Helmholtz Coils

Purpose

- To assess then uniformity of the magnetic field produced by Helmholtz coils

Equipment

- 1 base for Helmholtz Coils (of radius $a = 10$ cm) & 2 Field Coils (200-loop; 2 Amp max)
- I PASCO 850 interface
- 1 magnetic field sensor
- Board & 60 cm optics bench
- 2 long banana-to-banana leads
- 2 short banana-to-banana leads

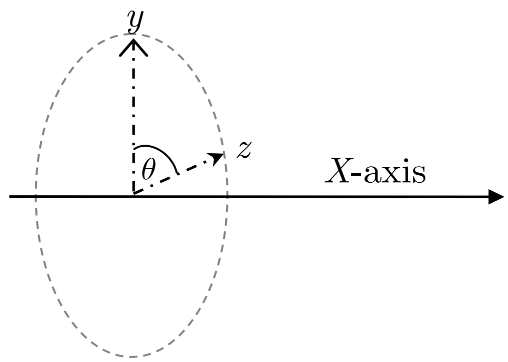
Verify that you have all of the equipment listed. Notify your TA if anything is missing.

Introduction

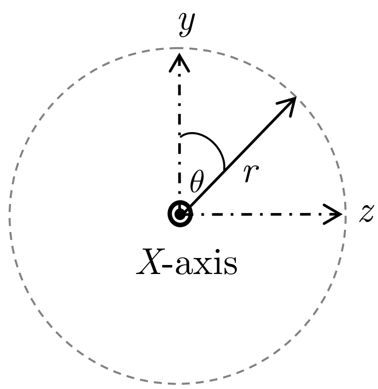
It is relatively straight-forward to produce a uniform electric field: the electric field between the plates of a parallel-plate capacitor is quite uniform. Easy access is allowed to the region between the plates. But what about producing an accessible uniform magnetic field? A solenoid will produce a magnetic field that is nearly uniform but won't allow us much access to the field. In this lab, we'll examine the magnetic field produced by Helmholtz coils: two circular coils of radius a. The centers of these coils are on the same axis and the coils are separated by a distance a.

You will measure the components of the magnetic field vector ($\vec{B}$) and from these you will use the construct the vector $\vec{B}$. In principle, this process is the same as you saw in physics one; if you know the components v_x and v_y then you can construct the vector $\vec{v}$ (since $\vec{v} = v_x\hat{\imath} + v_y\hat{\jmath}$). However, the magnetic field vector $\vec{B}$ is a three-dimensional vector. In general, this means that we need three components to specify $\vec{B}$. (For example, in Cartesian coordinates (x, y, z), the three components ; B_x, B_y and B_z are needed to specify $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$.) However, a symmetry in the Helmholtz coils) results in us only having to think about two components of the magnetic field.

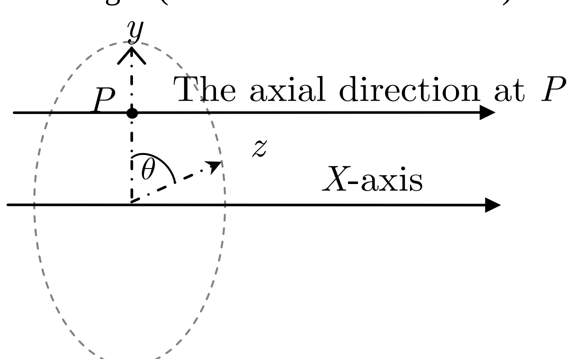
The following diagram shows an X-axis and a dotted circle that is perpendicular to the axis.



The diagram defines the cylindrical coordinates that we use to examine this magnetic field. One of the cylindrical coordinates is the distance, X, along the X-axis. We'll choose $X = 0$ to be the point on the X-axis at the center of the dotted circle. The next diagram is drawn so that the X-axis points out of the page;

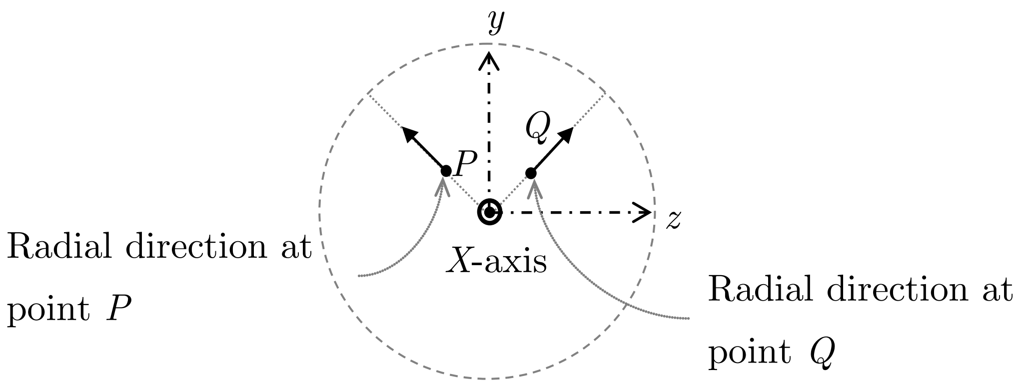


The "axial direction" is the direction of increasing X (whether on the axis or not).



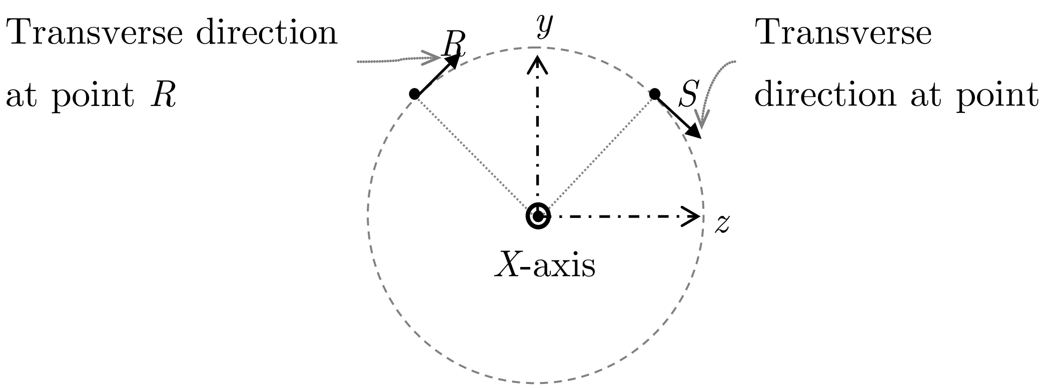
The sensor that you'll use in the lab will refer to the axial direction and you will measure the axial component of the magnetic field, B_{axial}.

The other cylindrical coordinates are the two polar coordinates r and θ. The direction in which the coordinate r increases is called "the radial direction". The following diagram shows the radial directions at points P and Q.



The sensor that you'll use will mention the radial component and you will measure the radial component of the magnetic field, B_{radial}. Notice that the radial direction is perpendicular to the axial direction.

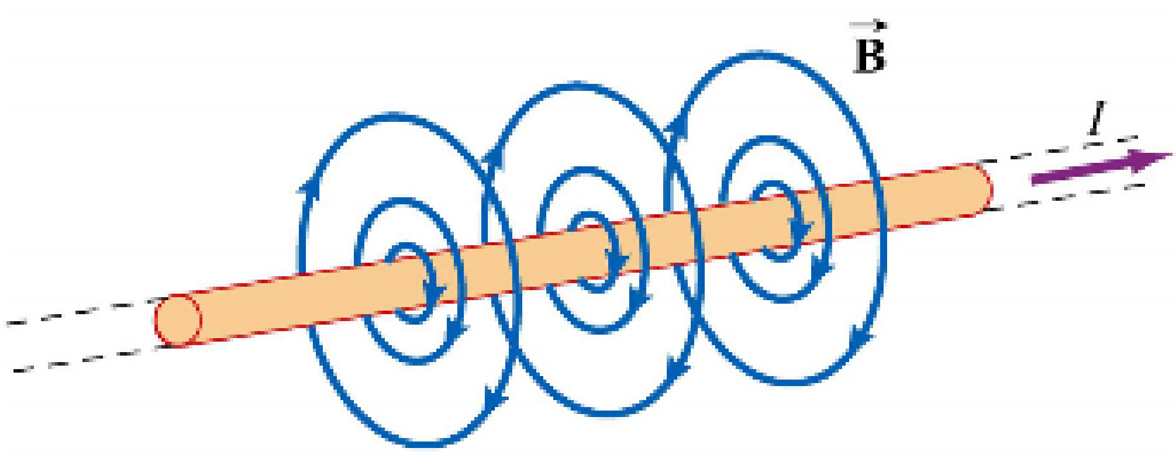
The transverse direction is the direction of increasing θ. This direction is tangent to the dotted circle. (Some people call it the 'circumferential direction'.) The component of the magnetic field in this direction is called $B_{\text{transverse}}$.



