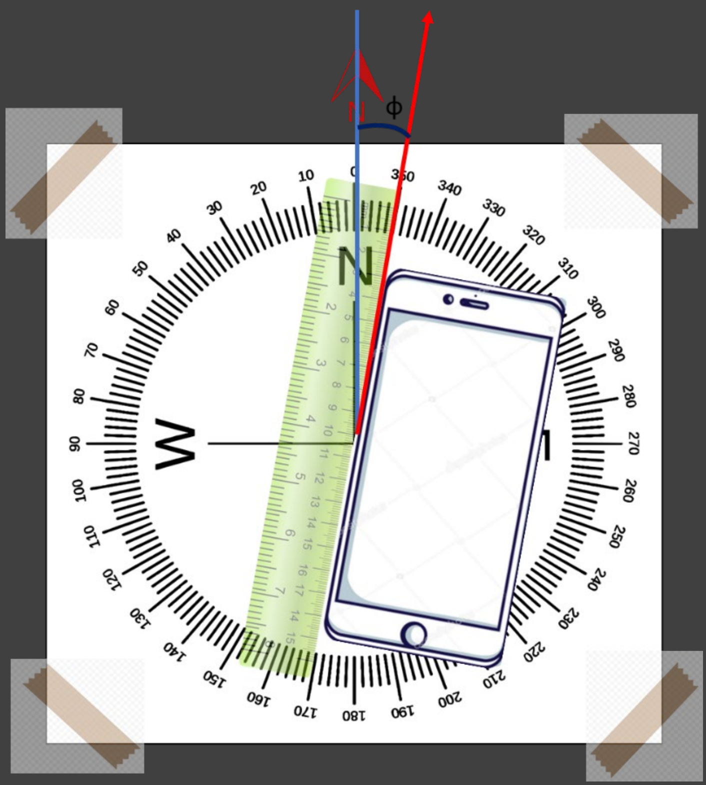
Magnetometry at home: Measuring the Inclination and Declination of the Earth's magnetic field with a smartphone



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Learning outcomes:

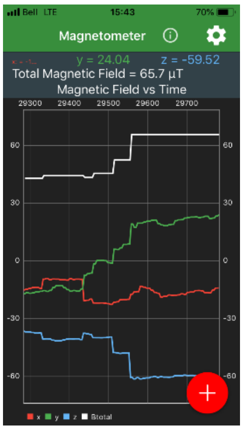
This exercise will allow you to

1. Measure the 3-component profile of the Earth's magnetic field as a function of angle with the geographic north,
2. Calculate the angle of inclination/dip-angle of the Earth's magnetic field,
3. Calculate the angle of declination of the Earth's magnetic field
4. document your survey,
5. complete a simple analysis of your data,
6. Compare your results with the real values from the NOAA website, and
7. communicate your findings.

Preparation

a) Download and install the free **"physics toolbox"** app [Fig.1], available for Android and iOS devices (see https://www.vieyrasoftware.net/ for info and link to download). You will just need the **"Physics Toolbox Magnetometer"** that you can download individually for this exercise.

b) After download, start the app. You should see a screen similar to the one in [Fig.1], the different colors mark the three components (x, y, z) and the total value of the magnetic field. By pressing the red button, you can record the measurements and save them as a spreadsheet (.csv) file. (This function saves data (magnetic field) as a function of time, we will not be using this; instead, we will need the magnetic field as a function of angle with respect to geographic-north)



[Fig. 1: Screenshot of "Physics Toolbox Magnetometer" app]

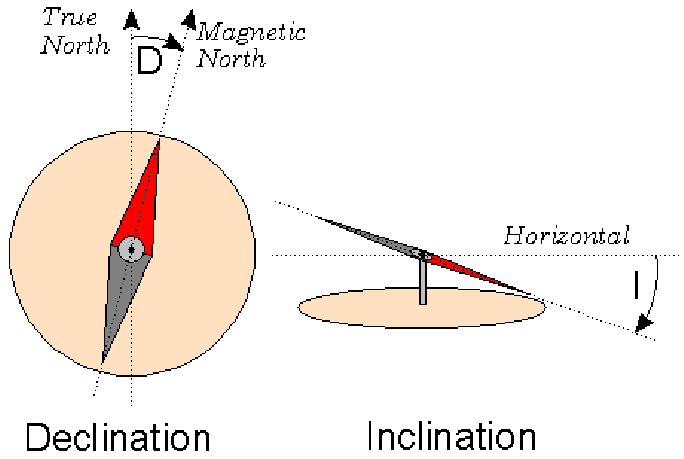
Equipment

i. Smartphone/tablet
ii. Printed 360° protractor
iii. wooden or plastic ruler
iv. tape/glue

Brief background *[For reading purpose: brief theory]*

The Earth's magnetic field is caused by the movement of molten Iron and Nickel in the Earth's outer core. Their motion creates electrical currents, resulting in the Earth's magnetic field vaguely aligned along Earth's geographic north and south pole. The poles of the Earth's magnetic field are not precisely aligned with the geographic north and south poles and in fact, vary continuously.

The angle that a compass needle makes with the Geographic north is called the **angle of declination** [Fig. 2].

