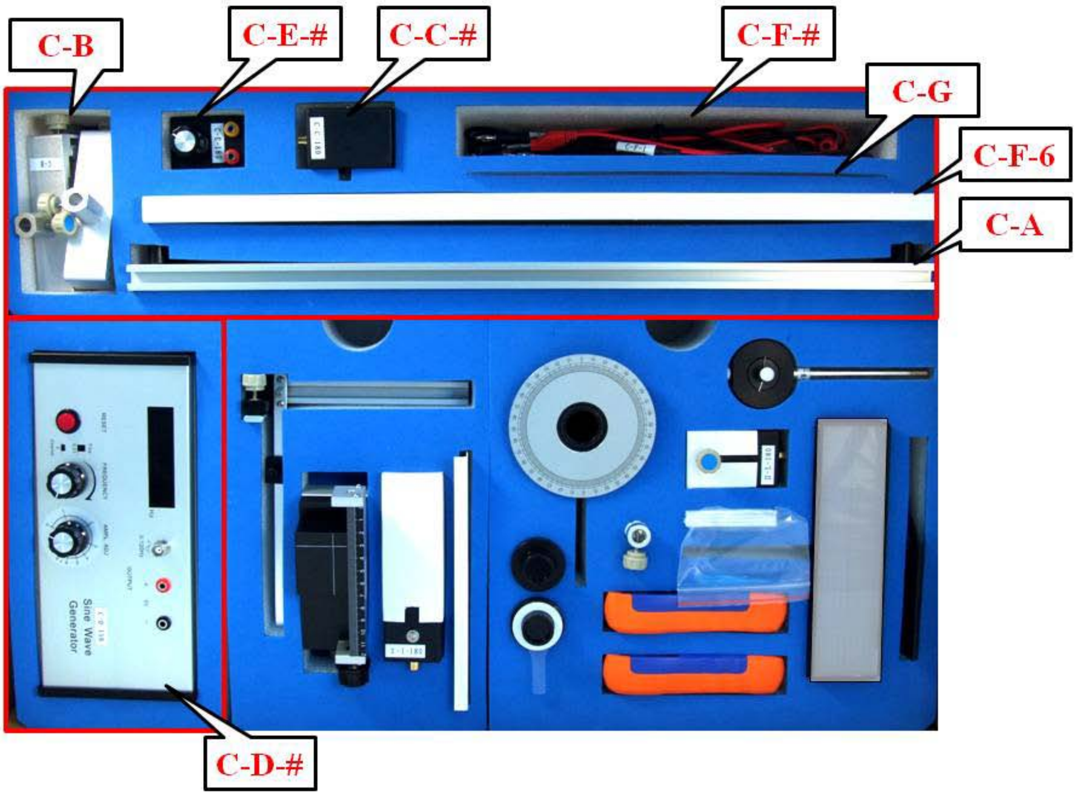
Experimental components

Set-C for common components：

Label	Items	Quantity
C-A	Optical track (60 cm)	1
C-B	Optical clamps	4
C-C-#	Collimated laser diode (CLD)	1
C-D-#	Sine wave generator (sine wave, DC 5V output)	1
C-E-#	Variable resistor (5 kΩ)	1
C-F-#	Connecting wires	4
C-F-6	Component stand	1
C-G	Ruler	1

