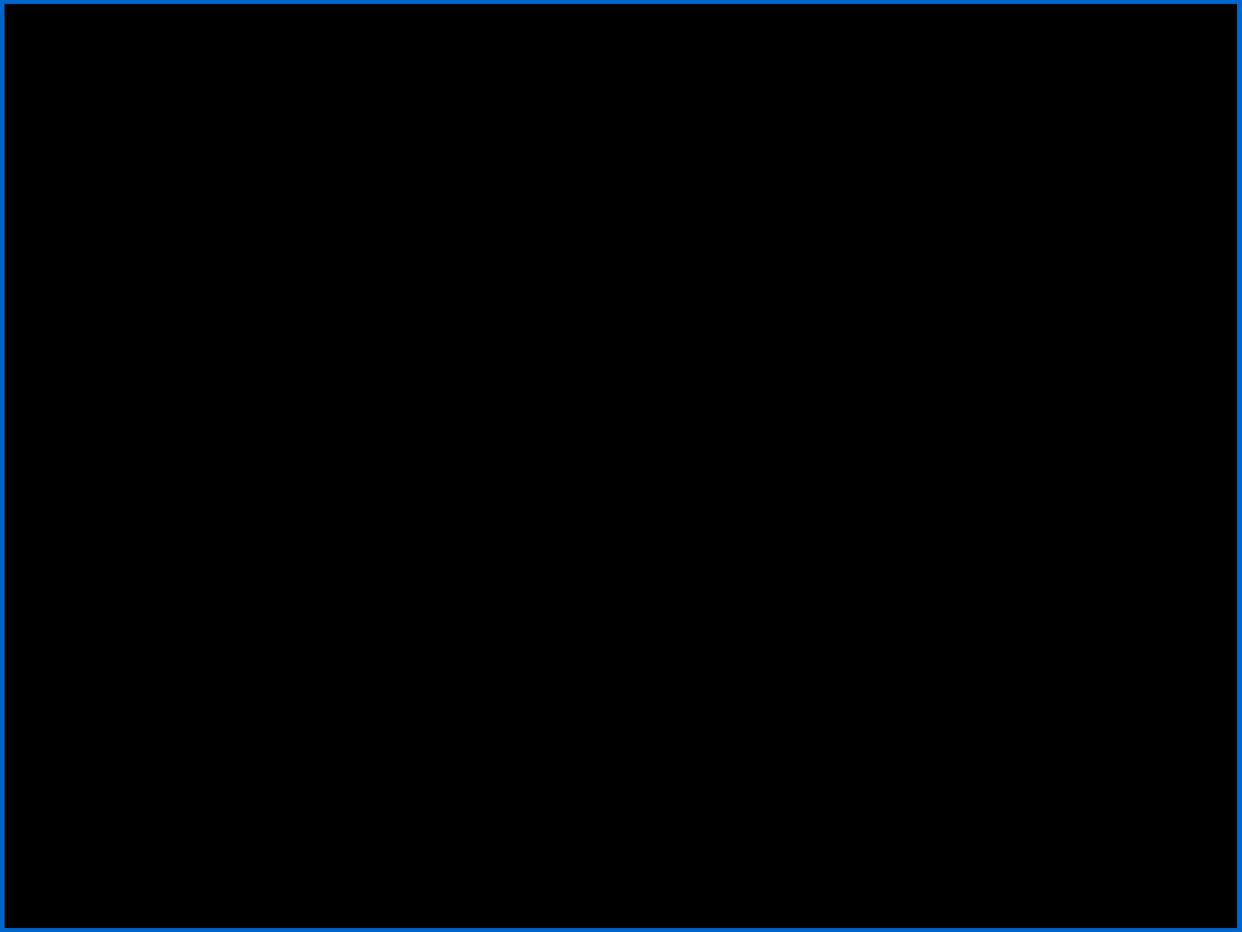
Vector Magnetometer: The magnetic field produced by any magnetic material is a vector quantity i.e. it has both magnitude and direction. Vector magnetometers measure all the vector components of the field in a particular direction, relative to the spatial orientation of the device.
Example: **Fluxgate Magnetometer**

Scalar Magnetometer (Total field) : Scalar magnetometer measure the total strength of the vector magnetic field.
Example: **Proton Precession, Alkali-vapor, Overhauser and SQUID magnetometers**

Fluxgate Magnetometer



Fluxgate Magnetometer



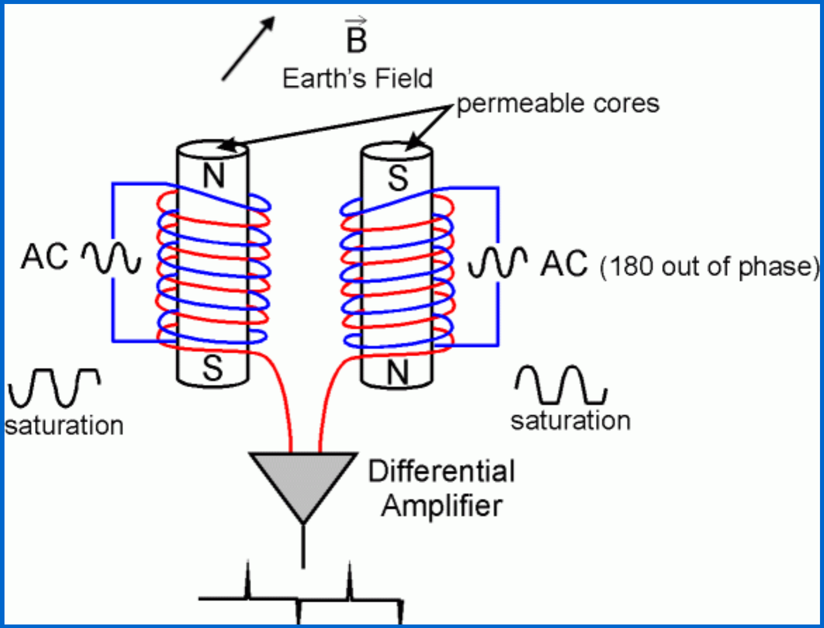
Fluxgate Magnetometer

A flux gate magnetometer is an instrument capable of measuring the strength of any component of the earth's magnetic field.

Fluxgate Magnetometer

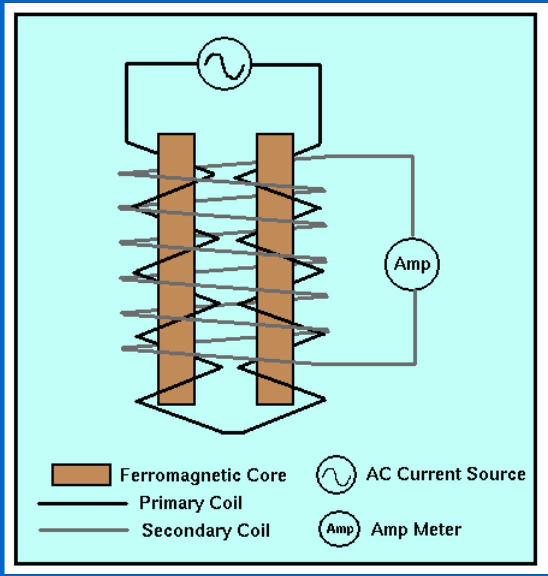
It consists of:

- **Primary coil.**
- **Secondary coil.**
- **Ac current source**
- **Ferromagnetic core.**



Fluxgate Magnetometer

- Measures component of magnetic field parallel to cores with accuracy of 1-10 nT.
- Comprises two parallel cores of high ferromagnetic material.
- Primary coil wound on two cores in series in opposite directions. Secondary coils also wound, but in opposite direction to primary.
- Operation of Fluxgate Magnetometer



Fluxgate Magnetometer

- The fluxgate magnetometer is based on what is referred to as the magnetic saturation circuit.
- Two parallel bars of a ferromagnetic material are placed closely together.
- The susceptibility of the two bars is large enough so that even the Earth's relatively weak magnetic field can produce near magnetic saturation in the bars.

Fluxgate Magnetometer

- Each bar is wound with a primary coil, but the direction in which the coil is wrapped around the bars is reversed.
- An alternating current (AC) is passed through the primary coils causing a large, artificial, and varying magnetic field in each coil.
- This produces induced magnetic fields in the two cores that have the same strengths but opposite orientations, at any given time during the current cycle.

Fluxgate Magnetometer

- If the cores are in an external magnetic field, one component of the external field will be parallel to the core axes.
- As the current in the primary coil increases, the magnetic field in one core will be parallel to the external field and so reinforced by it.
- The other will be in opposition to the external field and so smaller.

Fluxgate Magnetometer

- The field will reach saturation in one core at a time different from the other core.
- This difference is sufficient to induce a measurable voltage in a secondary coil that is proportional to the strength of the magnetic field in the direction of the cores.