At any point, the transverse direction is perpendicular to both the radial and axial directions.

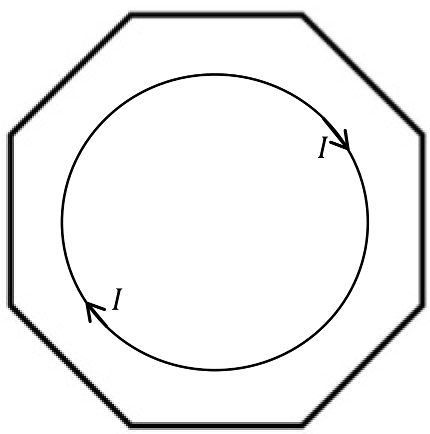
If the magnetic field had no symmetries then we would need all three components B_{axial}, B_{radial} and $B_{\text{transverse}}$ in order to specify $\vec{B}$. In the case of the magnetic field caused by Helmholtz coils, one symmetry will give $B_{\text{transverse}} = 0$. We can see this by thinking about how the field is produced.

Magnetic fields are produced by wires that carry current. An experimental observation about these fields is that the wire produces no component of magnetic field that is parallel to the wire that causes the field. The case of a long straight wire is the easiest to imagine.



The diagram shows a magnetic field caused by a straight piece of wire. Suppose that the X-axis is along the wire. **Does the field [that is caused by a straight wire] have an axial component? Does it have a radial component?**

The field that you will look at will be produced by two coils. Each coil will be made up of 200 closely-spaced circular loops of wire. For the sake of this discussion, you can restrict your attention to the magnetic field made by a single loop of wire. At first, imagine an approximation to the circular loop: a loop made out of straight sections. Current I flows through all the segments that are part of the loop. Each straight segment will give rise to a magnetic field as in the previous diagram.

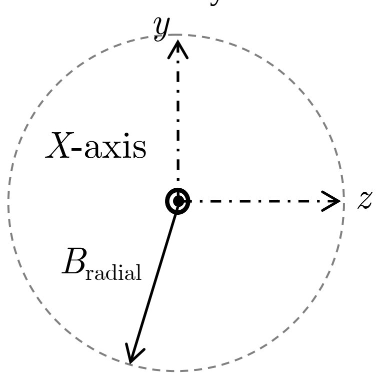


The magnetic field due to each of the eight straight sections can be drawn as circles 'edge-on' to the page. The field caused by the loop is the sum of the pieces contributed by the straight sections. No straight section of wire produces any magnetic field that is transverse to the loop (i.e. in [or against] the direction of the current I.) Since there aren't any transverse components contributed by any of the straight sections, the sum won't have a transverse component.

You can imagine doing the same thing with a loop made out of more straight sections. When the number of straight sections becomes large [so that the loop becomes more like a circular loop], we still have no transverse component. As the number of straight sections approaches infinity, the loop will become circular and we still have $B_{\text{transverse}} = 0$ for the loop. (Students of calculus-based physics that are familiar with Ampère's law can use this law to get $B_{\text{transverse}} = 0$.*)

<u>The fact that $B_{\text{transverse}} = 0$</u> for this magnetic field <u>means that $B_{\text{transverse}}$ doesn't have to be measured</u>. Further, if $B_{\text{tranverse}} = 0$ then we can visualize $\vec{B}$ on a plane (two dimensional) that includes the X-axis and any one of the radial directions. This plane is 'edge-on' in the previous diagram; if the spine of a book was along the X-axis, then this plane would be a page of the book. At the end of the lab after you have measured B_{axial} and B_{radial}, you will be able to draw a magnetic field vector.

We need to say something about the radial component of the field of the loop when we are at a point on the X-axis. (In the diagram below, the ***point*** on the axis that is chosen is at the center of the loop. However, the argument works if we choose any other point on the X-axis.) We'll begin by assuming that $B_{\text{radial}} \neq 0$ at $X = 0$. This will lead to a contradiction that can only be resolved if $B_{\text{radial}} = 0$.



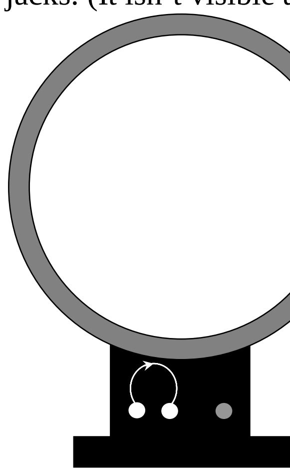
(In the diagram, the particular ***radial direction*** was also chosen at random but the argument works for any other radial direction too.) Imagine that θ is changed (by rotating the loop around the X-axis). The radial direction in the diagram will change. But nothing that causes the field changes. Since anything that causes the magnetic field has changed, the radial component shouldn't either. The only way out of this is to require $B_{\text{radial}} = 0$ so that the radial component of the field doesn't point anywhere!

Helmholtz coils are an arrangement of two coils. Each coil is made up of 200 loops of wire. All the loops are in the same plane and all have the same radius. This means that each coil has the same kind of symmetry as the loop imagined above. Thus the coils will also have $B_{\text{transverse}} = 0$ at all points and $B_{\text{radial}} = 0$ at points on the X-axis. Helmholtz coils involve two coils that aren't close to each other. We still have $B_{\text{transverse}} = 0$ at all points and $B_{\text{radial}} = 0$ at points on the X-axis. You'll measure B_{axial} and B_{radial} [at points that aren't on the X-axis] to see how uniform they are.

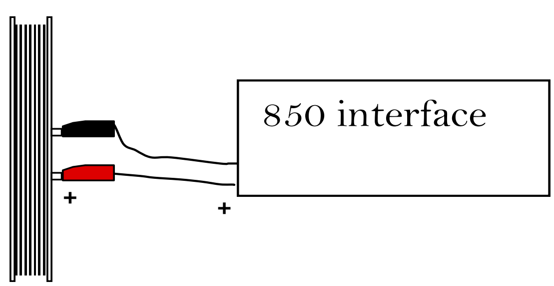
Each of the two coils looks like;

* Ampère's law for steady current is $\oint_C \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}}$. Choose a curve C to be a circle in the plane of the loop of current-carrying wire.

The two white banana jacks allow direct connection to the coil. (The other jack allows a connection to the coil but includes a 1.2 kΩ resistor. You won't be using this jack.) You'll need to know the direction in which the current flows around the coil in order to get the fields from the coils to point in the same way. The direction of the current is drawn above the two white jacks. (It isn't visible above but the following diagram shows it.)



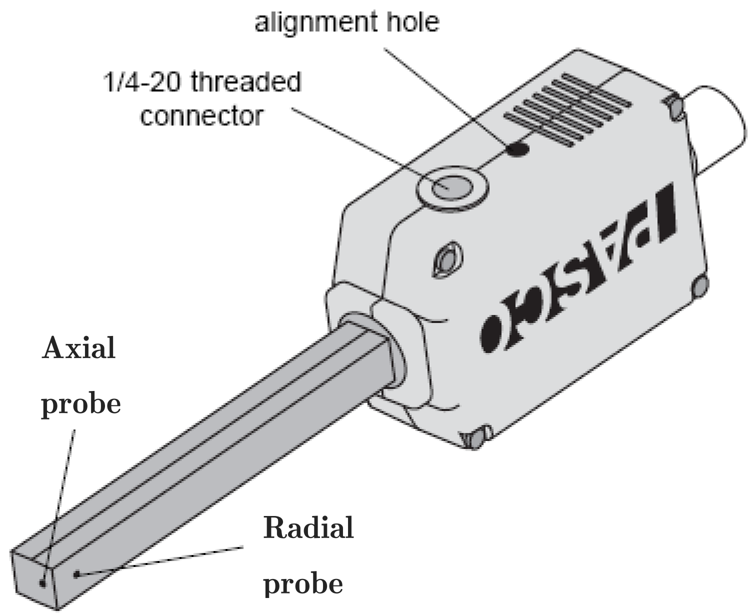
If a coil is connected to the signal generator on an 850 interface, then the view from the top of a coil is;



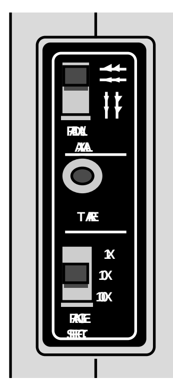
Copy the preceding is diagram into your pre-Lab. **Draw & label the <u>direction of the current</u> at the top of the coil**. **[1]** Then use this direction to find the direction of the magnetic field on the axis of the coil. **On the copy of this diagram in your pre-lab, draw & label the <u>direction of the magnetic field</u> on the axis of the coil**. **[1]**

The bottom of each coil is attached to a base.

You will use a magnetic field sensor to measure the field.