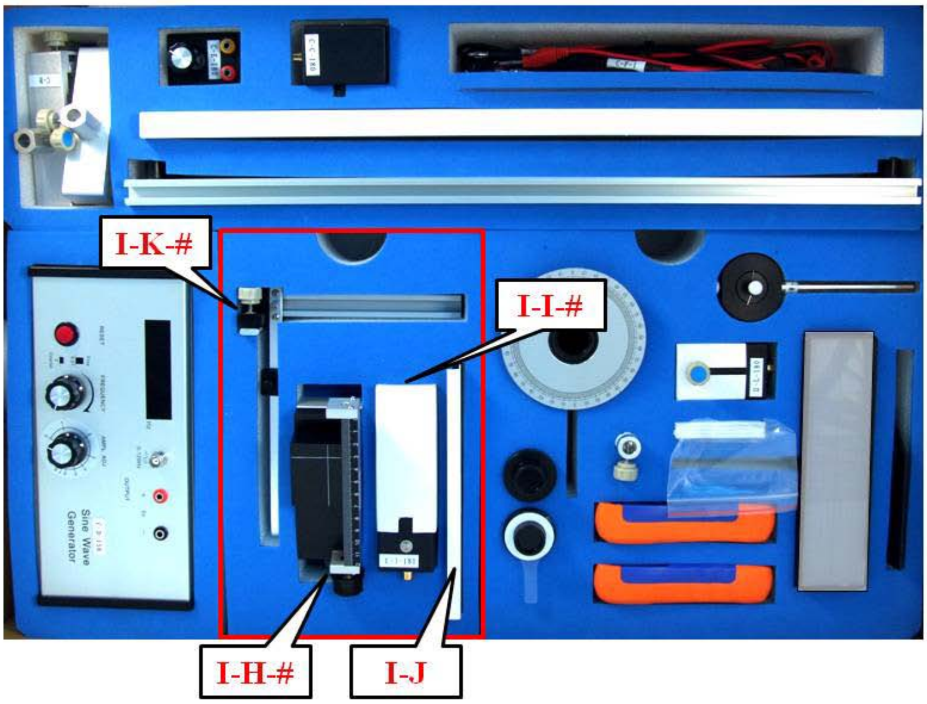
Note: “#” is the serial number for the component. This number is for examiner’s use.



Set-I for Experiment-I

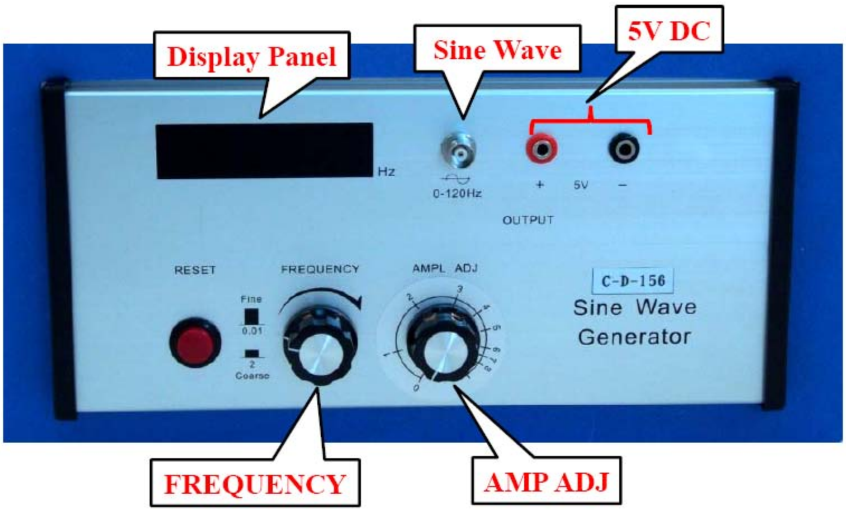
Label	Items	Quantity
I-H-#	Black box on a 1-D translational stage	1
I-I-#	Brass reed attached to a driving box*	1
I-J	Screen for amplitude measurement	1
I-K-#	Vertical slider (with a ruler and a magnet)	1

*The brass reed with a fixed end inside a box is attached to a piezo driven by an AC voltage.



◎ Instructions for the Sine Wave Generator:

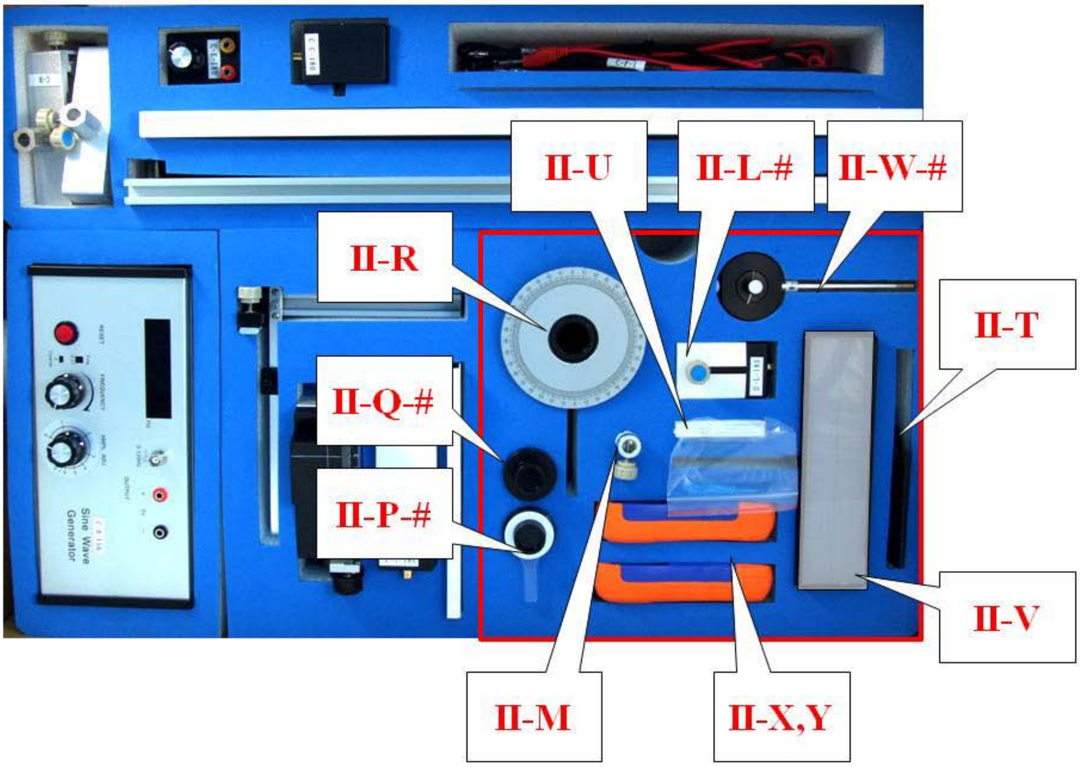
- The power button, not shown in the picture, is on the right-hand side of the instrument.
- The "Display Panel" shows the frequency of the output sine wave.
- Use the "Sine Wave" BNC connector for supplying a sine wave voltage.
- Use the "5V DC" banana connectors for supplying a constant voltage of 5V.
- The frequency of the sine wave can be changed by turning the "FREQUENCY" knob, faster for coarse adjustment and slower for fine adjustment. Ignore the fine and coarse labels next to the "FREQUENCY" knob.
- The amplitude of the sine wave voltage can be adjusted by turning the "AMPL ADJ" knob.
- The "RESET" bottom may be pushed to reset frequency to 0.00 Hz.



Set-II for Experiment -II

Label	Items	Quantity
~~**II-L-#**~~	~~Uncollimated laser diode (ULD)~~	~~1~~
II-M	Holders for ULD	1
II-P-#	Polarizer with indicator (PR2)	1
II-Q-#	Polarizer (PR1)	1
II-R	Holder for PR1 and PR2	1
II-T	Holder for light filter	1
II-U	Light filters	4
~~**II-V**~~	~~Beam viewing box (screen)~~	~~1~~
II-W-#	Photoconductor (PC)	1
II-X	Digital multimeter	1
II-Y	Digital multimeter	1

Items II-L-#, II-M, and II-V are not used.



◎ Instructions for the digital multimeter:

- You can turn the digital multimeter on or off by pressing the power button.
- Use the "VΩ" and the "COM" inlets for voltage and resistance measurements.
- Use the "mA" and the "COM" inlets for small current measurements.
- Use the function dial to select the proper function and measuring range. "V" is for voltage measurement, "A" is for current measurement and "Ω" is for resistance measurement.
- Do not press the "HOLD" button, which will hold the display reading and stop the measurement function. You can release it by pressing the button again.