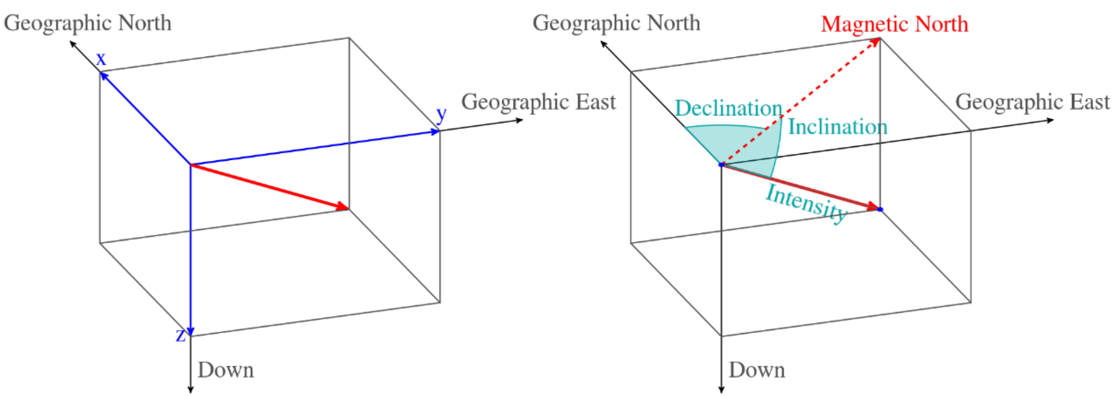


[Fig. 2: Magnetic declination and inclination (dip)] (Source: Wikipedia)

The Earth's magnetic field lines are not parallel with the surface but vary depending on the latitude. The angle that a magnetic field line makes with the horizon is called the **magnetic inclination/dip angle**, specific to the measurement's particular location [Fig 2].

Magnetic intensity B_I is the vector summation of the Bx, By, Bz components of the Earth's magnetic field. $B_I = \sqrt{(B_x{}^2 + B_y{}^2 + B_z{}^2)}$

A complete picture involving all three is represented below [Fig. 3]:



[Fig. 3: 3-D representation of Magnetic Intensity, Inclination, and Declination]

For more information, refer to the following links:

Earth's magnetic field: https://en.wikipedia.org/wiki/Earth%27s_magnetic_field

Magnetic declination:
https://en.wikipedia.org/wiki/Magnetic_declination#:~:text=Magnetic%20declination%2C%20or%20magnetic%20variation,meridian%20towards%20the%20geographic%20North

Magnetic dip: https://en.wikipedia.org/wiki/Magnetic_dip

If you want to learn more about magnetic surveys in geophysics, check out http://appliedgeophysics.berkeley.edu/magnetic/index.html (Berkeley Course in Applied Geophysics) or https://www.eoas.ubc.ca/ubcgif/iag/methods/meth_3/index.htm (UBC Applied Geophysics Learning Objects), the latter includes some self-test questions.

Task 1: What is the objective of your survey?

1. Measure the 3-component profile of the Earth's magnetic field as a function of angle with the geographic north,
2. Calculate the magnetic intensity
3. Calculate the angle of inclination/dip-angle of the Earth's magnetic field,
4. Calculate the angle of declination of the Earth's magnetic field
5. Verification of results with the precise measurements done by the National Oceanic and Atmospheric Administration (United States) (NOAA) or similar, obtained through their websites.

Task 2: General considerations

It is a good idea to consider some general questions: what is the date and time of day? Who are you with? If you are outside, what is the current weather? What are the ground conditions (did it rain, covered in snow, muddy)? Anything else noteworthy before you start?

- Saturday, 18 July 2020: 11:10 pm

- survey alone inside

- in my living room, wooden floor.

- Weather conditions: sunny and hot day (though it is irrelevant here, it will be necessary for outdoor field surveys.)

(Paste photo of your setup)

Task 3: Documenting your location

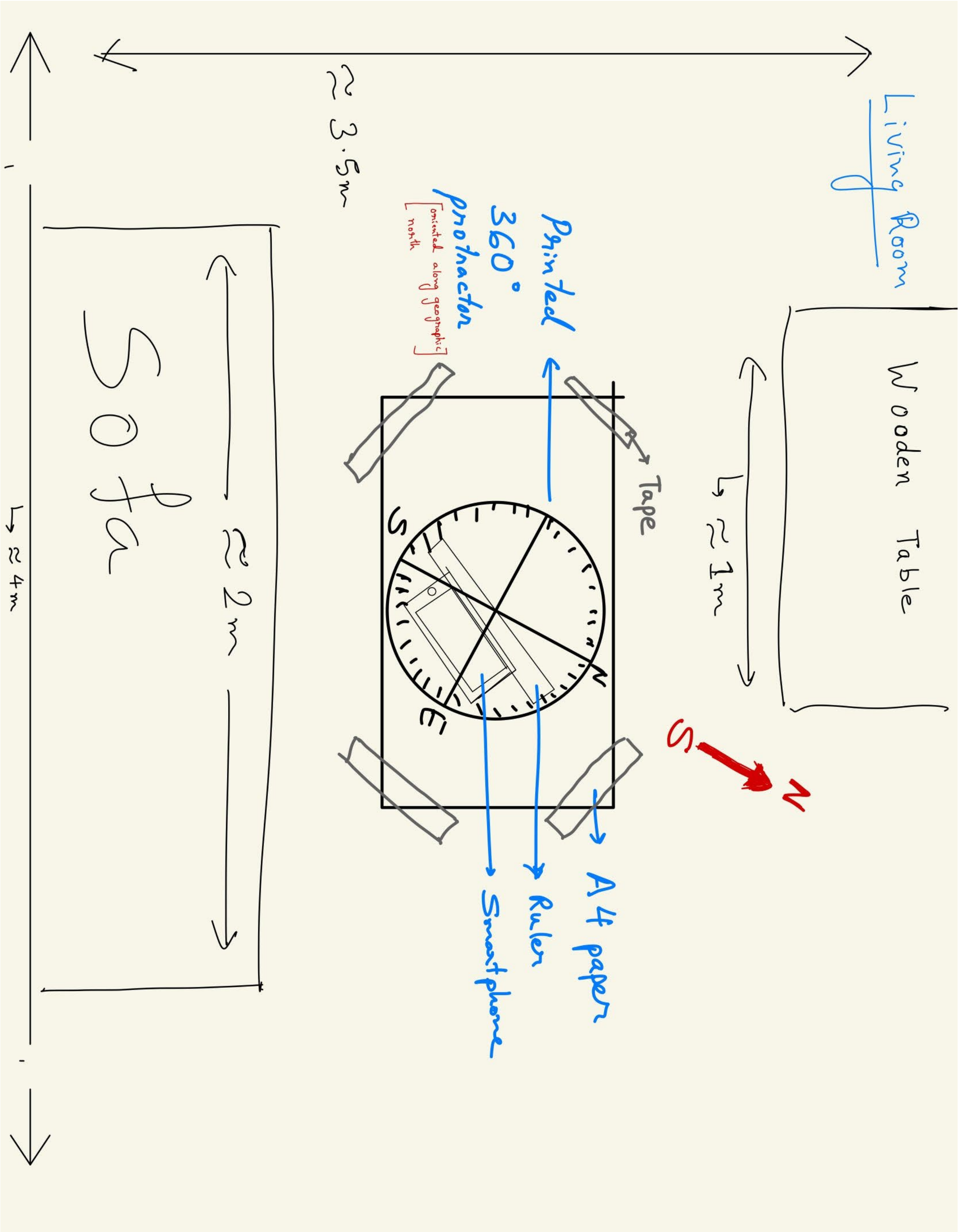
Your need to communicate to another person the location (and layout) of your experiment as accurately as possible so they could exactly recreate your experiment.

i. GPS co-ordinates: 29°41′13″ N 95°23′46″ W
Houston, TX
50 ft Elevation
(May be omitted if the student is concerned about privacy).

ii. Are there any features that may impact your survey (power lines, parked equipment, buildings, mountain, canyon, closeness to industrial operation, airport)?

- inside a building, still no varying magnetic fields
- interference from iron components in sofa but of constant signature [Fig. 4].

iii. A small sketch about the surroundings: *[Fig. 4]*
(Also include an approximate scale and the North direction.)



[Fig 4: (The layout of my experiment: include similar sketch in report)]

Task 4: Setting up your survey

We use the magnetometer in the smartphone to measure the 3-component magnetic field. The smartphone cannot differentiate between the Earth's magnetic field or the magnetic field from a local source like a fridge magnet or an electronic device like a speaker. Thus, to make sure we only measure the Earth's magnetic field and nothing else, place the setup away from any interference (permanent or electromagnets). To be sure, you can take the help of a permanent magnet like a fridge magnet. Take the magnet and start making movements near the smartphone, and you will observe jumps in the magnetometer readings. Slowly start moving the magnet away, and after a point, you will no more observe variations in the readings. This will give you an approximate idea about the area around the smartphone that should be made interference-free for correct readings.

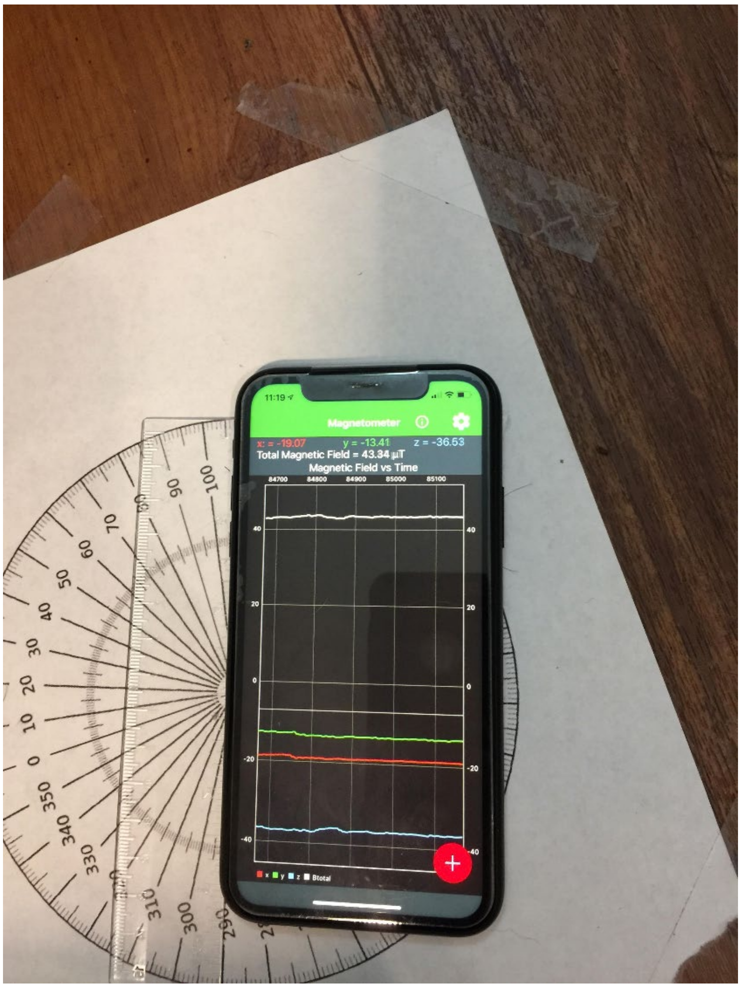
The setup is something as follows [Fig. 5]:

i. Fix the printed 360° protractor on some fixed background so that it doesn't move (I taped it to my wooden floor). Align it so that the 0° is oriented to the geographic north. You can use the compass or equivalent app on your smartphone to find the geographic north. This is accurate as modern phones measures it using GPS rather than magnetic readings (you can verify this by running your fridge magnet around the phone and check if there is any change in direction).

ii. The 1st Step will be to determine along which edge of the device the magnetometer is the nearest. This can be done by slowly dragging the magnet along the four edges. The edge with the most significant spike in the magnetic signature produced is the edge of interest. (For my iPhone XR the magnetometer is on the left side).

iii. While moving the magnet along this edge or interest, the position of the spike will give an approximate idea about the location of the magnetometer sensor in the device. Note it down(you can mark it with a piece of tape or temporary marker). Place the phone with this marked point in the center of the protractor. This will be the pivot while rotating the phone through different angles.

iv. I have used a clear plastic ruler to align the phone and see through the angle readings. You can improvise as necessary.



[Fig 5: The setup]

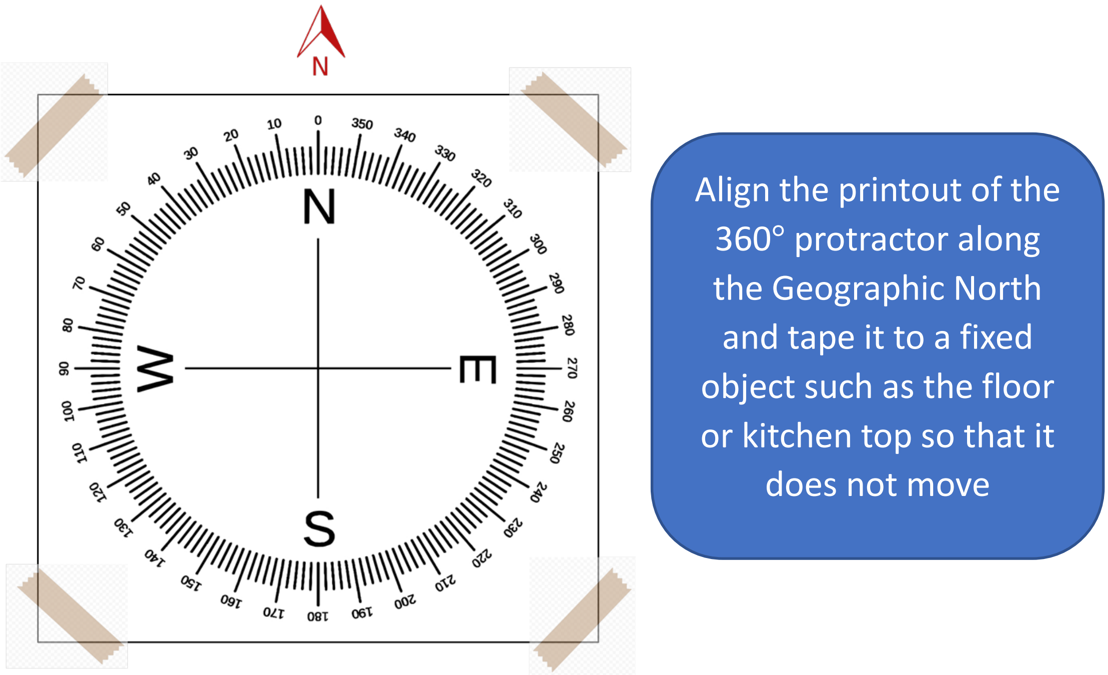
Suggestions for setup and equipment:

- Preferably indoors as measurements take a considerable amount of time, and a stable environment is necessary. As long as the survey location is free from time-varying EM-field, there will be no problem. *(this can be checked by opening the Physics toolbox magnetometer app, and if the readings flatline (become constant) after some time, then there is no time-varying magnetic field nearby)*
- If your smartphone/tablet has any cover/case, metal strips/magnets, consider removing it. *(Mandatory for metal cases as it will interfere with signal)*

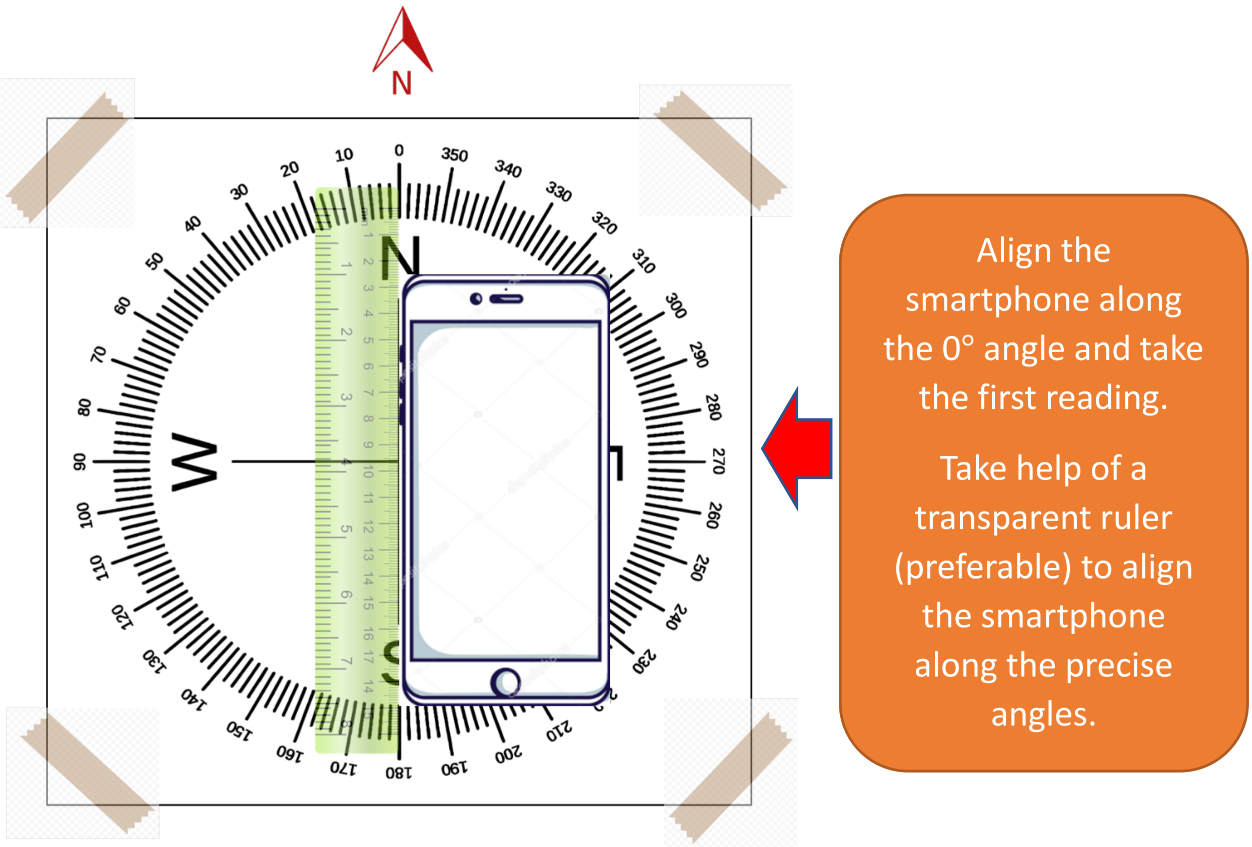
Task 5: Taking measurements

Given below is a brief flowchart of the setup and measurement process:

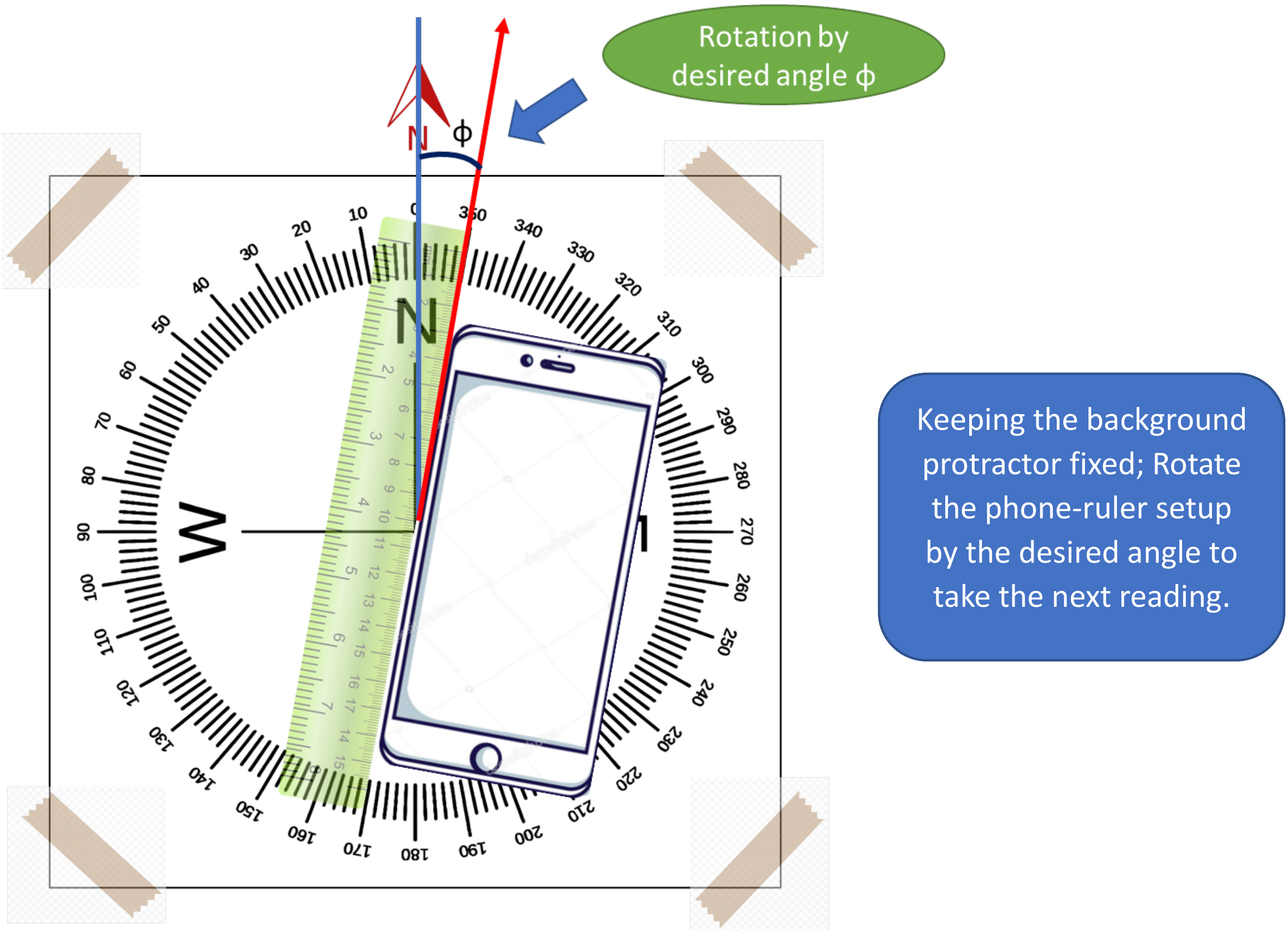
Step 1:



Step 2:



Step 3:



Magnetic Inclination and Intensity:

Start with the phone aligned in geographic north direction (0° azimuth). Measure the Bx, By, Bz, and the total field for each angle. The most convenient way to take readings is by using another camera/smartphone to take pictures of the phone screen. One may also take screenshots but may risk disturbing the setup while doing so. For a smooth profile like the one shown in this paper [Fig.6], take readings every 5° (0° to 180°). The magnetic inclination is obtained in the results section by further calculations of this data.

