UNITED SCIENTIFIC SUPPLIES, INC.

OPERATING INSTRUCTIONS AND ACTIVITY GUIDE

LORENTZ FORCE DEMONSTRATOR

LFD001

Figure 1

GENERAL DESCRIPTION

The LFD001 Lorentz Force Demonstrator is a “fine beam tube” device in which a sharply focused electron beam is projected into a vacuum containing a trace of inert gas. Ionization of the gas around the electron beam creates a glowing discharge marking the path of the electrons and helping to maintain the sharp focus of the beam. The demonstrator shows deflection of the beam by transverse electric fields and by magnetic fields of various orientations. The value of *e/m* can be found by bending the electron beam into a circular path with a homogeneous magnetic field and measuring the accelerating voltage of the electron gun, the strength of the magnetic field, and the radius of the circular beam path. The components of the device are shown in *Figure 1*:

1. “Fine beam” vacuum tube
2. Helmholtz coils
3. Transparent metric ruler
4. Angle scale and pointer for tube
5. Current direction indicators
6. Accelerating and deflection voltage controls
7. Power and coil current controls
8. Accelerating voltage and coil current meters
9. Mirror for parallax elimination
10. Case with black interior for better visibility

SPECIFICATIONS

Fine beam vacuum tube	Diameter: 160mm Rotation: tube and socket rotate ±180° Angle scale: 0° — ±180° x 5° Accelerating voltage: 250V max.
Helmholtz coils:	Coil mean diameter: 280mm Coil separation: 140mm 140 turns per coil Max. current: 2.5A
Power supply unit:	Accelerating voltage: 0—250V dc Coil current:0.5—2.5A, reversible, with current direction indicators Electrostatic deflecting voltage: 50—250V, reversible Accuracy of meters: ≤ ±2.5% Power input: 110VAC 60Hz, 45W
Maximum continuous operation:	1 hour
Operating conditions:	Temperature:0 – 40°C, Humidity: 20 –80%
Dimensions:	35cm x 30cm x 45cm (l x w x h)
Weight:	11kg

CONTROLS

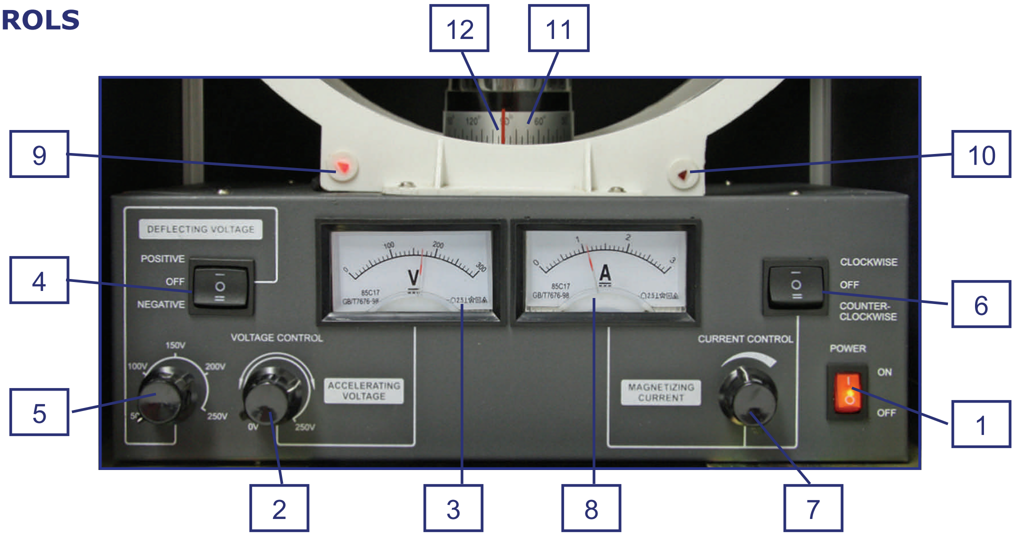

Figure 2

Figure 2 shows the front panel of the power supply unit:

1. Power on/off switch
2. Accelerating voltage adjustment knob
3. Accelerating voltage meter
4. Deflection voltage on/off/reverse switch
5. Deflection voltage adjustment knob
6. Coil current on/off/reverse switch
7. Coil current adjustment knob
8. Coil current meter
9. Coil current direction indicator – clockwise
10. Coil current direction indicator – counter clockwise
11. Angle scale for vacuum tube
12. Pointer for angle scale