Experiment I. Magnetic force probe

◎ Introduction

As shown in Fig. I-1, the free end of a reed can oscillate in the vertical direction when it is driven by an external oscillating force, and its frequency is determined by the external driver. If we plot the average power dissipated in the vibrating reed, which has certain damping mechanisms, as a function of frequency, we can find a maximum dissipated power at a certain frequency called the **resonance frequency** f_R, as illustrated in Fig. I-2. The sharpness of the resonance is described by the **quality factor** Q as:

$$Q = \frac{f_R}{\Delta f}$$

where Δf is the full width at half maximum of the P_{av}-f curve, as shown in Fig. I-2, i.e. $\Delta f = f_2 - f_1$ with f_1 and f_2 corresponding to $P_{\max}/2$ on the lower side and the higher side of the resonance frequency respectively.

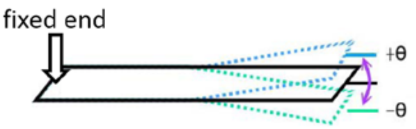


Fig. I-1. A vibrating reed.

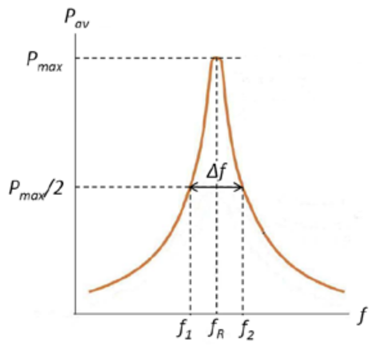


Fig. I-2. Plot of the average dissipated power versus the driving frequency.

Besides the oscillating driving force, if the free end of the reed is subjected to a uniform force, its resonance frequency, amplitude and quality factor remain the same. On the other hand, under a non-uniform force, many properties of the vibrating reed, such as the resonance frequency f_R, the maximum amplitude A, and the quality factor Q, may vary with the position of its free end.

In this experiment, a small magnet adhered to the free end of the reed serves as a probe tip as shown in Fig. I-3, while a target magnet underneath the tip magnet produces a non-uniform magnetic field and exerts a non-uniform force on the tip magnet. When the tip magnet approaches the target magnet underneath with same pole opposing each other, then the repulsive force becomes stronger. Thus the resonance frequency f_R of the reed varies with the distance between the tip magnet and the target magnet. The resonance frequency increases with decreasing separation distance between the two repulsing magnets. However, when moving the tip magnet horizontally away from the target magnet as shown in Fig. I-4, it may sense a weak attractive force at a certain distance. The resonance frequency shifts to lower values when the non-uniform force is attractive. We shall use this property, that the resonance frequency of the reed sensitively depends on the separation between the tip magnet and target magnet, to locate the hidden magnets inside a black box.

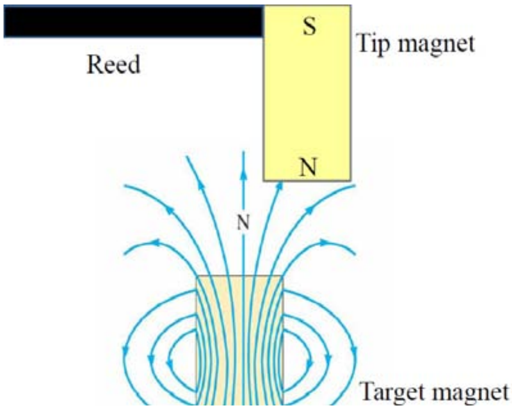


Fig. I-3. Near a pole of a target magnet, the magnetic field is non-uniform.

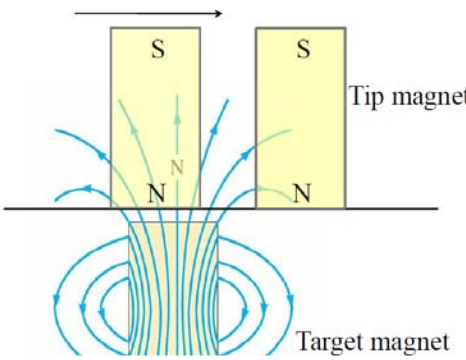


Fig. I-4. Moving a tip magnet horizontally may cause it to sense an attractive or repulsive force.