Magnetic declination:

Start with the phone aligned in -1° to -5°/6° (or after the Bx component becomes positive) and take a reading for every 1°. The angle the Bx component becomes 0 is the true geographic north. I started with -1° and went clockwise as I had an idea from the previous measurements in 5° increments where the Bx=0 would be. You may have to go the anticlockwise way if the magnetic declination at your place of the experiment is negative (towards the west). The magnetic declination is obtained in the results section by further calculations of this data.

Magnetic Inclination and Intensity:

Note:

1. For each measurement, as the smartphone is moved to a new position, wait for a few seconds for the readings to flatline and stabilize before noting it down. This would ensure more accuracy.
2. **How to record the readings**: I could think of 2 ways:
    i. Take a screenshot for each measurement, but later on, one will have confusion correlating between the screenshots and the angles. Also, the device may shake and change position while taking a screenshot if one is not careful.
    ii. Take a photo with another device for each measurement. This will enable the magnetic and angle measurements to be in one place and create less confusion.

3. This Task will take some time (10-20mins) and is preferable to complete in one go to maintain consistency in the background magnetic fields. Prepare accordingly.

Task 6: Results- Viewing and analyzing the data

Magnetic Inclination and Intensity:

Create an Excel sheet with the Bx, By, Bz, and the total field (Magnetic Intensity) as a function of angle. (See attached Excel sheet)

Create tables such as (sample: I did this one)

Angle from Geographic North (°)	**Bx (µT)**	**By (µT)**	**Bz (µT)**	**Total (µT)**	**Inclination angle (°)**
0	-0.56	17.62	-36.6	40.62435	64.28156455
5	-2.29	16.79	-35.92	39.71643	64.74415985
10	-3.9	16.86	-35.93	39.88025	64.28284855
15	-5.61	16.04	-35.73	39.56497	64.56480662
20	-7.16	15.63	-35.91	39.8132	64.41720671
25	-8.86	15.38	-35.81	39.96749	63.63436072
30	-10.69	14.33	-35.55	39.7923	63.30222295
35	-12.65	13.03	-35.47	39.84877	62.88774544
40	-13.89	11.99	-35.77	40.2018	62.84323604
45	-14.93	10.77	-35.74	40.20255	62.74763386
50	-16.28	9.71	-36.12	40.79187	62.30947645
55	-17.48	6.36	-35.56	40.1312	62.38639042
60	-18.5	5.24	-35.31	40.20577	61.42984692
65	-18.69	4.28	-35.6	40.43507	61.69354707
70	-19.47	2.12	-36.23	41.18481	61.60539605
75	-19.92	0.3	-35.44	40.65575	60.65789639

80	-20.05	-1.53	-36.34	41.53238	61.04259109
85	-20.38	-3.44	-35.96	41.47649	60.11153493
90	-20.16	-5.33	-35.83	41.45628	59.80104195
95	-20.11	-7.55	-36.38	42.2483	59.44028239
100	-19.92	-9.7	-35.84	42.13552	58.27576596
105	-19.52	-11.67	-36.09	42.65803	57.78253116
110	-19.07	-13.41	-36.53	43.33513	57.45454908
115	-18.13	-15.84	-36.61	43.8166	56.67086265
120	-17.31	-16.96	-36.3	43.64594	56.27299951
125	-16.19	-18.84	-36.61	44.24199	55.84220583
130	-14.78	-20.68	-36.25	44.27384	54.96163942
135	-13.52	-21.99	-36.48	44.68938	54.7162333
140	-12.4	-22.92	-36.14	44.55543	54.20594896
145	-10.68	-24.68	-36.24	45.12762	53.42290911
150	-9.09	-25.77	-36.68	45.73995	53.31429491
155	-7.43	-26.3	-35.85	45.07901	52.68079346
160	-5.59	-27.45	-35.65	45.33953	51.84010433
165	-3.74	-27.81	-35.41	45.18021	51.60522964
170	-1.97	-28.7	-36.01	46.09003	51.37947478
175	-0.27	-28.56	-35.69	45.7113	51.33111252
180	1.49	-28.38	-35.83	45.73219	51.57979459
			Avg:	**42.35356**	**58.68973617**

The average of the total magnetic field results in the average magnetic intensity: **42.35 µT**

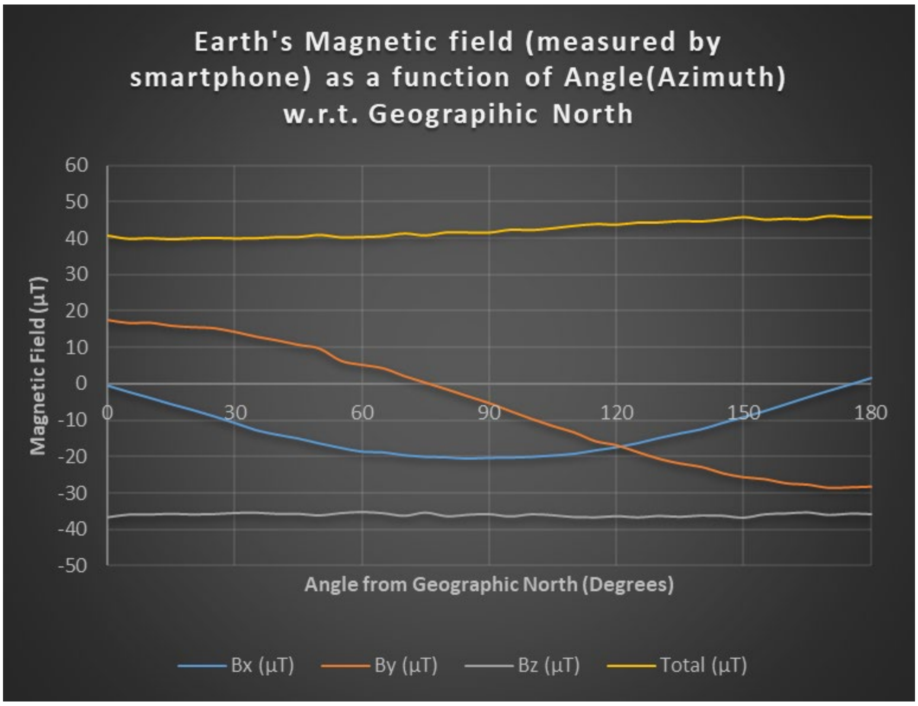
From [Fig. 2] and [Fig. 3] we can derive the magnetic inclination formula as:

$$Inclination\ Angle = \tan^{-1}\left[\frac{|B_z|}{\sqrt{{B_x}^2 + {B_y}^2}}\right]$$

The average inclination angle comes out to be: **58.7°**

A graph of the above table is provided in [Fig. 6]. The result is consistent with the value obtained NOAA website (https://www.magnetic-declination.com/) (58° 37') [Fig. 9a].

Theoretically, the total magnetic field (magnetic intensity) and Bz (as the smartphone is rotated on a horizontal surface) should be constant for all angles. By analyzing the graph [Fig. 6] we observe both the total magnetic field and Bz vary slightly with variation in angle. This slight variation is due to the smartphone magnetometer's limitations and constraints in our simple home setup. Nonetheless, the results depict the behavior of the Earth's magnetic field, which fulfills the experiment's goal for educational purposes.



[Fig.6: Bx, By, Bz and the total magnetic field (magnetic intensity) as a function of angle w.r.t to the geographic north. The setup for this measurement is given in Step. 3 of the flowchart]

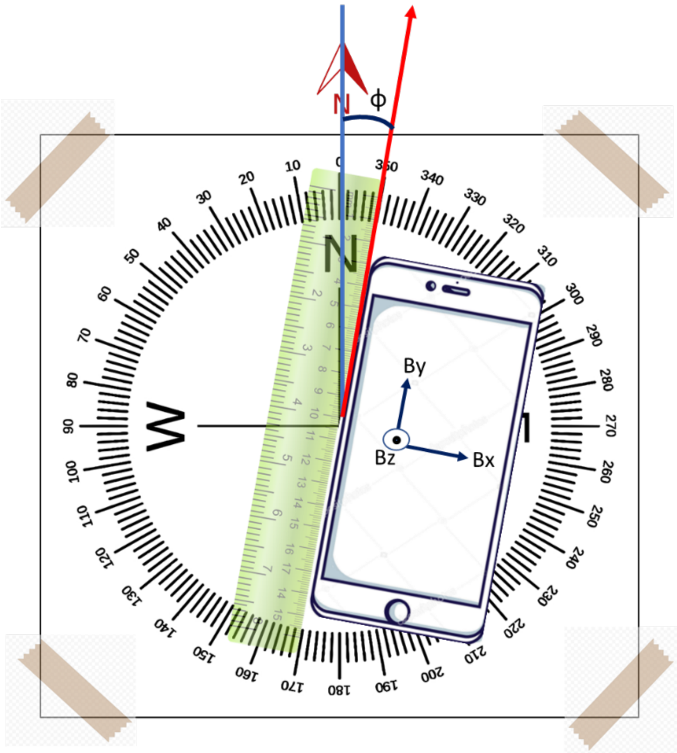
Magnetic declination:

The magnetic axes of the smartphone are aligned, as shown in [Fig. 7]. Thus, when the By axis of the smartphone is precisely aligned with the magnetic north, theoretically, the Bx component should be 0. This property is used to find the true magnetic north and the angle that the By axis makes with the geographic north is the angle of declination.

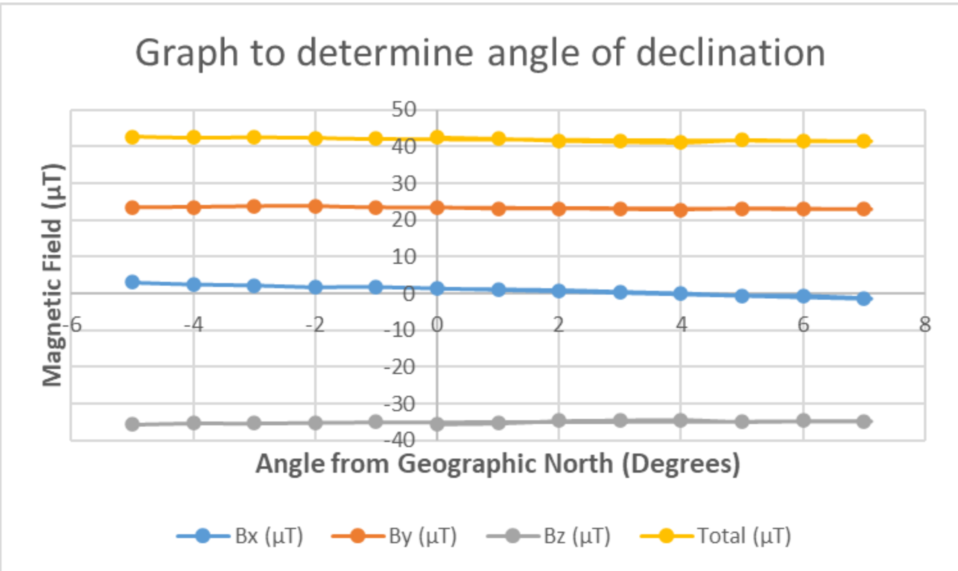
Angle from Geographic North (°)	Bx (µT)	By (µT)	Bz (µT)	Total (µT)
-1	1.28	23.4	-35.42	42.47087
0	1.1	23.06	-35.24	42.12875
1	0.87	23.15	-34.62	41.65602
2	0.39	22.96	-34.47	41.41853
3	-0.02	22.85	-34.32	41.23088
4	-0.64	23.14	-34.85	41.83768
5	-0.68	23.01	-34.64	41.59149
6	-1.51	22.91	-34.67	41.58313
-2	1.74	23.39	-34.96	42.09895
-3	1.67	23.72	-35.07	42.37136
-4	2.21	23.68	-35.25	42.52281
-5	2.46	23.48	-35.21	42.39229
-6	3	23.42	-35.56	42.68501