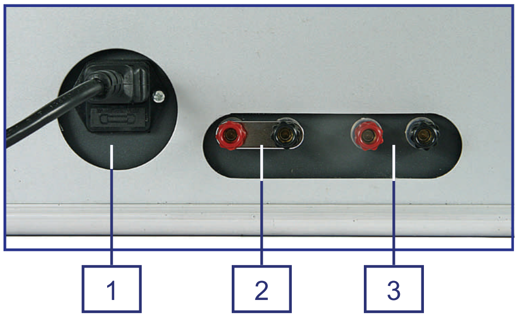

Figure 3

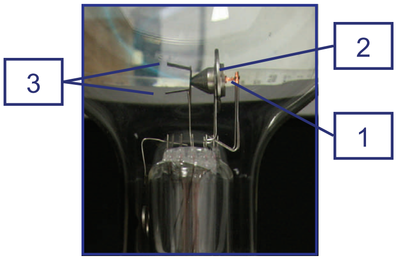

Figure 4

Figure 3 shows connections on the rear panel of the demonstrator:

1. Power socket and fuse holder
2. Binding posts for connecting an external ammeter to measure the coil current more accurately (built-in meter accuracy: ≤± 2.5% f.s.d., range:0—3A d.c.). These binding posts should be shorted together when not in use, otherwise the coil circuit will be open.
3. Binding posts for connecting an external voltmeter to measure the accelerating voltage more accurately (built-in meter accuracy: ≤± 2.5% f.s.d., range:0—300V d.c.).

Figure 4 shows the electron gun assembly:

1. Filament/cathode assembly. Light is visible when the filament is energized. On startup, the filament/cathode assembly should be allowed to warm up for 5 minutes before applying an accelerating voltage.
2. Accelerating anode.
3. Electrostatic deflection plates.

THEORY:

The Lorentz fine beam tube is a vacuum tube containing small amount of inert gases, an electron gun, and a pair of deflection plates. When the appropriate voltages are applied to the tube, the electron gun emits a beam of electrons. Electron collisions with the gas molecules excite the gas molecules and produce light emission in a cylindrical sheath around the electron beam as the excited molecules relax, rendering the electron paths visible.

The Helmholtz magnetic field arrangement consists of a pair of identical ring coils connected in series and placed parallel to each other at a separation of one coil radius. When a current I flows in the coils, it produces a fairly homogeneous magnetic field in the central region between the coils, with a magnetic induction B given by:

$$B = 9 \times 10^{-7}\ n\ I / R = 9 \times 10^{-4}\ I \text{ for this apparatus} \qquad (1)$$

where n is the number of turns on the coil, I is the magnetizing current in amps, R is the radius of the coil in meters, and B is given in Tesla.

In the magnetic field produced by Helmholtz coil, the electron beam will be subject to a force **F** known as Lorentz force:

$$\mathbf{F} = e.\mathbf{V}\times\mathbf{B} \qquad (2)$$

its magnitude is

$$F = e.v.B.\sin\alpha \qquad (3)$$

Where F is the Lorentz force on an electron, e is the charge of the electron, v is the velocity of the electron, B is the strength of the magnetic field, and α is the angle between the direction of the electron's velocity vector and that of the magnetic field.

When the Lorentz tube is rotated so that the electrons and the magnetic field are in the same direction ($\alpha = 0$) or opposite directions ($\alpha = 180°$), the electrons are not subject to any force. Their path will be a straight line.

When the direction of the electrons is perpendicular to that of the magnetic field, the Lorentz force will take its maximum value and will be directed perpendicular to both the direction of the electrons' velocity and the magnetic field. In equation (3), when both v and B are constant, F will be constant and the Lorentz force will serve as a centripetal force, producing a circular motion of the electrons (see *Figure 5*). The radius of the circle depends on the magnitude of the force, which is in turn determined by the magnetic field and hence by the magnetizing current.

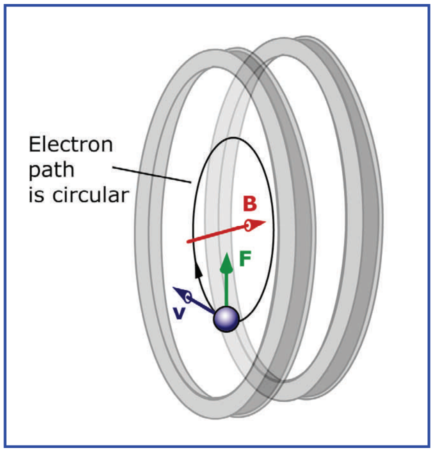

Figure 5

When α assumes a value other than 0 or 180°, the motion of the electrons can be decomposed into to two parts: a motion parallel to the magnetic field and one perpendicular to it. The parallel component, which is not subject to the Lorentz force, will be a straight line, while the perpendicular component will result in a circular motion under the Lorentz force. The resultant of these two motions will be a spiral.

The centripetal force on electrons in a uniform circular motion can be expressed as mv^2/r, where m is the mass of the electron and r is the radius of the circular trajectory. As discussed above, the centripetal force is provided by the Lorentz force, so: