4. Operation of Apparatus

Upon receipt of the apparatus, the CRT and longitudinal coil need to be installed following these steps:

a) Ensure the power of the apparatus is off (**<u>Warning</u>**: handle the fragile CRT with care!);

b) Align the pins of the CRT with the holes on the socket and insert it into the socket;

c) Use one hand to hold the CRT horizontally, use another hand to hold the longitudinal coil horizontally and rotate it a small angle axially;

d) Slip the coil onto the CRT completely.

e) When the bakelite (or ceramic) end of the coil reaches the two positioning slots of the plastic blocks on the panel, rotate the axis of the coil back to let the bakelite (or ceramic) frame sit into the two positioning slots.

f) Check if the coil is mounted firmly and is stable. Place the division plate (also on a bakelite (or ceramic) frame) in front of the coil and push the locking mechanism to make the division plate close to the coil.

g) Connect the coil to current source (i.e. "Current Output" terminals) with the black and red wires with correct polarity.

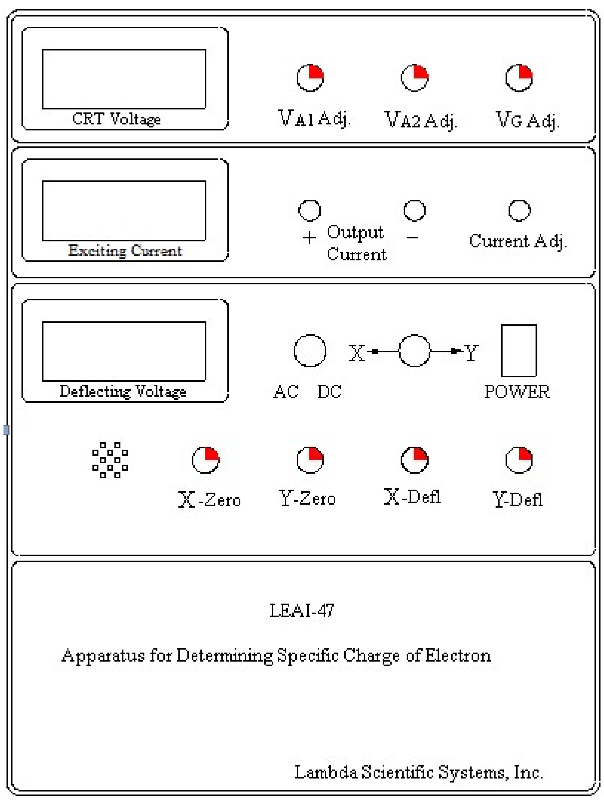

Figure 13 Schematic diagram of front panel

As seen in the schematic of the front panel of the apparatus shown in Figure 13, the panel is divided into three blocks. The top block is used to let electrons gain an initial velocity v_0, while achieving a good focusing effect of electrons. The second block is used to adjust the magnetic field strength of external magnetic induction coils. The third block is used to adjust X- and Y-deflecting voltages.

Voltage display meter shows V_{A2} of the CRT in real time while V_{A1}, V_{A2} and V_G can be adjusted through corresponding adjustment knobs. V_G: changing the electron amount hitting the screen (grey level); V_{A2}: changing the electron speed hitting the screen (brightness); V_{A1} and V_{A2}: focusing electrons hitting the screen (used in combination).

Note: V_G and V_{A2} cannot be set too high, as otherwise the screen life could be reduced.

"Current Output" terminals are used to provide current for the solenoid coil (the large coil) with connection polarities of red-to-red and black-to-black. "Current Adj." knob is used to adjust the current of the solenoid coil (or the transversal coils- small coils, if connected) displayed on the current meter.

Warning: the longitudinal coil (large coil) and the transversal coils (two small coils) cannot be connected simultaneously to the current source, as otherwise the coils could be burned!

The AC/DC selection switch has three positions, AC, DC, or no voltage output for deflection electrodes, respectively. At AC, an AC voltage is applied to Y-deflection electrodes; at DC, a DC voltage is applied to both X- and Y-deflection electrodes. The X and Y selection switch is used to display the DC deflection voltage applied to X-deflection electrodes or Y-deflection electrodes, which can be adjusted with "X-Deflect" or "Y-Deflect" knobs, respectively. When no voltage is applied to either X- or Y-deflection electrodes, "X-Zero" and "Y-Zero" knobs can be used to bring the bright spot to the center of the screen (the origin point).

5. Experimental Contents

5.1 Electron beam in transversal electric field: measure deflection sensitivity

1) The previously mounted solenoid coil (large coil) does not need to be disconnected, but no excitation current should be provided to the coils at present. Turn on the power.
2) Adjust V_G, V_{A1} and V_{A2} to focus the electron spot with moderate brightness. **Warning**: high brightness is harmful to the screen. Note: in case no spot can be observed on the screen by adjusting V_G, V_{A1} and V_{A2} extensively, please place the AC/DC selection switch at DC and adjust "X-Zero" and "Y-Zero" knobs to find the bright spot and bring the bright spot onto the screen.
3) Place the AC/DC selection switch at DC while adjusting "X-Deflect" and "Y-Deflect" knobs to zero deflection voltage displayed on the meter.
4) Adjust "X-Zero" and "Y-Zero" knobs to bring the bright spot to screen origin.
5) Adjust "X-Deflect" and "Y-Deflect" while measuring the relationship between deflection voltage and deflection displacement in the transversal electric field in X and Y directions. A linear relationship between the transverse electric field strength and the deflection displacement should be obtained with the slope representing the electric deflection sensitivity which is a function of the accelerating voltage, or the velocity of the electron.

5.2 Electron beam in longitudinal electric field: observe electric focusing phenomenon

1) Adjust "V_G" knob while observing the influence of the voltage at grid *G* relative to cathode *K* on spot brightness. Adjust the focusing knob, i.e. voltage V_{A1} of the 1st anode, to change

the focal length of the lens. Adjust auxiliary focusing A_2, i.e. voltage V_{A2} between electrode G' and the 2nd anode A_2, for focusing. **Note**: do not make the spot too bright as otherwise the screen life could be reduced.

2) Adjust focusing and auxiliary focusing knobs to optimize electron beam focusing. Use (9) to calculate focal length f with the parameters given in Figure 14. **Note**: in Figure 14, the parameters are only for reference, actual parameters for individual CRT may vary.

It is assumed the center of the lens is at the middle point of electrodes G' and A_2, and the 1st focused point is at the middle point of electrodes G and G'. So, we have:

Object distance: μ = (2+22+14)/2 + 3/2 = 20.5 (mm),
Image distance: v =191-(2+22+14)/ 2 =172 (mm).
Using Eq. (9), we get focal length $f \approx 18.32$ mm.

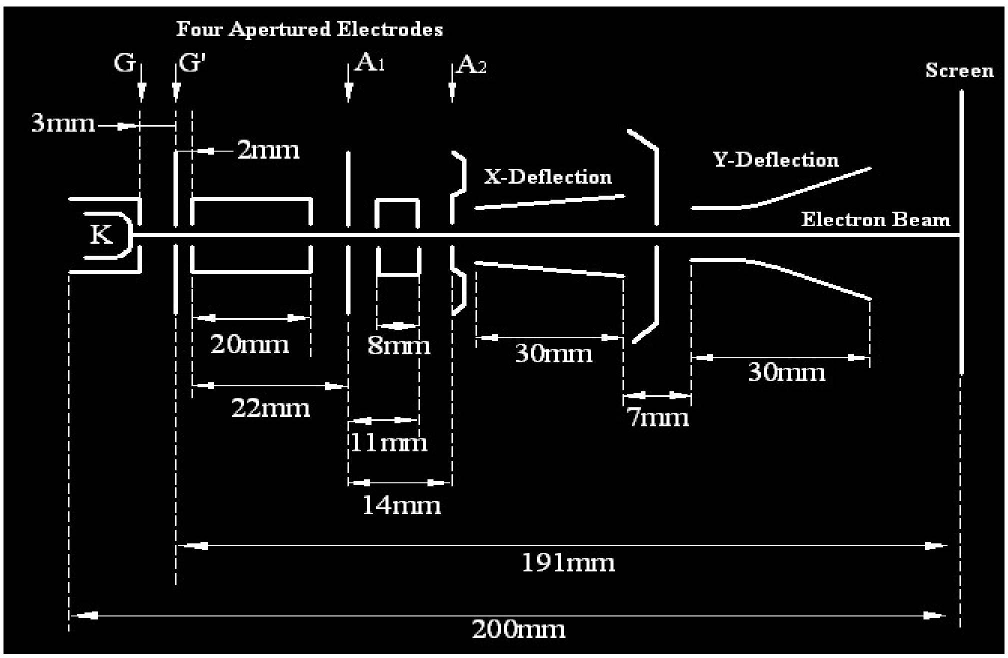

Figure 14 Internal structure of CRT

5.3 Measure the horizontal component of geomagnetic field

1) With the aid of a compass, place the CRT parallel to the North-South direction. Turn on the power. Set AC/DC selection switch to DC while adjusting "X-Deflect" and "Y-Deflect" to set deflection voltage to zero. Adjust "X-Zero" and "Y-Zero" to bring the bright spot to screen origin.

2) Orientate the apparatus by 90° so that the CRT is parallel to the East-West direction while recording spot deflection value D_1. Rotate the apparatus by 270° while recording deflection value D_2. Let D equal to the average of D_1 and D_2.

3) Use formula (19) to derive B, where l is the distance between acceleration electrode and screen (l= 0.153 m for this apparatus).

5.4 Electron beam in transversal magnetic field: measure magnetic deflection sensitivity

1) Turn off power. Set the CRT along North-South direction with the aid of a compass;

2) Disconnect the two connection wires of the large coil from "Current Output" terminals. Install two transversal deflection magnetic induction coils (two small coils);

3) Turn on power. Set AC/DC selection switch to DC while adjusting "X-Deflect" and "Y-Deflect" to set deflection voltage to zero. Adjust "X-Zero" and "Y-Zero" to bring the electron spot to screen origin. Or place the AC/DC selection switch at the middle position (no voltage), while adjusting "X-Zero" knob to bring the electron spot onto the origin vertical line of the screen.

4) Apply a certain acceleration voltage V_2 (i.e. V_{A2}) while adjusting "Current Adj." knob to change the magnetization current I of the magnetic induction coil. Measure deflection displacement S versus current I. A linear relationship between S and I should be obtained with the slope representing magnetic deflection sensitivity that is a function of the velocity of the electron.

5.5 Electron beam in longitudinal magnetic field: measure e/m using magnetic focusing

To observe the spiral phenomenon of electron in a magnetic field, voltages V_{A1} and V_{A2} of 1st anode and 2nd anode are adjusted to focus the electron beam emitted from cathode K on the screen of the CRT. Next, a proper AC voltage is applied to Y-deflection electrodes (vertical) to form the electron beam to a segment of bright line in Y direction on the screen. Finally, a longitudinal magnetic field is introduced making the electron beam undertake spiral motion in the CRT. Therefore, when the axial magnetic field increases from zero, the bright line segment on the screen shortens while rotating until the pitch of the spiral trajectory equals the distance between the Y-deflection electrode and the screen, L'. Now, the electron beam is focused onto a bright spot. Under such condition, e/m can be calculated from V_{A2}, B, and L'.

1) Turn off power. Dismount the two small coils. Connect the longitudinal coil with current source (terminals: red to red and black to black). **Warning**: make sure the small coils are removed;

2) Turn on the power. Place the AC/DC selection switch at the middle position (no voltage), adjust "X-Zero" knob to bring the bright spot onto the vertical line in the screen center. Adjust V_G, V_{A1} and V_{A2} knobs to get moderate spot brightness on the screen. **Note**: by adjusting either V_G or V_{A2}, the voltage displayed on the voltage meter changes accordingly, since the displayed voltage is the potential difference between V_G and V_{A2};

3) Place the AC/DC selection switch to AC, adjust "Y-Deflect" (or "Y-Zero") knob to achieve a bright line in the screen center with moderate length and brightness;

4) Adjust "Current Adj." knob to gradually increase the excitation current from zero while observing the change of the bright line on screen (the segment will shorten while rotating until being focused onto a bright spot, record the excitation current as I_1). Continue to increase current until a bright spot is observed for the second time and record the excitation current as I_2. Continue to increase current until a bright spot is observed for the third time and record the excitation current as I_3 and the accelerating voltage as V_{A2}. **Note**; the 2nd and 3rd focusing spots may not be perfectly round as long as they are the brightest and sharpest). The equivalent excitation current for one focusing is:

$$I = \frac{I_1 + I_2 + I_3}{1 + 2 + 3} \tag{34}$$

5) Use (29) to derive B, and substitute it to (26) to derive e/m using the following parameters of $d=L'=0.153$ m, $K=0.8$, and $N=1160$ while referring the label on the apparatus to find L.

6) To eliminate the effect of geomagnetic field on e/m measurement, the solenoid can be orientated in East-West direction; or the excitation current can be reversed by averaging the measurement data from both current directions.

7) To enhance the measurement accuracy, V_{A2} can be measured for several times, and then the averaged V_{A2} should be used.

Warning:

1) Do not supply large current to the magnetic induction coil (large coil) for a long time;

2) Large and small coils cannot be connected to current source simultaneously;

3) Do not open the cover panel of the apparatus when powered on due to internal high voltage.

6. Examples of Data Recording and Processing

Note: Following data are for reference only, not the criteria for apparatus performance.

6.1 Electron beam in transversal electric field: measure electric deflection sensitivity

Accelerating voltage V_{A2} = 674 V					
D_X, D_Y (mm)	V_X (V)	V_Y (V)	D_X, D_Y (mm)	V_X (V)	V_Y (V)
-20	-32.8	-16.1	4	5.8	3.3
-16	-25.7	-13.2	8	11.9	7.0
-12	-20.2	-9.8	12	18.5	10.7
-8	-13.5	-6.6	16	24.7	14.1
-4	-6.4	-3.0	20	31.4	17.5
0	0	0			

Using the data in the above table, D_X~V_X, and D_Y~V_Y relationship curves are plotted in Figure 15.

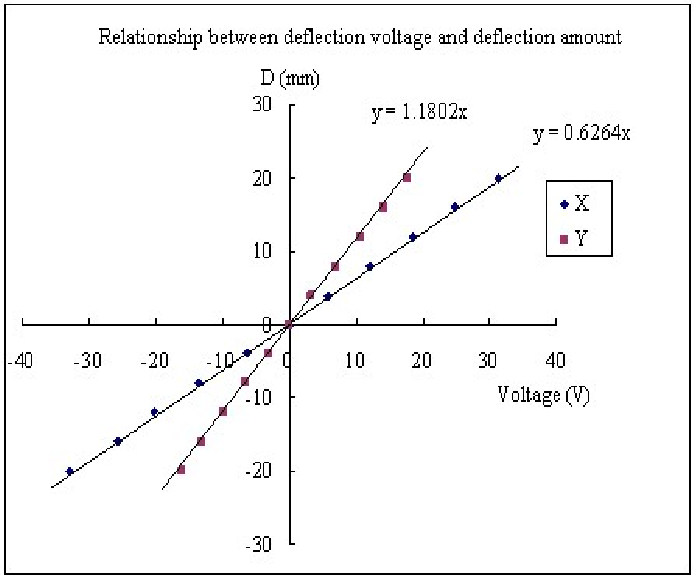

Figure 15 D_x~Vx/D_Y~V_Y curves

It is apparent from Figure 15 that the deflection displacement of electron beam is proportional to the deflection voltage with the slope representing the deflection sensitivity calculated below:

$$\delta_{ex} = \frac{D_{X1}}{V_{X1}} = k_{X1} = 0.63 \text{ mm/V}$$

$$\delta_{ey} = \frac{D_{Y1}}{V_{Y1}} = k_{Y1} = 1.18 \text{ mm/V}$$

6.2 Electron beam in longitudinal electric field: observe electric focusing phenomenon

Optional.

6.3 Measure the horizontal component of the geomagnetic field

	1	2	3
D_1 (mm)	4.0	4.0	3.9
D_2 (mm)	3.8	4.2	4.0
$D = (D_1+D_2)/2$	3.9	4.1	4.0
$\overline{D} = \frac{3.9+4.1+4.0}{3} = 4.0$ (mm)			

$V_2 = V_{A2} = 1140$ V, $l = 0.15$ m, $m = 9.11\times10^{-31}$ kg, $e = 1.60\times10^{-19}$ C.

From (19), we get: $B = \frac{2D\sqrt{2meU_2}}{el^2} \approx 4.1\times10^{-5}$ T = 0.41 G.

6.4 Electron beam in transversal magnetic field: measure magnetic deflection sensitivity

S (mm)	0	4	8	12	16	20	24	28	32
I (A)	0	0.04	0.09	0.13	0.18	0.22	0.26	0.31	0.35

(accelerating voltage V_2 = 837 V)

From the data in the above table, S~I curve is plotted below:

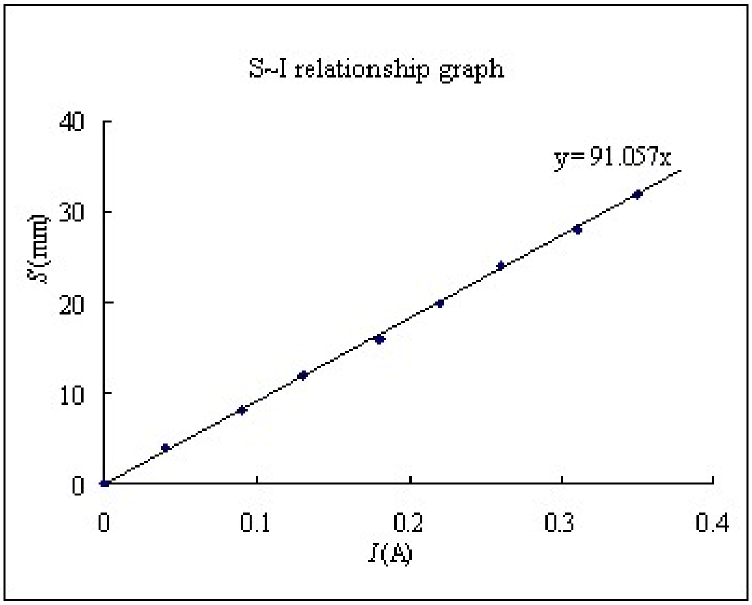

Figure 16 S~I curve

It is apparent from Figure 16 that there is a linear relationship between deflection displacement S and magnetic field current I with the slope representing the magnetic deflection sensitivity as calculated below

$$\delta_m = \frac{S}{I} = 91 \text{ mm/A}$$

6.5 Electron beam in longitudinal magnetic field: measure e/m using magnetic focusing

The parameters of apparatus: L'= 0.153 m, K = 0.8, N = 1160, and L = 0.205 m.

	1	2	3
I_1 (A)	0.63	0.69	0.64
I_2 (A)	1.28	1.41	1.28
I_3 (A)	1.81	1.97	1.85
$\bar{I}$ (A)	0.62	0.68	0.63
V_{A2} (V)	686	855	680
B (10^{-3} T)	3.53	3.87	3.58
e/m (10^{11} C/kg)	1.85	1.92	1.79
Average: $\overline{e/m}$ = (1.85+1.92+1.79)/3 ≈ 1.85×10^{11} C/kg			
Relative Error: η = [(1.85-1.76)/1.76]×100% ≈ 5%			

Reference physics constants:

$\mu_0 = 4\pi\times10^{-7}$ H/m $= 1.257\times10^{-6}$ H/m
$\varepsilon_0 = 1/36\pi\times10^{-9}$ F/m $= 8.854\times10^{-12}$ F/m
$k = 1.381\times10^{-23}$ J/K

$c = 2.998\times10^{8}$ m/s
$e = 1.602\times10^{-19}$ C
$m_e = 9.110\times10^{-31}$ kg
$e/m_e = 1.759\times10^{11}$ C/kg
1T (Tesla) = 10^4 G (Gauss)