Plotting the above table, we get the graph as shown in [Fig. 8]. Observing the line for Bx, it is observed that it crosses the x-axis as it changes sign from positive to negative. This point of change of sign gives the approximate value of the angle of declination. Thus we can observe from the table the angle of declination is between 2° and 3° E (highlighted by green). The result is consistent with the value obtained NOAA website (2°15'E) [Fig. 9b]

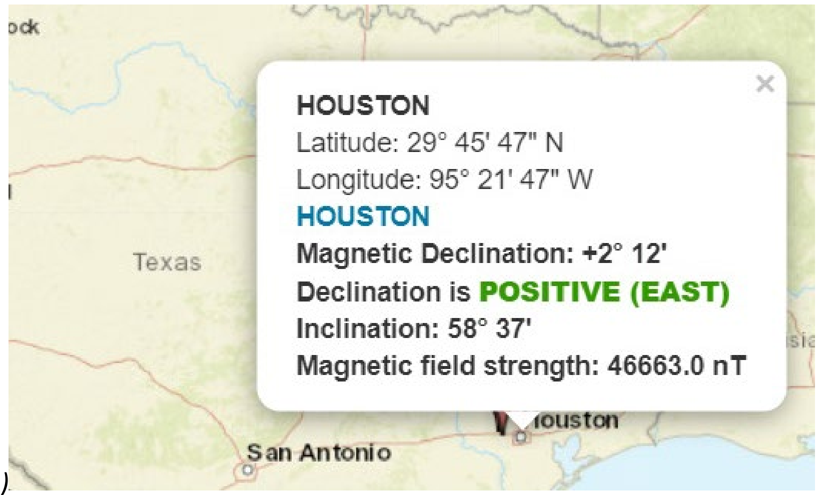
(https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination) .



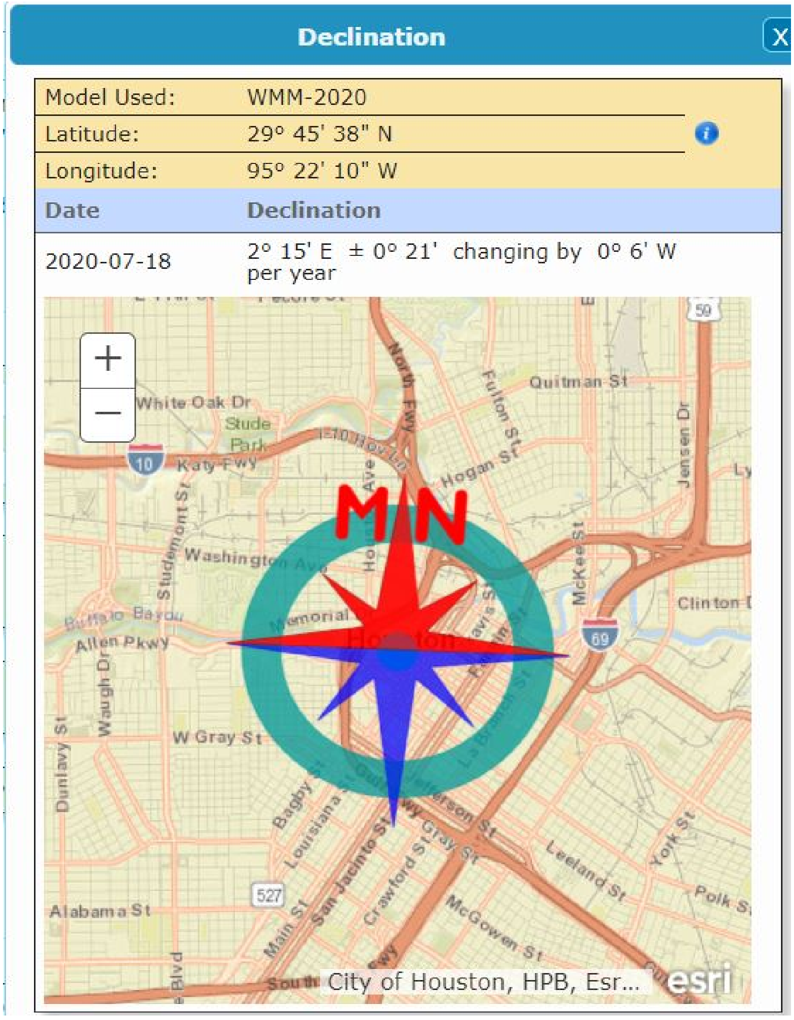
[Fig.7: The magnetic axes of the smartphone: Bx is along the shorter side, By along the longer side, and Bz is oriented out of the plane.]



[Fig. 8: Magnetic field as a function of angle w.r.t to the geographic north in increments of 1°. The line for Bx is seen to change sign and cross the x-axis; this gives the approximate value for the angle of declination.]



(a)



(b)

[Fig.9: Magnetic inclination (a) and declination (b) as obtained from the NOAA website for my place of experimentation-Houston, Texas, USA.]