There are two Hall probes at the tip of the sensor. Each probe measures a component of the magnetic field. A slide switch (in the diagram below) on the top of the sensor allows you to choose either of the probes.



The two probes are labeled AXIAL and RADIAL on the sensor. Orient the sensor as in the following picture so that AXIAL and RADIAL on the sensor correspond to the directions that we expect. The top of the sensor also has a TARE button. This button allows you to ‘zero’ the sensor (when it is exposed to ‘background’ magnetic fields such as fields from the Earth, the interface, etc.) Pressing TARE [before you switch on the coils] allows you to subtract these ‘background’ fields from the measurement made by the sensor. The sensor also has a slide switch for changing the sensitivity of the sensor; 0 – 10 gauss (1X), 0 – 100 gauss (10X) and 0 – 1000 gauss (100X). 100X gives a reading that is multiplied by 100.

<u>At points on the axis</u> (that are given by a value of the X coordinate), **a single loop** of radius a produces the

magnetic field;

$$B_X = \frac{\mu_0 I}{2}\frac{a^2}{(a^2+X^2)^{\frac{3}{2}}},$$

and $B_y = 0, B_z = 0$.* where the permeability of the vacuum is $\mu_0 = 4\pi \times 10^{-7} N/A^2$.
<u>This expression assumes that $X = 0$ is the point on the axis that is at the center of the loop</u>. (This expression will have been derived in calculus-based physics II lecture or presented as an experimental result in the algebra-based lectures. ***You don't need to derive/prove this result for this prelab***.)

Helmholtz Coils is a pair of coils of radius a that is a distance a apart. Each coil consists of N loops. Before writing an expression for the magnetic field cause by Helmholtz Coils, you'll need to justify the expression below for the field due to a coil (of N loops). Suppose that each loop carries current I. The loops are so close together that they all can be considered to have their center at $X = 0$. **We are given the expression for the magnetic field due to one loop (above). Justify the claim that the magnetic field on the axis of a coil has the components,**

$$\boldsymbol{B_X = \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X^2)^{\frac{3}{2}}}}.$$

[2] (First, justify the expression for the X-component of the magnetic field. Justify the expressions for B_y and B_z separately.)

B_X is the axial component in the previous expressions. The components B_y and B_z are two radial components (but there are an infinite number of them). The previous expressions assumed that the loop (or coil) was at position $X = 0$. **Will the axial component of the field caused by *N* loops be $\boldsymbol{B_X = \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X^2)^{\frac{3}{2}}}}$ if the loops are loosely packed and so don't have their centers near $\boldsymbol{X = 0}$? Explain your answer. [2]**

I hope that your previous answer showed you that you superposed magnetic fields in just the way that you superposed forces in physics I: you just added them! You'll want to do something similar to find the magnetic field caused by the two coils that form Helmholtz Coils. There is a complication though.

Suppose that one coil is at position X_1 (giving field $B_X = \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X_1^2)^{\frac{3}{2}}}$ and $B_y = 0, B_z = 0$) and the other coil is at position X_2 (giving field $B_X = \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X_2^2)^{\frac{3}{2}}}$ and $B_y = 0, B_z = 0$). To superpose the two fields, we'd begin with a combined axial field of $B_X = \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X_1^2)^{\frac{3}{2}}} + \frac{\mu_0 I}{2}\frac{Na^2}{(a^2+X_2^2)^{\frac{3}{2}}} = \frac{\mu_0 I}{2} Na^2 \left[\frac{1}{(a^2+X_1^2)^{\frac{3}{2}}} + \frac{1}{(a^2+X_2^2)^{\frac{3}{2}}}\right]$.

However, this last expression still involves the two distances X_1 and X_2 from the centers of coil 1 and coil 2. There is a relation between the two distances.

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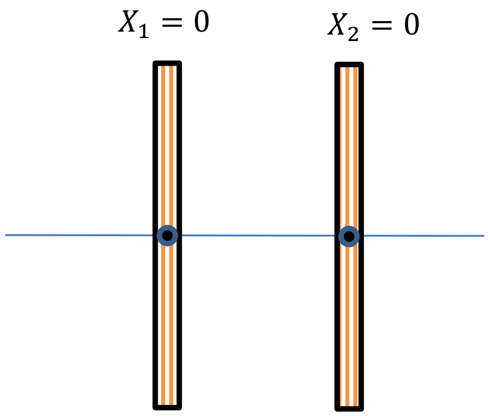
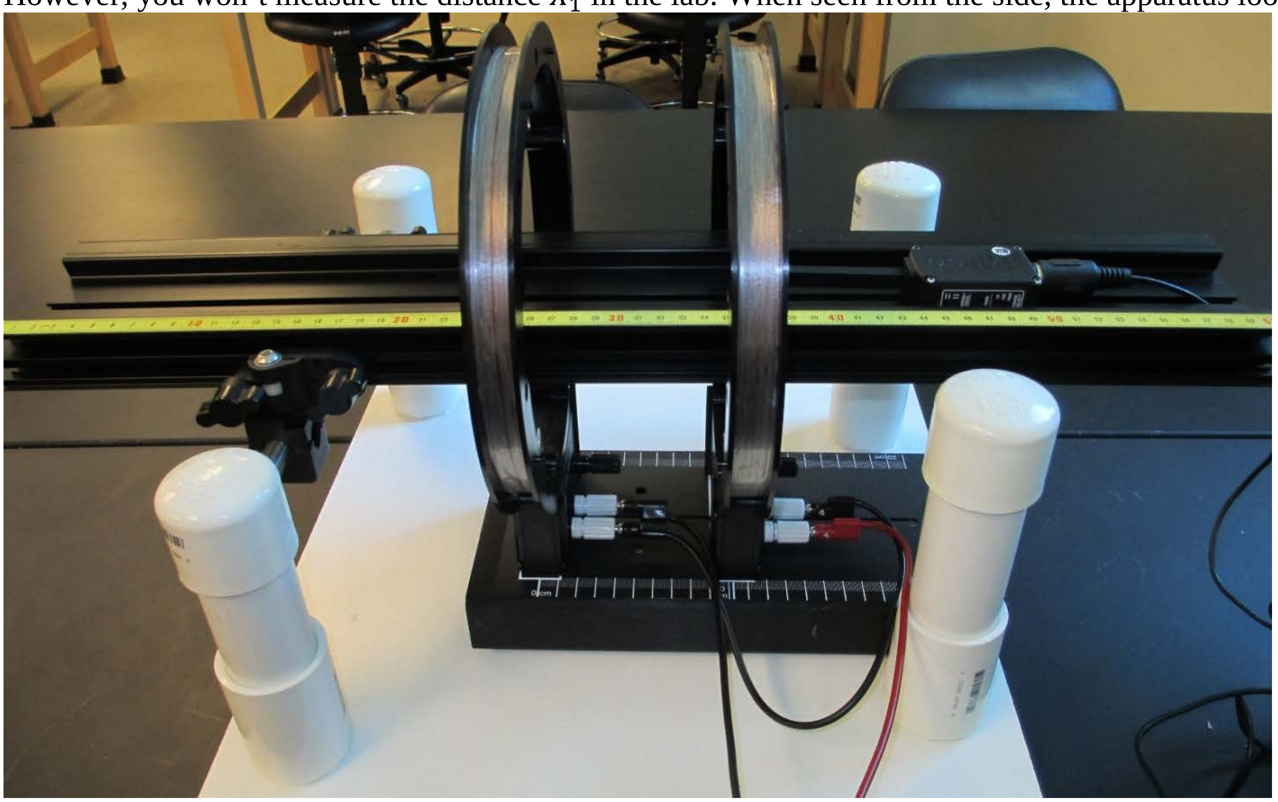
* This expression is derived in calculus-based textbooks. In the book by Young & Freedman it is equation (28.15) in the twelfth edition. This expression does not have to be derived in this lab.

The following diagram shows a top-view of the two coils. $X_1 = 0$ at the center of the coil on the left and $X_2 = 0$ at the center of the coil on the right. (The centers of the two coils are indicated by the two black dots on the axis.)



Find a relation between X_1 and X_2 given that X_1 and X_2 are the centers of the two coils that form Helmholtz coils. (Hint; you'll need to recall the distance that separates the two coils in the Helmholtz arrangement.) [1] Use the relation between X_1 and X_2 to simplify $B_X = \frac{\mu_0 I}{2} N a^2 \left[\frac{1}{(a^2+X_1^2)^{\frac{3}{2}}} + \frac{1}{(a^2+X_2^2)^{\frac{3}{2}}} \right]$**.**
Give your answer in terms of μ_0, N, a, I and X_1 (but not X_2). [1]

However, you won't measure the distance X_1 in the lab. When seen from the side, the apparatus looks like;



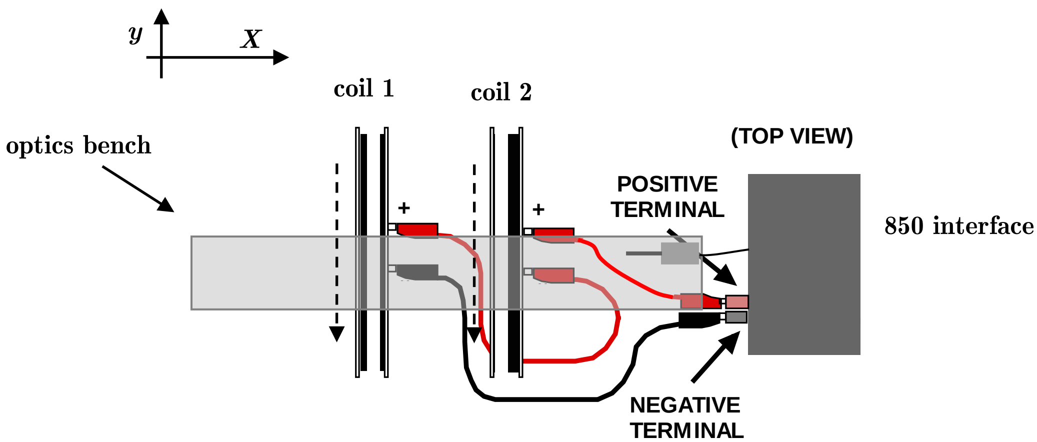
In the lab, you will measure distances along the (yellow) tape-measure that is attached to an optics bench. I'll call the distance along the tape-measure x where $x = 0$ at the left-hand-side of the tape-measure. Suppose that the coil on the left is at position $x = d$ along the measuring-tape. **Remembering that $X_1 = 0$ at the center of the coil on the left, write an expression that relates distance x along the measuring-tape, to distance X_1 from the coil on the left. [1]**

Use the answer to the previous question to further simplify your expression for the axial component of the magnetic field produced by Helmholtz coils. [1]

Instructions

You will begin by measuring the magnetic field on the axis through the centers of the field coils. *Adjust position of the Helmholtz coils & optics bench so that the sensor points along the axis.*

When seen from the top, the apparatus should be;



In this diagram, the dotted vectors show the direction of the wire at the top of the coils. (The diagram doesn't show the jack that includes the $\mathbf{1.2}$ $\mathbf{k\Omega}$ *resistor. You don't need to use it. Use the two white connections.)*

Physical set-up

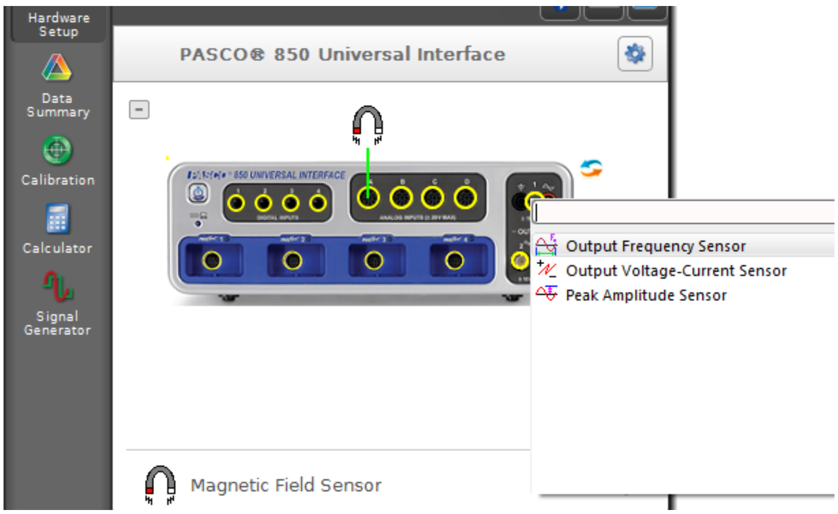
1. Connect two coils in series using banana-banana cable. It is important that you arrange things so that the current flows through the two coils in the same direction
2. Connect the other ends of the coil to the signal generator (Output 1 of the 850 interface)
3. Insert the magnetic Field sensor in Analog inputs A
4. Use the slide switch on the magnetic field sensor to select 100X range

Using the interface

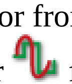
1. Connect the 850 interface to the computer using a USB cable
2. Switch on the interface
3. Launch Capstone software. (A shortcut to Capstone is on the Desktop.)
4. **Setting up hardware**
    a) The Tools Palette is on the left of the Capstone screen. Click "Hardware Setup"  from the Tools Palette
    b) On the picture of the 850 interface, click Analog Input A. Choose "Magnetic Field Sensor "from the drop-down menu.
5. Arrange the base of the coils so that the center of the Helmholtz coils is at the 35 cm mark on the yellow scale. (The coils will then be at the 30 cm and 40 cm positions.) The coils are positioned to

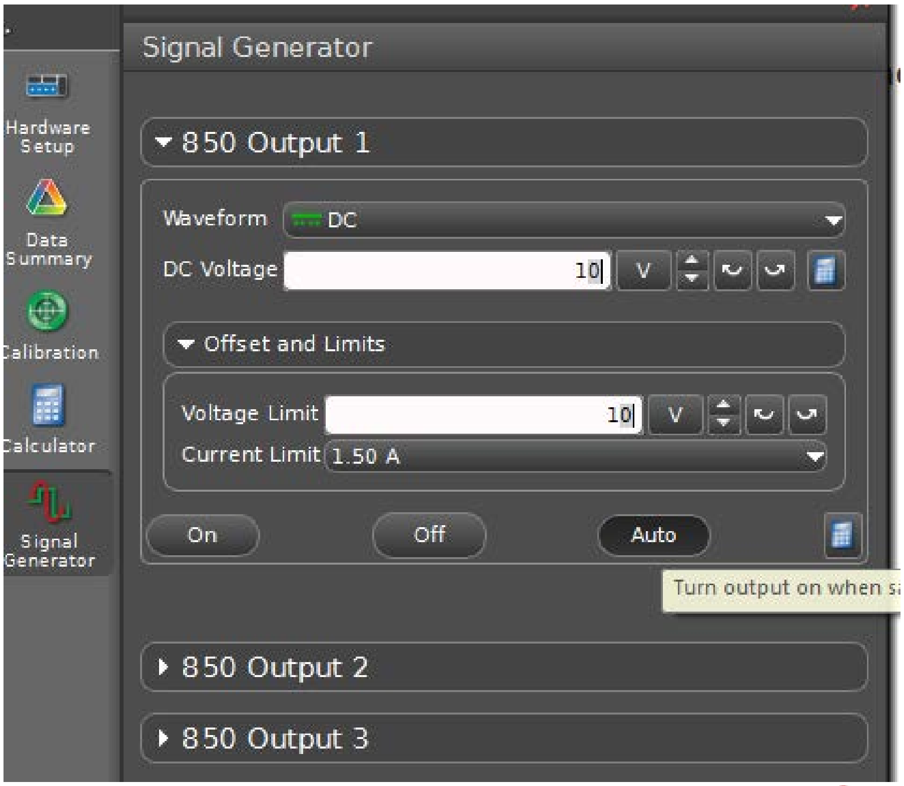
be nearer the 60 cm end of the optics bench. Put the sensor on the 'long' end of the bench so that the white dot on the sensor probe is at the 15 cm mark on the yellow scale.

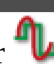
a) On the magnetic Field sensor, slide a slide switch to AXIAL. Save the Capstone file with the name **Helmholtz – axial - on-axis.** Create the file on a flash-drive if you have one with you. Otherwise, you can save it on the desktop. (Remember that the position of the axial sensor is marked with a white dot on the very front of the probe.)
b) Click on "Output 1" <u>on the picture of the interface</u>.



Choose Output Voltage-Current Sensor from the drop-down menu.

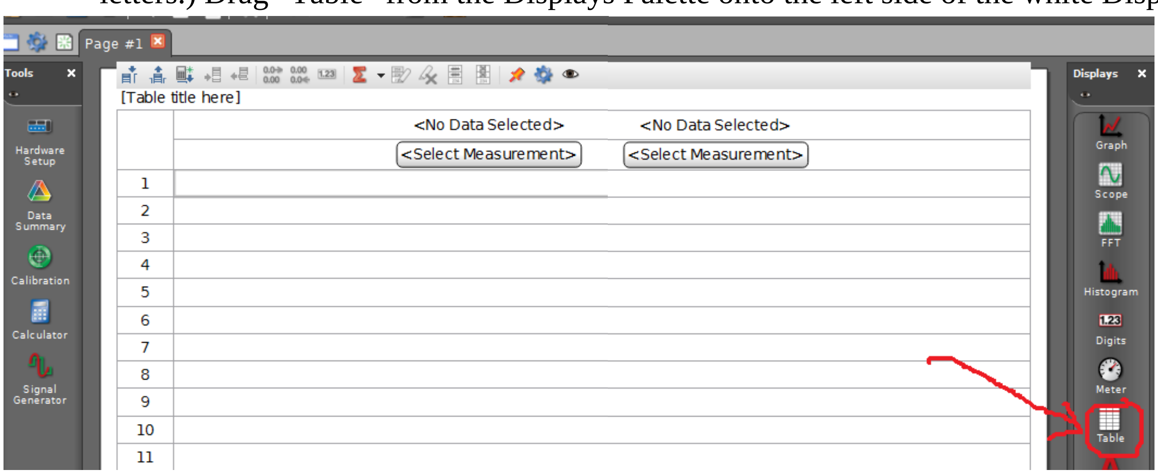
c) Click the icon for the signal generator  from the Tools Palette.
d) Click on "850 Output 1".
e) Select the following (as in the picture below); waveform: "DC", DC Voltage: "10V", Voltage limit: "10V". Click "Auto".



f) To finish with this dialog, click the icon for the signal generator  from the Tools Palette.

6. Setting up a table for collecting data

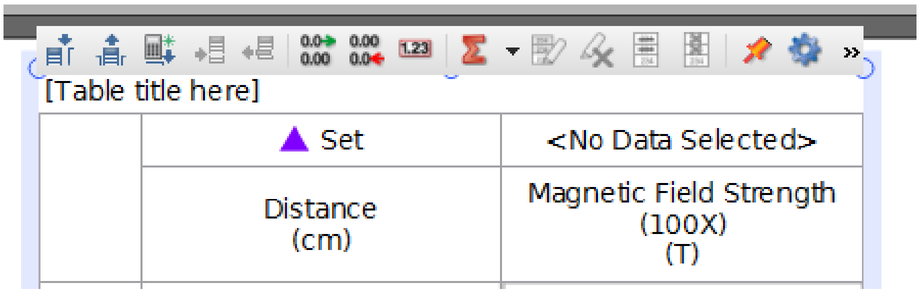
a) The Displays Palette is on the right or your screen (under the heading “Displays” in white letters.) Drag “Table” from the Displays Palette onto the left side of the white Displays Area.



b) Click the heading “<Select measurement>” on the column on the left. This will open a dropdown menu.

c) Select “Create New” then “User-Entered Data”. The heading title will be highlighted. Edit the heading title to be “Distance”.

d) Click tab to select the "(units)" under your new title. Rename the units to be "cm".
e) Click the heading "<Select measurement>" on the column on the right.
f) From the dropdown menu, select "Magnetic Field Strength (100x) (T)".

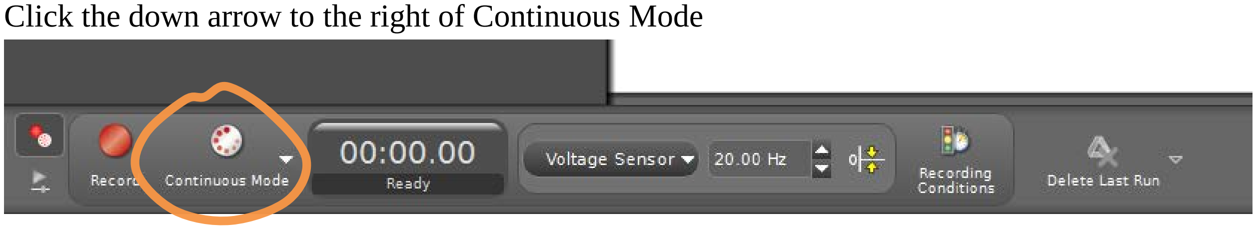


g) Select the cell corresponding to the one that is highlighted below. Type the list of distances that you'll actually use. Notice that the first three distances are separated by 5 cm. Data will be taken more frequently beginning 5 cm before the first coil and ending 5 cm past the second coil. The last three distances are again separated by 5 cm.

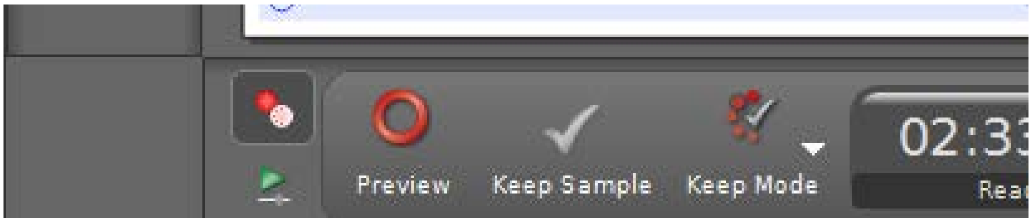
Distance (cm)	Magnetic Field Strength (100x) (T)
15	
20	
25	
26	
27	
28	
⋮ ⋮	⋮ ⋮
42	
43	
44	
45	
50	
55	

7. Preparing to Collect Data

a) Click the down arrow to the right of Continuous Mode



b) From the drop-down menu, select Keep Mode. The Continuous Mode control will turn into  . This will tell the software to measure data only when you tell it. The “Record” button also turns into a “Preview” button (as below)

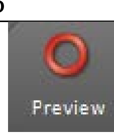


c) The next task is to tare the sensor. Move the sensor (as far as its cable will allow) away from the Helmholtz coils, interface and power supply for the interface. Press the button on the sensor marked “Tare”. Put the magnetic field sensor on the optics bench. Be careful not to touch the TARE button again when you move the sensor!

8. Taking Data

a) Select the cell corresponding to the one highlighted below:

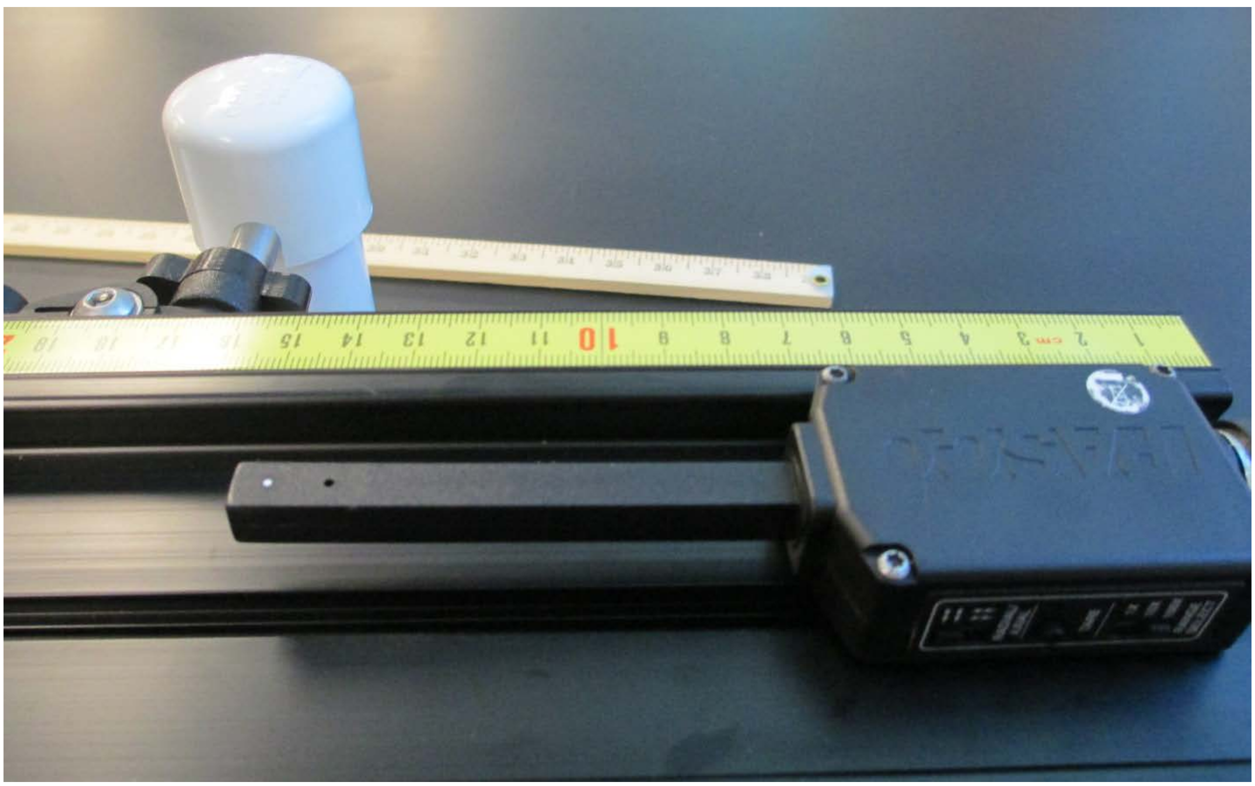
Distance (cm)	Magnetic Field Strength (100x) (T)
15	
20	
25	
26	
27	
28	
⋮ ⋮	⋮ ⋮
42	
43	
44	
45	
50	
55	

b) Click “Preview” 