◎ Experimental procedures

Error analysis is not required in any parts of Experiment I.

Exp. I-A、Measuring the resonance frequency

Carefully take out the experimental components from Set-C and Set-I, and set up the experimental apparatus as shown in Fig. I-A-1. The schematic plot is shown in Fig. I-A-2. Connect the 5V-DC voltage source to the laser box (**C-C-#**). Connect the oscillating output of the sine wave generator to the driving box of the brass reed (**I-I-#**). Turn on the power and fix the output voltage of the sine wave generator. Direct the laser beam into the mirror at the free end of the brass reed so that the reflected beam spot on the screen (**I-J**) can be used to determine the vibrating amplitude of the reed.

Caution: 1) Carefully remove the paper protected cover before using the brass reed (**I-I-#**) for experimental measurements. The resonance frequency of the brass reed is very sensitive to its shape, and any deformation of reed during the experiment may give an inaccurate result.

2) Do not directly look into the laser beam, which can damage your eyes.

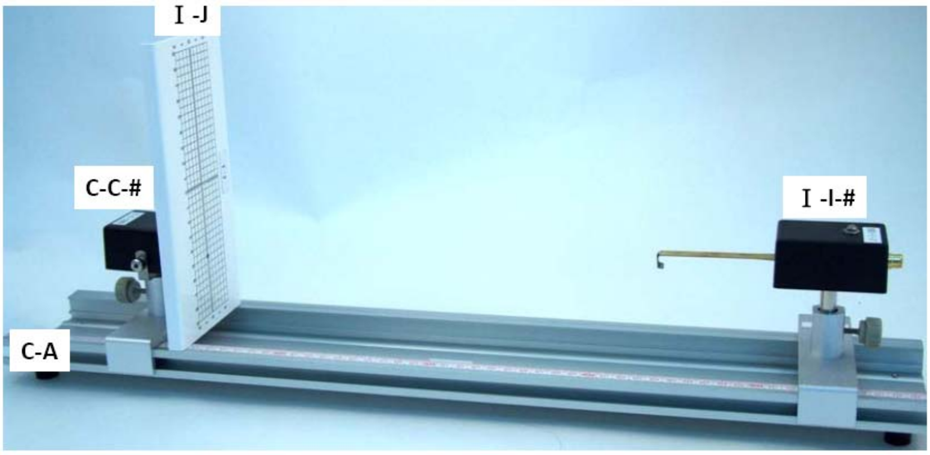


Fig. I-A-1. Experimental setup for finding the resonance frequency.

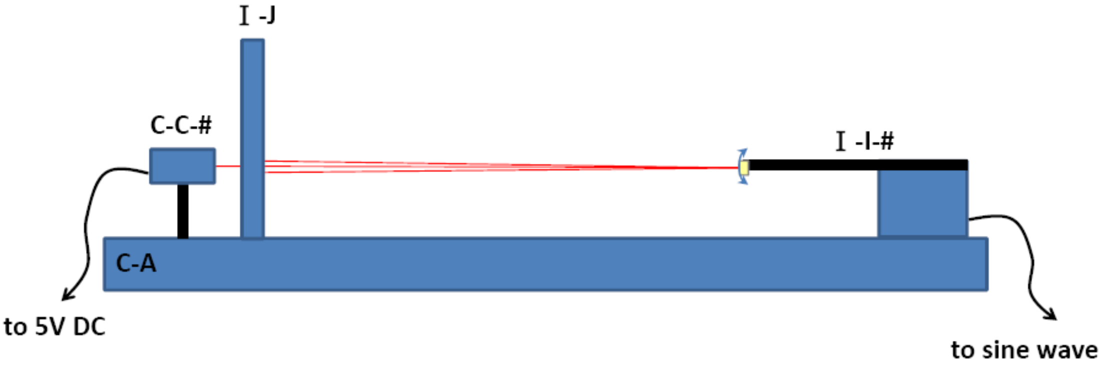


Fig. I-A-2. The schematic plot of Fig. I-A-1.