Proton Precession Magnetometer

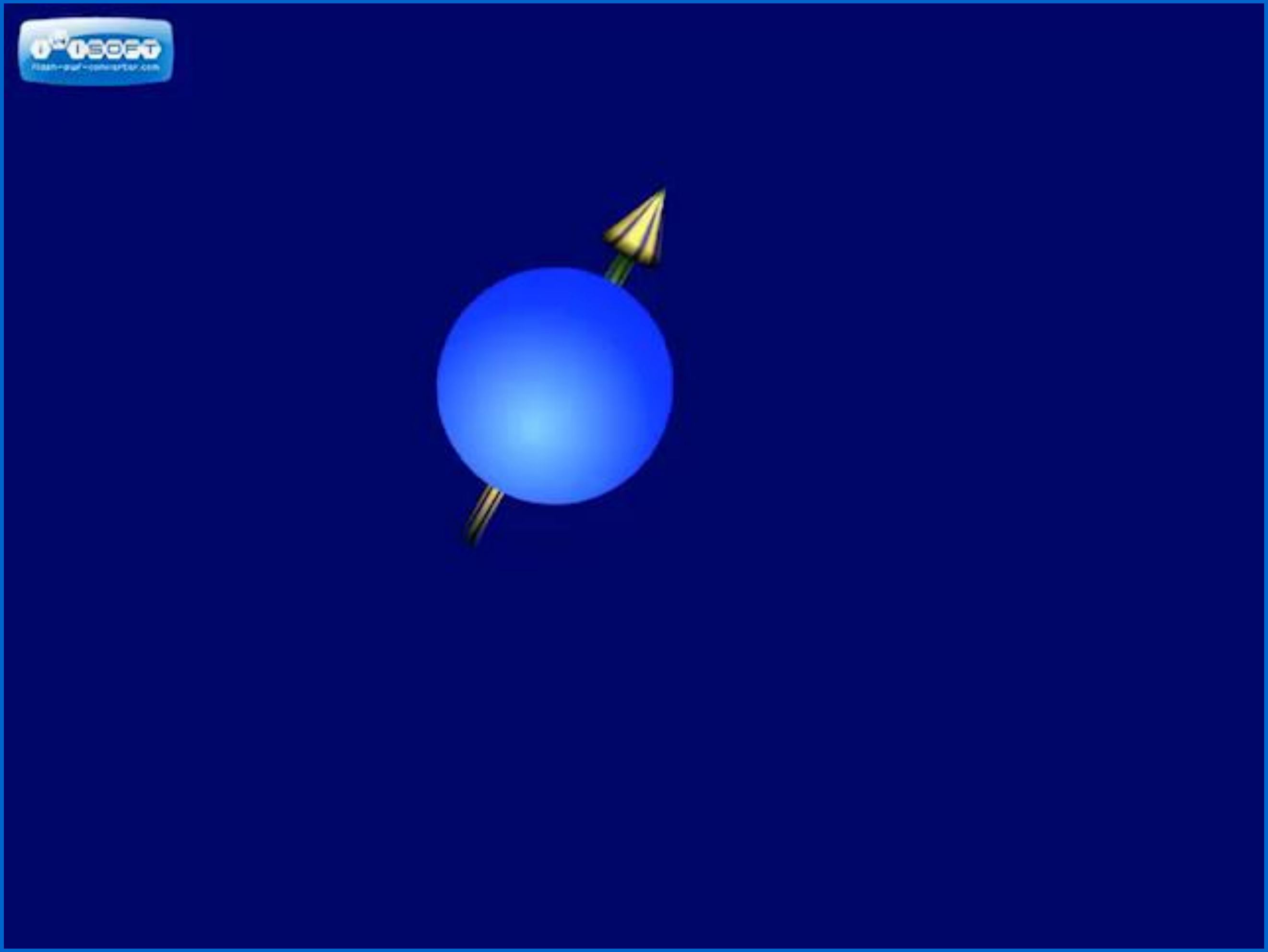
Proton Precession Magnetometer

- Proton magnetometers are of detecting the tiny changes in magnetic field.
- You will have seen the action of a spinning top toy with the handle rotating slowly while the top spins.
- The motion is called precession and the frequency depends on the mass and rotation speed of the top.

Proton Precession Magnetometer

- Protons spin and have charge, making them into tiny magnets.
- If they are placed in a strong magnetic field, they will line up with the field.
- When the field is switched off, the protons precess around the Earth's magnetic field.

