Electromagnetism

Purpose

Using Arduino micro-controllers with "Lab in Your Pocket" app as magnetometer to investigate the magnetic field strength of a solenoid with electric current flowing in it.

Theory

- Magnetic field is generated by moving charges, expressed by magnetic field lines. The closer the adjacent field lines, the stronger is the field, and vice versa.
- For a solenoid with N turns in a length L, the magnetic field strength generated by a current I flowing in it is given by $B = \frac{\mu_0 N I}{L}$, where μ_0 is the permeability of free space and its value is 1.26×10^{-6} TmA^{-1}. For fixed amount of current I, the relationship between B and number of turns per unit length N/L can be investigated. For fixed number of turns per unit length, the effect of current I on B can be studied.
- The magnetic field is uniform, i.e. it is the same everywhere, inside the solenoid. The magnetic field outside the solenoid resembles that of a permanent magnet, diverging at one end and converging at another end, determined by right-hand grip rule (Fig 1).

Fig 1

- The SI unit of magnetic field strength is Tesla (T). The unit used in this experiment is microtesla(μT).
- A resistor with suitable resistance should be included in the circuit to prevent short circuit. Resistors with different resistance can also be used for experimentation with different current.
- The Arduino current sensor is connected to take the reading of current in the unit of milliampere (mA).
- The "Lab in Your Pocket" app connects with the Arduino sensors to measure the magnetic field strength.
- By the principle of superposition, the resultant magnetic field is the sum of the background "stray" (unwanted) magnetic field and the magnetic field generated by the wire and solenoid. The background magnetic field will be assessed in order to reduce the error in the study.

Apparatus

- A power bank or D.C. electricity supply with appropriate voltage
- A mobile device with “Lab in Your Pocket” app
- An Arduino current sensor and an Arduino hall sensor (provided by PolyU)
- A solenoid
- A variable resistor