(1) Measure the amplitude A of the oscillating laser beam spot by changing the frequency of the sine wave generator. Record the measured amplitude as a function of frequency in the data table on the answer sheet. **(0.8 points)**

(2) Make a proper plot on one of the supplied graph papers to determine the resonance frequency f_{RO} and quality factor Q. Also record the obtained f_{RO} and Q in the proper blank spaces on the answer sheet. **(1.2 points)**

Exp. I-B、Resonance frequency versus the external force.

In this part of experiment, the resonance frequency under the influence of a non-uniform force is investigated. The non-uniform force is provided by a small 3-mm cylindrical metallic calibration magnet M_C fixed on a vertical slider (**I-K-#**) with its N pole pointing upward. The tip magnet M_T, adhered at the free end of the oscillating reed, has its N pole pointing downward. The pole axes of both magnets should be aligned along the same vertical line.

Set up the experiment as shown in Fig. I-B-1. The schematic plot is shown in Fig. I-B-2.

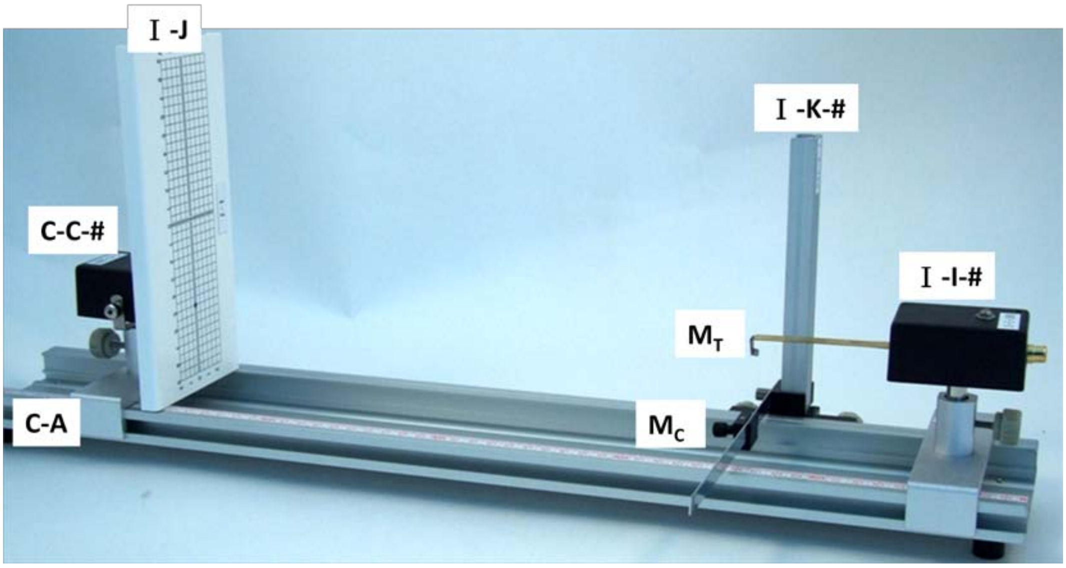


Fig. I-B-1. Experimental setup of finding the relation of resonance frequency with the nominal distance between two magnets, M_C and M_T.