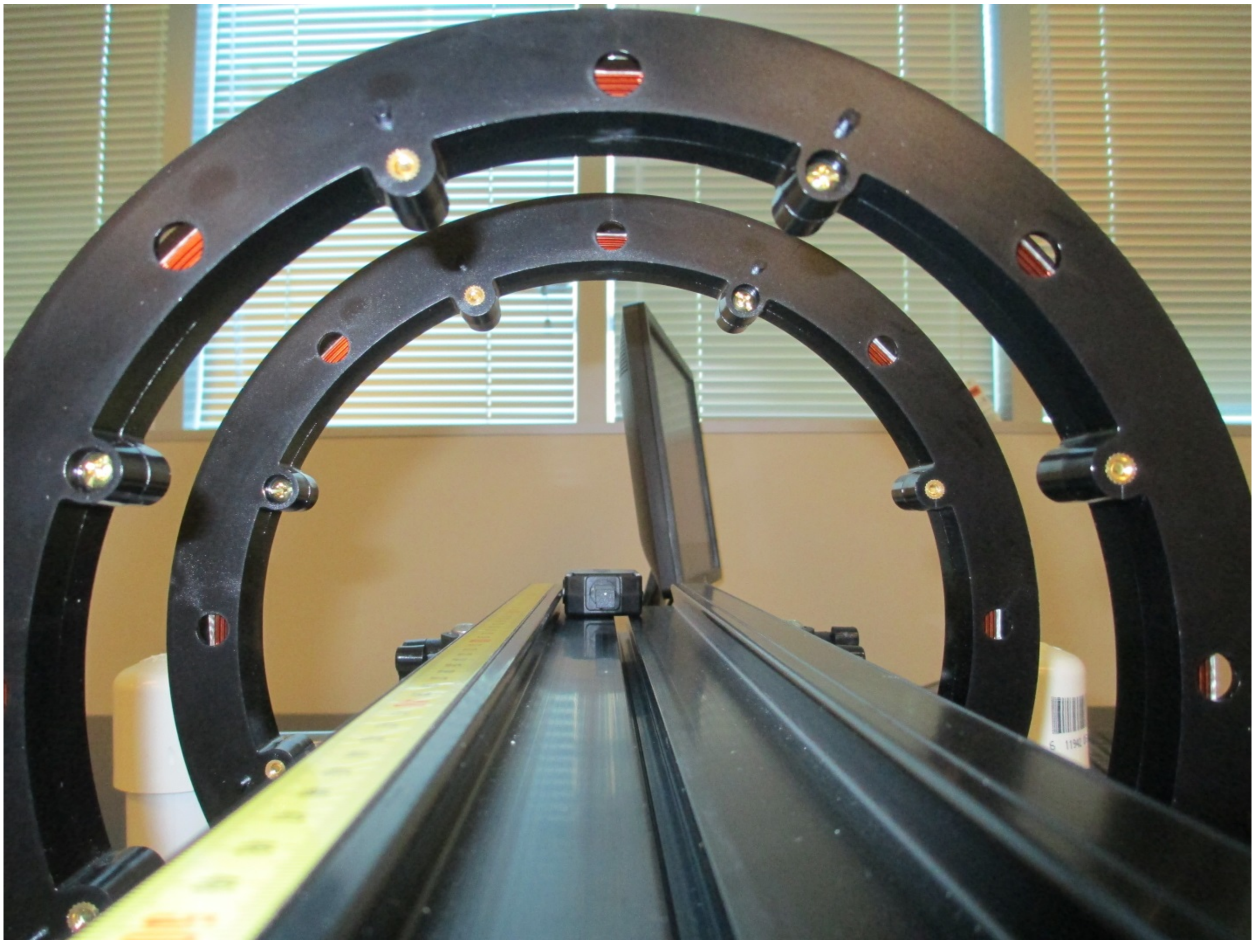
. When you do, current will flow through the Helmholtz coils and the sensor will detect the resulting field. The reading from the sensor will appear in the highlighted cell. (When you click it, the “Preview” button turns into a “Stop” button.)

c) The format of the reading gives two significant figures. Move the cursor over the table and notice that a toolbar appears above your table. (If it doesn’t appear then you can leave this step for later. If you skip this, then please don't worry if you get measurements of "0.0"). The toolbar includes the icon:  that lets you increase the number of digits in the readings from the sensor. Click it. (Six significant figures are usually enough.)

d) To align the sensor parallel to the X-axis, push the sensor against the optics bench (as below).

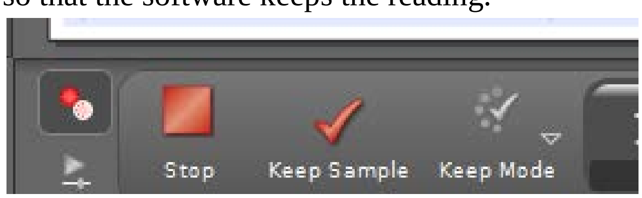


e) Look at the sensor from one end of the optics bench (as below).



Move the base of the Helmholtz Coils and/or slide the optics bench to the side so that the white dot on the front of the sensor is along the X-axis of the coils.

f) When the sensor is at 15 cm and you have checked the alignment of the sensor, click "Keep" so that the software keeps the reading.



The reading in the selected cell will become permanent. The cell below it will become active and display the current reading of the sensor.

g) Being careful not to touch the tare button, move the sensor along the optics bench so that the white dot is at the distance specified in the same row as the current reading. Push the sensor back against the optics bench so that you align it.

h) Press "Keep".

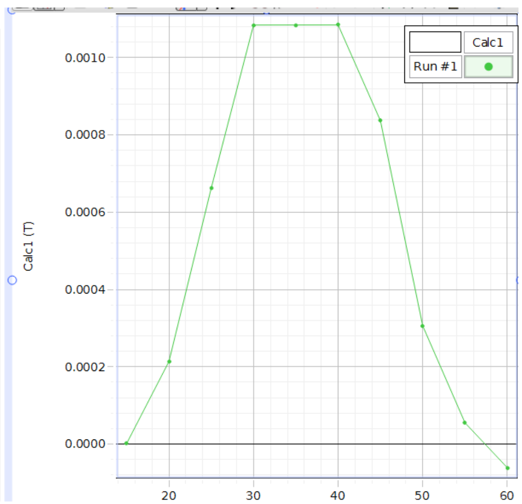
i) Repeat the last two steps until you reach the end of the list of distances. Then press Stop. Save your file!

9. Getting a graph

a) From the Display Palette, drag the Graph display to the white Displays Area. Select "Distance (cm)" for the x-axis and "Magnetic Field Strength (100X) (T)" for the y-axis. You'll get a graph that is (roughly) like this one.

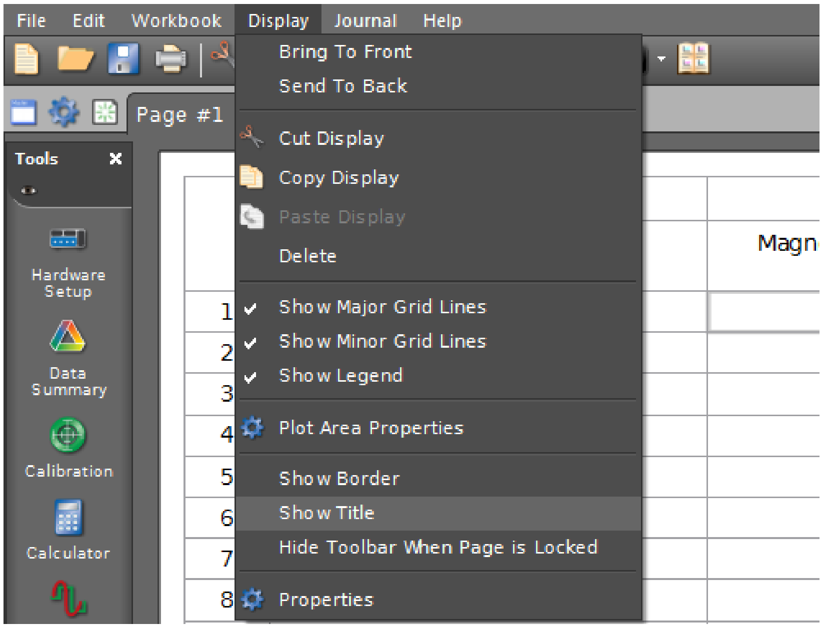
[Table title here]