Proton Precession Magnetometer



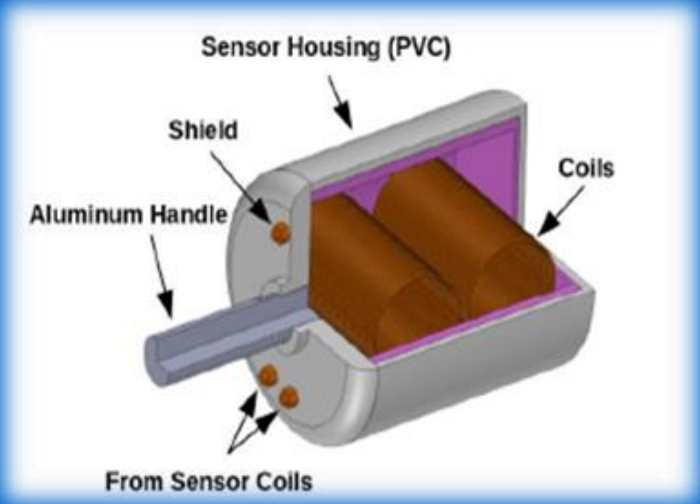
Proton Precession Magnetometer

- The precession causes a changing magnetic field which induces an EMF in a coil.
- The frequency of precession can be measured and is proportional to the Earth's magnetic field, as the spin and charge of the proton are constants.

Proton Precession Magnetometer

Two coils surrounding bottle of water or hydrogen rich fluid.

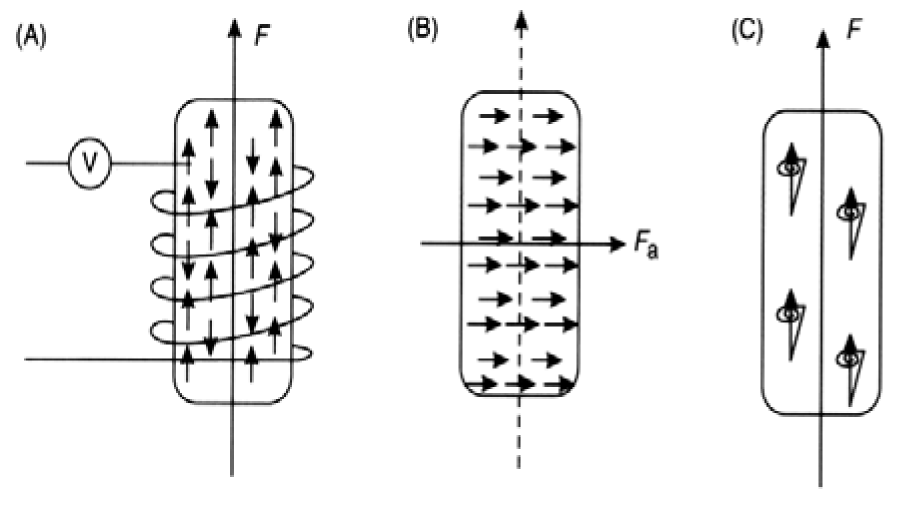
- One to induce field in different direction then natural field.
- One to measure voltage caused by precessing protons.



Proton Precession Magnetometer

Measurement process:

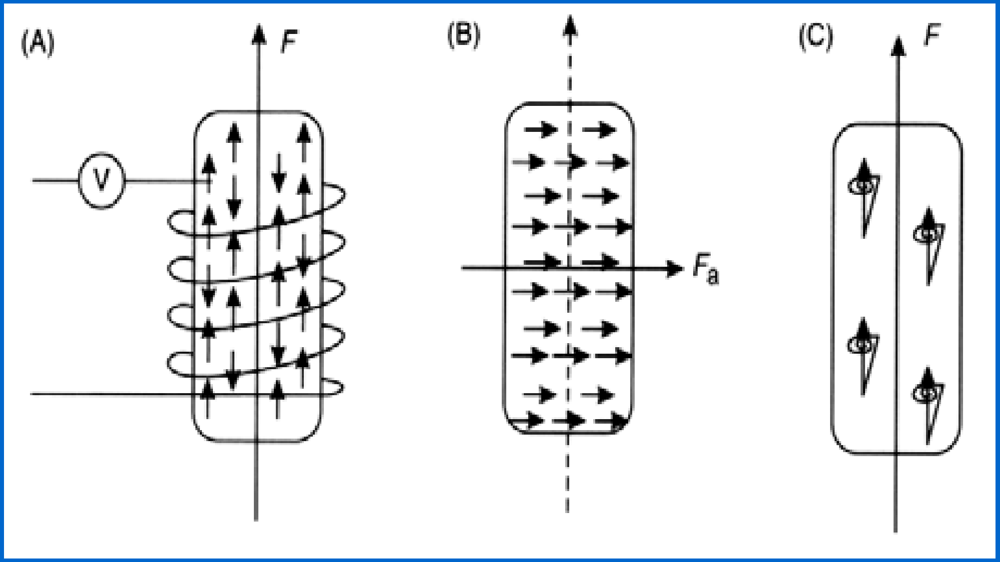
- Protons originally aligned with natural field (A).
- External coil is energized with a DC current resulting in a strong B field that aligns protons (B).