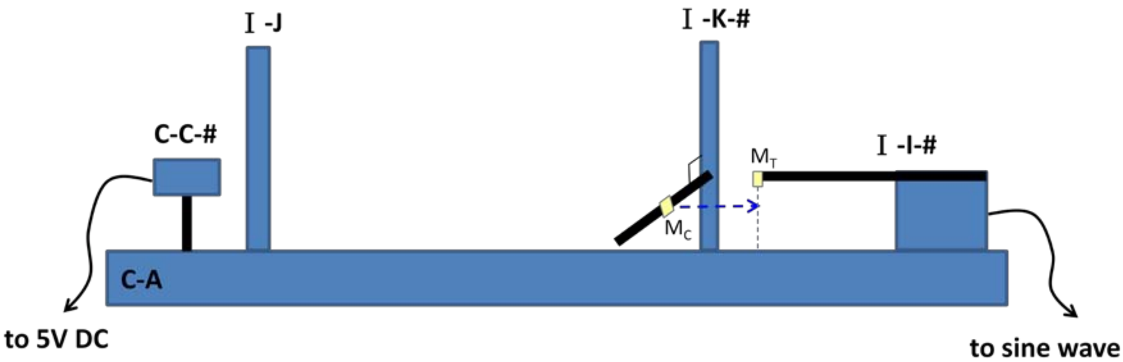


Fig. I-B-2. The schematic plot of Fig. I-B-1.

(1) On the scale of the vertical slider, read out the position z_0 of the bottom plane for the tip magnet M_T without the interaction of M_C by properly moving M_C away from M_T. Record the measured z_0 in the data table. **(0.2 points)**

(2) Adjust the position of the magnet M_C to be right underneath M_T. The pole axes of both magnets should be aligned along the same vertical line. Determine the position z of the top plane of the N-pole of M_C. Calculate the nominal distance d by defining $d = z_0 - z$. Record z and d in the data table. (Note: The equilibrium separation between the two magnets is not the same as d because the two magnets repel each other.)

(3) Determine the resonance frequency f_R for the distance d by tuning the frequency of

the sine wave generator until the maximum amplitude is reached, plotting amplitude versus frequency is not necessary for determining f_R of each distance *d*. Record the determined resonance frequency f_R in the data table.

(4) Change the vertical position of the magnet M_C and repeat the steps (2) and (3) for a number of measurements of different distance d and the corresponding resonance frequency f_R. **(1.2 points)**

(5) Plot a graph of f_R as a function of distance d using a graph paper. Guiding by eyes, draw the best line through the data points. **(1.2 points)**

(6) Define $\Delta f_R = f_R - f_{RO}$, and plot $\ln(\Delta f_R)$ as a function of d using another graph paper. Guiding by eyes, draw the best line through the data points. **(1.0 points)**

Exp. I-C、Finding the positions and depths of the magnets inside a black box.

There are two magnets M_A and M_B buried in the black box (I-H-#) which is fixed on a 1D translational stage. The N poles of both magnets are pointed upward. Magnets M_A and M_B, and M_C used in **Exp. I-B** are very close in size, shape, and magnetic properties. The depths of the magnets M_A and M_B may be different. Magnet M_A is located at the intersection of the two lines marked on the top surface of the black box. Magnet M_B is located somewhere along the longer line as shown in Fig. I-C-1. The horizontal distance between magnets M_A and M_B is denoted by $\overline{AB}$.

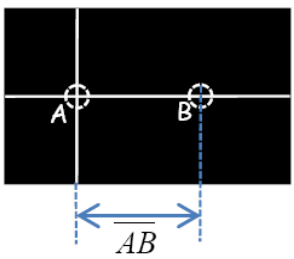


Fig. I-C-1. Magnet M_A is located beneath the intersection of the two lines marked on the top surface while the magnet M_B is located somewhere along the longer line.

(1) On the scale of the vertical slider, read out the position z_0 (in this part, z_0 may be different from the z_0 in Exp. I-B) of the bottom plane for the tip magnet M_T without the interaction of the magnets inside the black box. On the scale of the vertical slider, read out the position z_{box} of the top plane of black box. Record z_0 and z_{box} on the answer sheet. **(0.2 points)**

(2) Move the black box along the longer line and observe the variation in resonance frequency f_R of the reed to find the position of M_B. Record the measured distances y and their corresponding resonance frequencies f_R in the data table. **(1.4 points)**

(3) Plot f_R as a function of y on a graph paper to determine the position of magnet M_B. Mark the positions of magnets M_A and M_B on the y-axis of your graph, and write down the value of $\overline{AB}$ on the answer sheet. **(1.2 points)**

(4) Determine the depths d_A and d_B of the magnets M_A and M_B from the top surface of the black box using the results in Exp. I-B. Write down the values of d_A and d_B on the answer sheet. **(1.6 points)**