	Set	Run #1
	Distance (cm)	Magnetic Field Strength (100X) (T)
1	15	-1.48546E-6
2	20	-2.13520E-4
3	25	-6.62359E-4
4	30	-0.00108
5	35	-0.00108
6	40	-0.00108
7	45	-8.36806E-4
8	50	-3.05863E-4
9	55	-5.49430E-5
10	60	6.12017E-5
11		
12		
13		
14		
15		
16		
17		
18		
19		



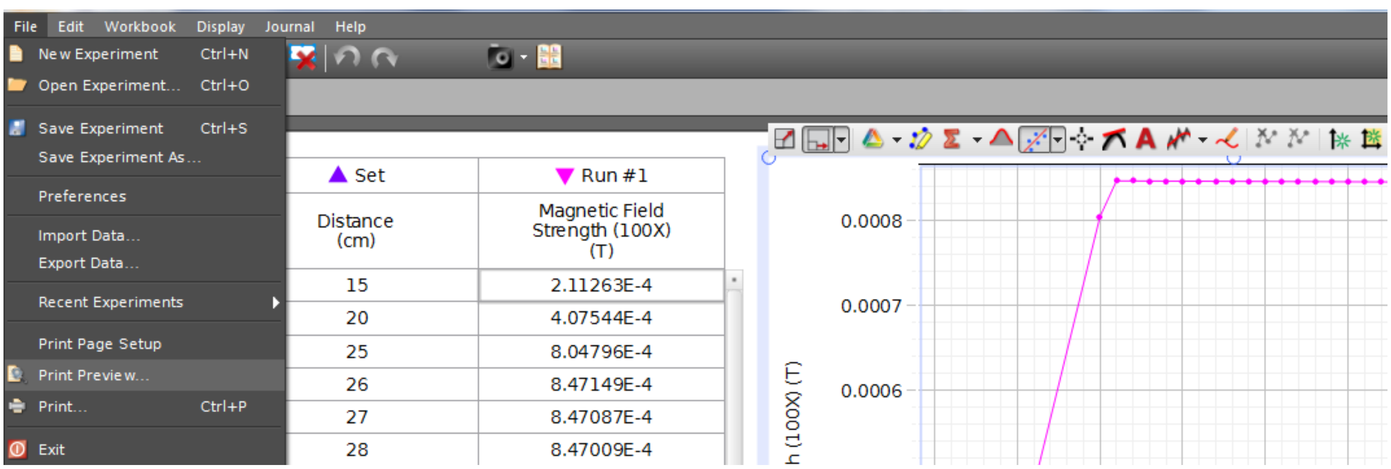
b) Data was only plotted every 5 cm for this data-set. It isn't clear if the axial component of the field drops quite so sharply at the coils (30 cm and 40cm). That is why you are gathering more data near the coils!

c) You will need four graphs and will want to label them to avoid mixing them up. To put a title on your graph, click Display on the main toolbar and select "Show Title" from the dropdown menu (below).



A title appears under (and to the left of) the graph. Name the graph "Axial – on-axis".

d) Select Print Preview from the main toolbar



Select the "landscape" button.

e) **Print the graph using the printer icon. Submit it with your report. [1]**

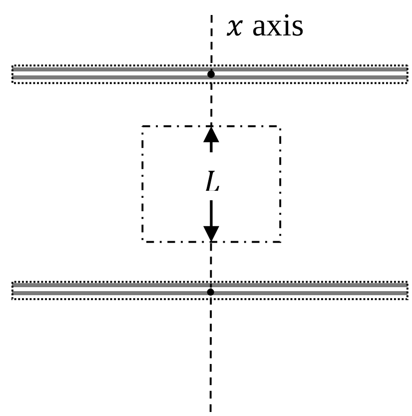
f) Save your experiment file. Don't delete this file: there are questions to follow about it!

Now measure the RADIAL components of the field on the X-axis. Begin by making a new Capstone file: ***Helmholtz – radial - on-axis.*** Many of the instructions are the same as for – axial - on-axis. Begin at step 4 of "***Using the interface***". At 4 c), select RADIAL with the slide switch. You'll need to look at the white dot on top of the sensor-probe during step 7 (***Taking Data***). Continue to step f) of "Getting a graph". Label the graph: **radial - on-axis. Print the graph of the radial component of magnetic field (on axis). Include a copy with your report**. **[1] Comment on the size of the radial component (relative to the size of the axial component). Is the following statement consistent with your results; "the radial component is zero at points along the axis of the coils"? [2] (**For comparison, the earth's magnetic field has a strength of about 65 micro T = 6.5×10^{-5}T .)

Now measure the AXIAL components of the field **off** the X-axis. Begin by making the Capstone file: **Helmholtz – axial - off-**axis and continue as for the on-axis measurements of the axial component. **Print the graph of the axial component of magnetic field (off axis). Include a copy with your report. [1]**

Last measure the RADIAL components of the field **off** the X-axis. Begin by making the Capstone file: **Helmholtz – radial - off-axis.** Continue as for the on-axis measurements of the radial component. **Print the graph of the radial component of magnetic field (off axis). Include a copy with your report. [1]**

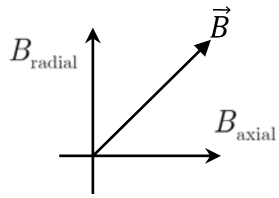
Now look back at your file for the axial – on – axis field. Use the Coordinates Tool (: on the toolbar over your graph) to help **measure & record the maximum value of the axial component of the field**. **[1]** Your graph will show that the axial component is almost uniform in some region between the coils. Let L be the length of this region.



The axial component will decrease as you move away from the point at which you measured its maximum value. *Find the distance L for your set of Helmholtz coils*. Do this by finding the two points (at the top & bottom of the region above) at which the axial component is at least 5% smaller than its maximum value. **Report the distance *L* as a <u>percent of the separation of the coils</u>**. **[3]**

Have your TA check your data

Recall that $B_{\text{transverse}} = 0$ allows us to draw $\vec{B}$ on a 2D plane (where one of the directions is axial and another independent direction is radial).



Your graphs of the axial and radial components at points along either path of the sensor contain this information. Since the distance scale for both graphs is the same, you can use the graphs to find both axial and radial components <u>at the same point</u>. You will do this at three points on the axis and at three points that aren't on the axis. (For my data and coil separation, I'd chose T and W to be at 30 cm along the paths, M and P to be at 35 cm along the paths and R and N to be at 40 cm along the paths.

Please copy the following diagram and table one into your report

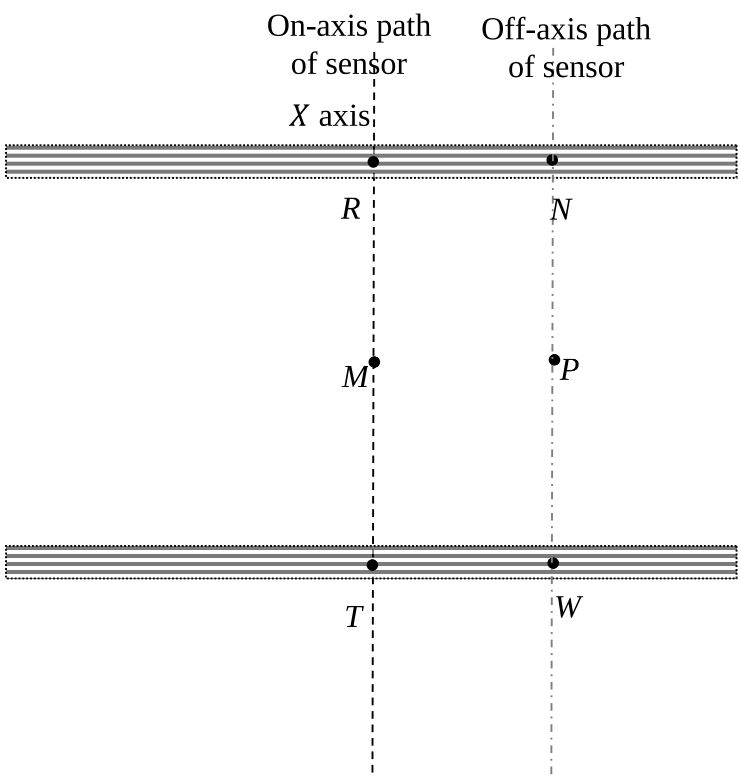


Table 1

Point	Value of *X*	Axial Component (T)	Radial Component (T)
R			
M			
T			
N			
P			
W			

The two coils are shown. Points *R*, *M* and *T* are on the axis. Points *R* and *T* are at the centers of either coil. Point *M* is at the midpoint between the coils.