Setup

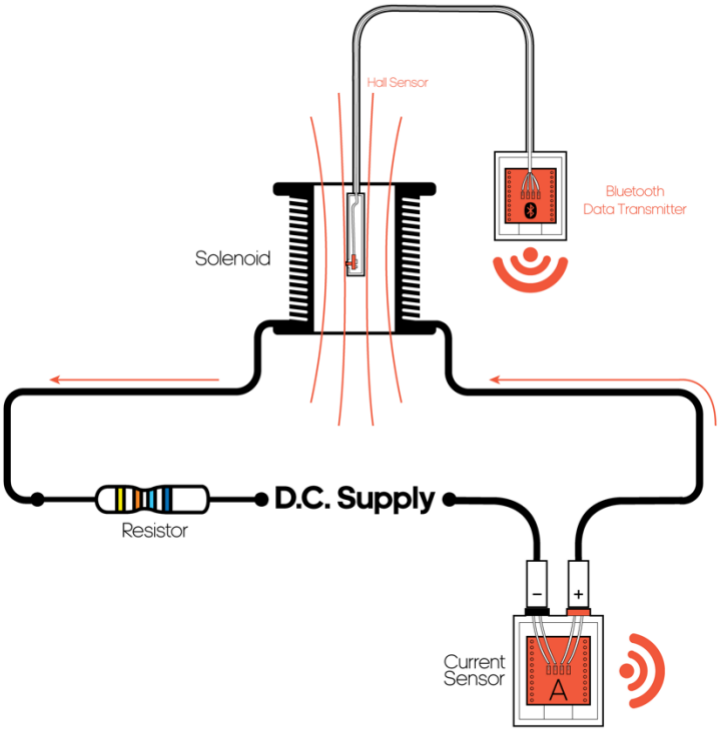

Fig 2

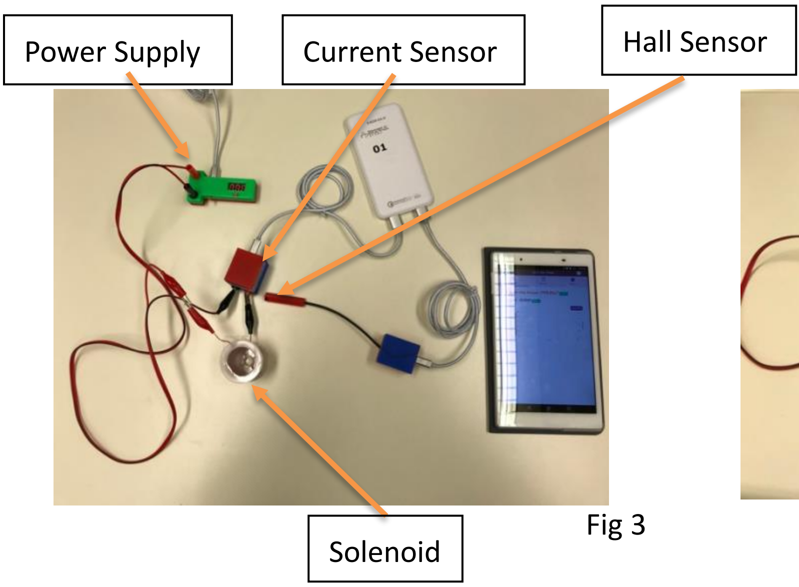

Fig 3

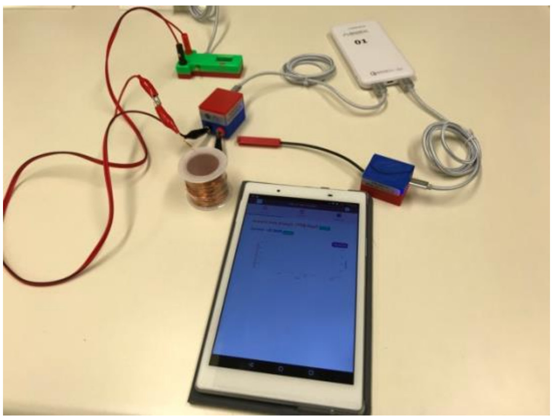

Fig 4

Precautions

1. The current through current sensor and solenoid shall not exceed 1000mA (i.e. 1A) to avoid overheat or damage of the components.
2. Avoid touching or colliding the emerged hall sensors.
3. Finish the experiment as quick as possible since the coil will be overheated by the current flow. If the power supply module provided by PolyU is used, turn off the voltage supply by pressing the red button on the module when not in use.

Procedure

<u>Set up the Experiment</u>

1. Set up the circuit as shown in Fig 2.
2. Connect the Arduino current sensor and hall sensor to a 5V power supply respectively.

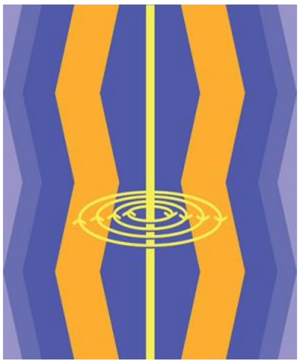

Fig 5

3. Open "Lab in Your Pocket" app in the mobile device and choose "Electromagnetism" (Fig 5).
4. Register the Arduino sensors with the address printed on the sensors (Fig 7). Press "Connect" to connect the sensors (Fig 6). When the connection finishes, the app will automatically jump into a real-time graph of the current in mA and magnetic field strength in microtesla.

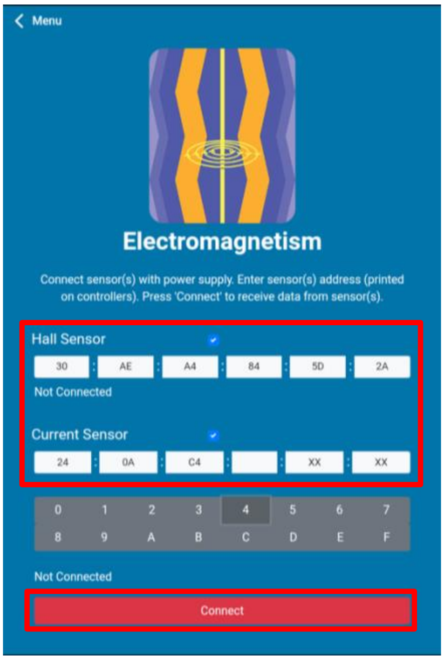

Fig 6

Fig 7

5. Observe the background noise and error from both sensors. Note: The Hall sensor reading DOES NOT represent earth magnetic field. It arises from built-in error of the sensor.
6. Press “Set Zero” button on the app interface to remove offsets (Fig 8 & 9).

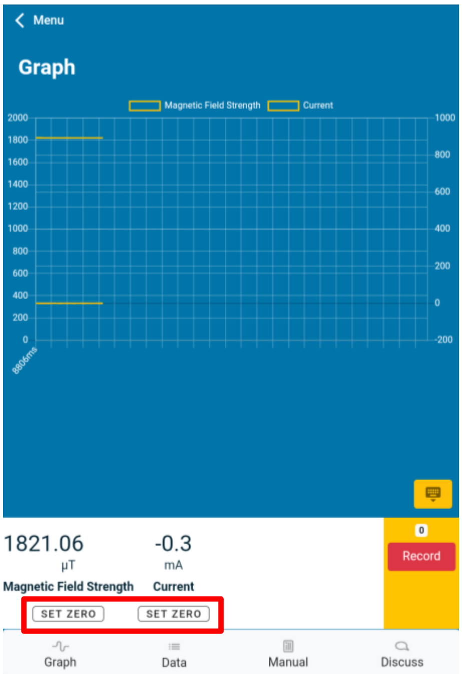

Fig 8

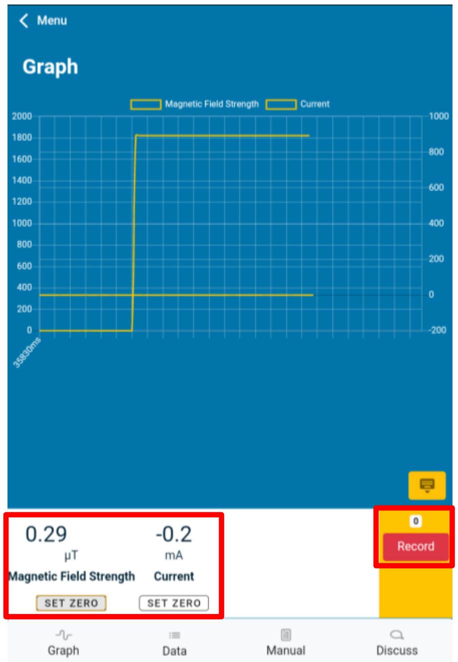

Fig 9

<u>Testing for Solenoid</u>

7. Place the Hall probe at the middle part inside the solenoid with the flat surface lying on the same plane as the opening of the solenoid (Fig 10).
8. Turn on the D.C. power supply with the lowest voltage.
9. Record the instantaneous current and magnetic field values by pressing the “Record” button at the bottom-right corner (number of recorded data point is stated in the bracket).
10. Move the hall sensor inside the solenoid to observe how the magnetic field varies in different position of the solenoid.
11. Optional: Slowly move the Hall sensor away from the solenoid to observe how the magnetic field strength changes.

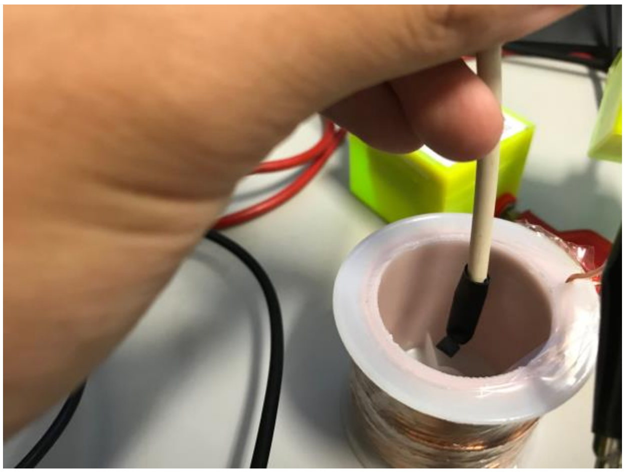

Fig 10

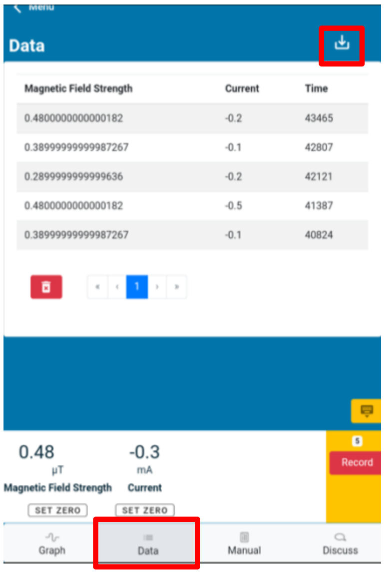

Fig 11

12. Repeat the above steps with increasing current by changing the voltage supply, e.g. 200mA interval, until it reaches 1000mA (to prevent current overflow that may cause danger).
13. Export the data in the “Data” page (Fig 11). Plot the graph in the data sheet and find the relationship between current and magnetic field strength.

Data

<u>Magnetic Field of Solenoid with Different Current</u>

Number of Turns of Solenoid (*N*) = ___________

Length of Solenoid (*L*) in meter = ___________

Number of Turns Per Unit Length (*N*/*L*), i.e. n = ___________

Current *I* (A)	Magnetic Field Strength *B* (μT)

Plot a graph of magnetic field strength *B* against the current *I*.

Discussion

1. What are the sources of background magnetic field? Are they significant to the experiment?
2. For solenoid, what is the relationship of the magnetic field strength against the current *I*?
3. How does the magnetic field vary at different position inside the solenoid?
4. From the slope of the graphs above, you can determine the experimental value of permeability in free space μ_0. What is the value? Compare your experimental value with the theoretical value.
5. What are the possible errors of the experiment? How can we improve to reduce the errors?
6. Optional: How does the magnetic field vary at different position *outside* of the solenoid?