Proton Precession Magnetometer

Current turned off; protons precess back to alignment with external field, generating AC current in receiver coil at Larmor Frequency (C).

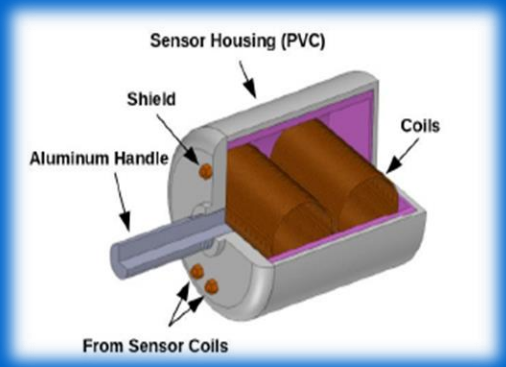
Larger fields > higher frequencies



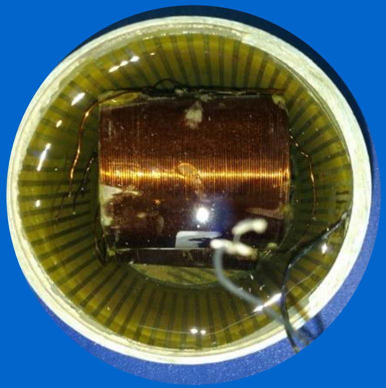
Proton Precession Magnetometer

- This precession frequency is directly proportional to the external magnetic field (i.e. the Earth s).
- The proton precession magnetometer has a resolution of 0.1 nT and accuracies of 0.5 nT are achievable in the field.

Proton Precession Magnetometer



Sensor Design



Sensor Top View

PPM and Sensor

Analog and Digital PCBs

Specification

Temperature Range : -40º to 60º Celsius
Operating range : 30,000 to 80,000 nT
Input/output: RS-232 link
Power: 12V, 1.5 A during polarization, 200 mA standby
Accuracy: 0.1 nT
Sampling rate: Optional (default 30 seconds)
Display: Monochrome character display (20x4 line)
Weight: 5.1 kg (Sensor & Console)

Other types of magnetometer

- Alkali-vapor magnetometers
- Overhauser magnetometers
- SQUID (Superconducting QUantum Interface Divice) magnetometers

Comparison of magnetometer types

Instrument	Sensitivity	Type
Fluxgate	1 to 10 nT	Vector Magnetometer
Proton Precession	0.1 to 1 nT	Scalar Magnetometer
Alkali-vapor	10^{-2} to 10^{-3} nT	Scalar Magnetometer
Overhauser	10^{-1} to 10^{-2} nT	Scalar Magnetometer
SQUID	10^{-5} nT	Scalar Magnetometer

Magnetic Gradiometer

Magnetic Gradiometer

- Takes differences between two measurements that are made close together
- Divides result by distance between sensors

Magnetic Gradiometer

- If no anomalous body is present, both magnetometers register the Earth’s field equally strongly and the difference in output signals is zero.
- If a magnetic contrast is present in the subsurface rocks, the magnetometer closest to the structure will detect a stronger signal than the more remote instrument, and there will be a difference in the combined output signals.

Magnetic Gradiometer

Advantages

- Eliminating temporal magnetic variations (i.e don’t need to be corrected for diurnal variation).
- Provides high resolution of near surface feature
- Minimizing regional effects.

Magnetic Gradiometer

Uses

Surface gradients have been used for decades in shallow zone studies in association with archaeological investigations and the detection of ferrous objects such as land mines and ordnance.

They are also being used increasingly in airborne and marine studies for petroleum and mineral exploration.

Magnetic Gradiometer

Disadvantages

- Won’t measure large scale features
- Essentially automatic removal of regional

Total field measurements

The magnetic field we record with our magnetometer has two components:

1. The *main* magnetic field.
2. The *anomalous* magnetic field.