Use your graphs to find the radial and axial components of the magnetic field at *R, M* and *T*. Record this information in the first three rows of table 1 in your report. [6]

Points *N*, *P* and *W* are along the off the X-axis. **Use your graphs to find the radial and axial components of the magnetic field at *N, P* and *W*. Record this information in the fourth through sixth rows of table 1 in your report. [6]**

On the last diagram in your report shows the two coils, the *X* axis and another parallel line that is not on the axis. (This line should be close to the line that you used to collect data off the axis.) The diagram is drawn to scale. **Use your data in table 1 to draw $\vec{B}$ at *R, M, T, N, P* and *W* on the last diagram in your report**. **[6]**

If you had more time, then you would repeat in this way; you would move the sensor along other paths off the axis. You would gather data about the axial and radial components and would draw more magnetic field vectors. Since doing this would take time, you would want to choose paths that gave as much information about the field as possible. **With this in mind, why would you only need to choose paths that are on one side of the axis? Explain. [2]**

Remember leave the apparatus as it was when you arrived.
Ask your TA to check your apparatus before you turn in your reports
Shut-down the computer.
Turn the PASCO 850 interface off.

Helmholtz Coils
Paul Mac Alevey © Spring 2017

PRE-LAB

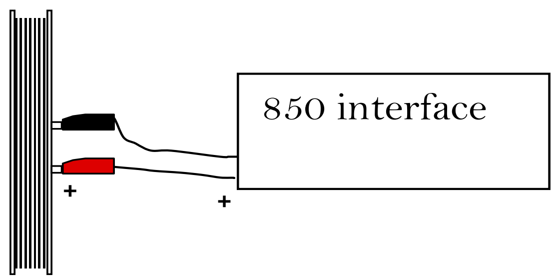
NAME:____________________________ Course & Section ________________________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

Does the field [that is caused by a straight wire] have an axial component? Does it have a radial component?

____

____**[2]**



On the diagram above, draw & label the <u>direction of the current</u> at the top of the coil. **[1]**

On the diagram above, draw & label the <u>direction of the magnetic field</u> on the axis of the coil. **[1]**

We are given the expression for the magnetic field due to one loop (in the prelab introduction above). Justify the claim that the magnetic field on the axis of a coil has the components,

$$B_X = \frac{\mu_0 I}{2} \frac{Na^2}{(a^2 + X^2)^{\frac{3}{2}}}.$$

____

____

____**[2]**

Will the axial component of the field caused by N loops be $B_X = \frac{\mu_0 I}{2} \frac{Na^2}{(a^2+X^2)^{\frac{3}{2}}}$ if the loops are loosely packed and so don't have their centers near $X = 0$? Explain your answer.

____

____**[2]**

Find a relation between $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ given that $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ are the centers of the two coils that form Helmholtz coils. (Hint; you'll need to recall the distance that separates the two coils in the Helmholtz arrangement.)

____**[1]**

Use the relation between $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ to simplify $B_X = \frac{\mu_0 I}{2} N a^2 \left[\frac{1}{(a^2+X_1^2)^{\frac{3}{2}}} + \frac{1}{(a^2+X_2^2)^{\frac{3}{2}}}\right]$. Give your answer in terms of $\boldsymbol{\mu_0}$, $\boldsymbol{N}, \boldsymbol{a}, \boldsymbol{I}$ and $\boldsymbol{X_1}$ (but not $\boldsymbol{X_2}$).

____**[1]**

Remembering that $X_1 = 0$ at the center of the coil on the left, write an expression that relates distance x along the measuring-tape, to distance X_1 from the coil on the left.

____**[1]**

Use the answer to the previous question to further simplify your expression for the axial component of the magnetic field produced by Helmholtz coils.

____**[1]**

REPORT

NAME:____________________________ Course & Section: ___________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

…. measure & record the maximum value of the axial component of the field.

____ **[1]**

Report the distance L as a <u>percent of the separation of the coils</u>.

____ **[3]**

Print the graph of the axial component of magnetic field (on axis). Include a copy with your report. **[1]**

Print the graph of the radial component of magnetic field (on axis). Include a copy with your report. **[1]**

Comment on the size of the radial component (relative to the size of the axial component). Is the following statement consistent with your results; "the radial component is zero at points along the axis of the coils"?

____

____ **[2]**

Have your TA check your data

Print the graph of the axial component of magnetic field (off axis). Include a copy with your report. **[1]**

Print the graph of the radial component of magnetic field (off axis). Include a copy with your report. **[1]**

Use your graphs to find the radial and axial components of the magnetic field at R, M and T. Record this information in the first three rows of table 1 in your report.

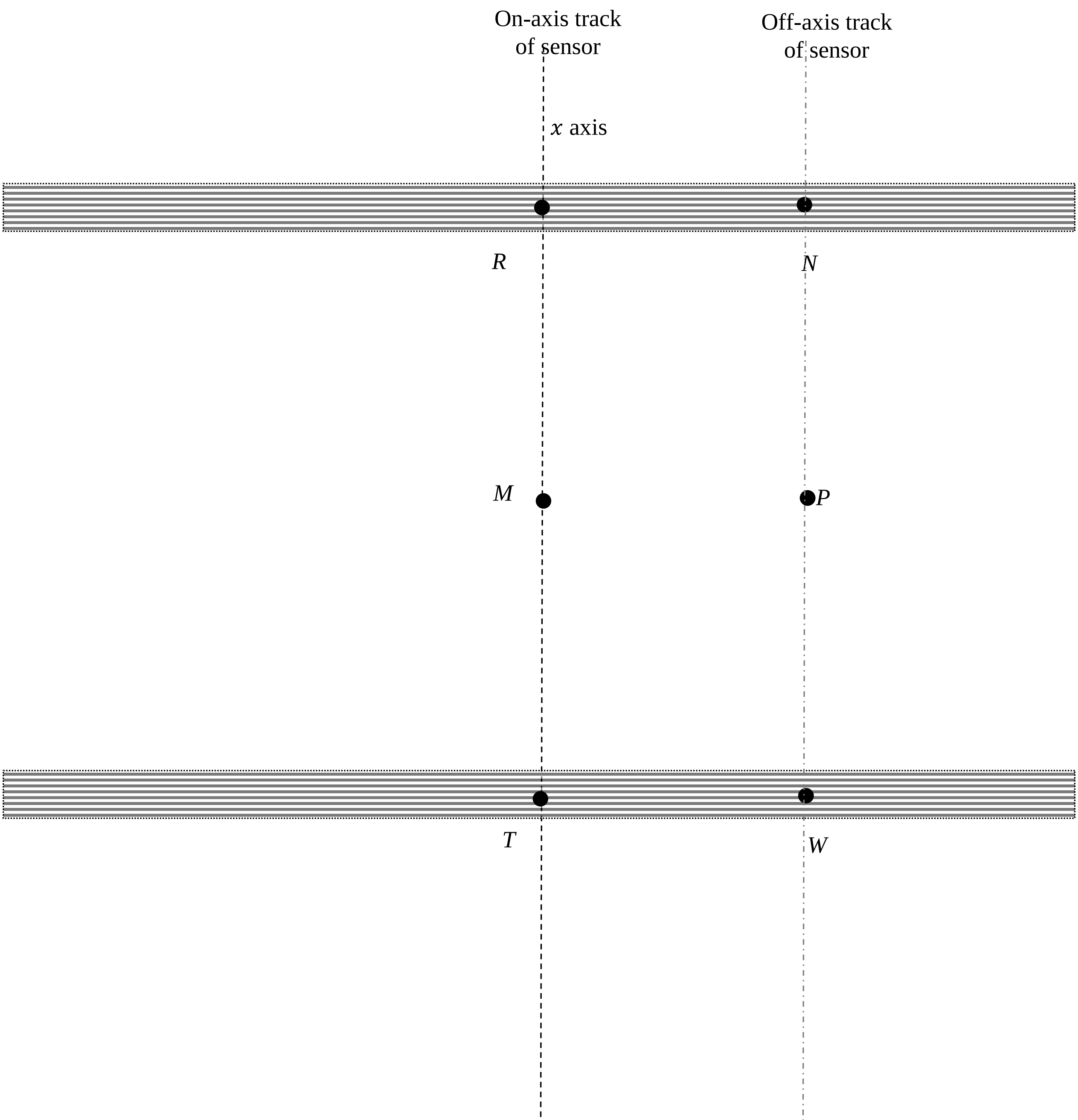
Use your graphs to find the radial and axial components of the magnetic field at *N*, *P* and *W*. Record this information in the fourth through sixth rows of table 1 in your report.

Table 1

Point	Value of *X*	Axial Component (T)	Radial Component (T)
R			
M			
T			
N			
P			
W			

[12]

Use your data in table 1 to draw $\vec{B}$ at *R*, *M*, *T*, *N*, *P* and *W* on the last diagram in your report. **[6]**


On-axis track of sensor
Off-axis track of sensor
x axis
R
N
M
P
T
W

With this in mind, why would you only need to choose paths that are on one side of the axis? Explain.

____

____

____ **[2]**