3. Working Principle

This optical pumping apparatus consists of 5 portions including a main unit, a power supply, an auxiliary source, a RF signal generator (supplied by user), and an oscilloscope (supplied by user). Figure 2 shows the schematic diagram of the system configuration.

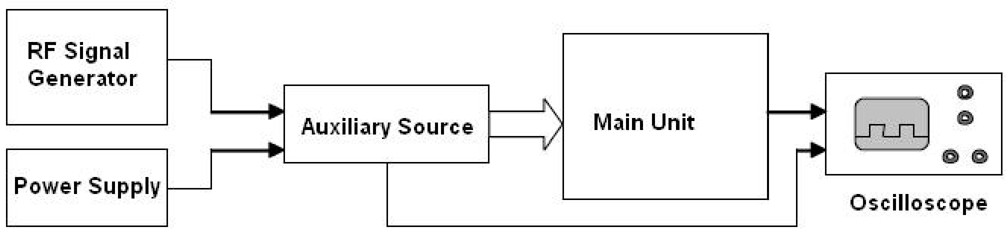


Figure 2 Schematic diagram of apparatus configuration

1) Main unit

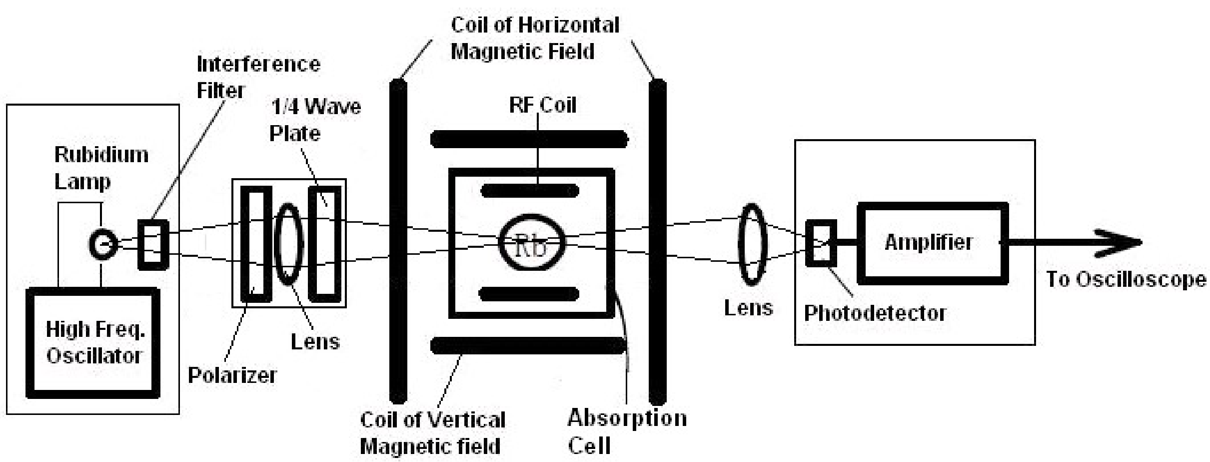


Figure 3 Schematic of main unit

The main unit is the core of the experimental apparatus, as shown in Figure 3. It consists of a rubidium (*Rb*) spectral lamp, a collimating lens, an absorption cell, two sets of Helmholtz coils, a condenser, and a photo-detector.

As shown in Figure 3, natural *Rb* and inert gases are filled in a glass bulb with a diameter of about 52 mm, which is placed between a pair of small RF coils providing a RF magnetic field for the transitions of *Rb* atoms. Both *Rb* bulb and RF coils are kept in a temperature controlled cylinder called “absorption cell”, which is placed at the center of two pairs of Helmholtz coils, with temperature controlled at approximately 55 °C. The small pair of Helmholtz coils is used to offset the vertical component of the earth's magnetic field. The large pair of Helmholtz coils has two groups of coil windings. One is to generate a horizontal magnetic field for Zeeman splitting of the hyperfine energy levels of *Rb* atoms; the other is to generate a sweep field superposed to the DC magnetic field created by the horizontal Helmholtz coils.

The *Rb* spectral lamp acts as the pumping source. There are two lenses in the light path, a collimating lens and a condenser with identical focal length of 77 mm. The interference filter, mounted on the output port of the *Rb* spectral lamp, selects the spectral line (λ=7948 A) from the *Rb* spectral lamp. The polarizer and the $\lambda/4$ plate, assembled together with the collimating lens, circularly polarize the light. Since polarized light has different transition probabilities for ground state hyperfine Zeeman energy levels, large population difference between these levels can be achieved. If applying a RF magnetic field of specific frequency, the phenomenon of "optical pumping" or "optical magnetic resonance" will occur. Thus, light intensity in the resonant zone is weakened due to *Rb* atomic absorption, which can be detected by the photo detector by using magnetic field modulation method, and further displayed on the oscilloscope.
As a high-frequency gas-discharge lamp, the *Rb* spectral lamp is composed of a high-frequency oscillator, a temperature control device, and an *Rb* bulb. The *Rb* bulb, placed in the inductance coil of a high-frequency oscillation circuit, emits light through electrodeless discharge excited by a high frequency electromagnetic field. The oscillator and the *Rb* bulb are kept inside the same cavity with temperature controlled at around 90 °C. The frequency of the high-frequency oscillator is approximately 65 MHz.

2) Power supply

The power supply provides three DC power sources for the main unit, an adjustable stabilized-current source from 0 to 1 A for the horizontal magnetic field, an adjustable stabilized-current source from 0 to 0.5 A for the vertical magnetic field, and a 24V/2A regulated power supply for the *Rb* spectral lamp, the temperature control circuit, and the sweep field.

3) Auxiliary source

The auxiliary source provides triangle wave, square wave, and temperature control circuit for the main unit. There is an "Ext. Sweep" (external sweep) socket that can be connected to the sweep signal output of the oscilloscope. The jagged sweep signal can be used to substitute the internal sweep signal of the auxiliary source. The auxiliary source is connected to the main unit by a 24-pin cable.

4) RF signal generator

The RF signal generator used for this apparatus is supplied by user, with frequency range from 10 kHz to 2 MHz, output power no less than 0.5 W for 50 Ω load, and output amplitude adjustable. The RF signal generator provides RF current for the small RF coil in the absorption cell to create a RF magnetic field for the excitation of *Rb* atoms in resonance transitions.

4. Structure and Features

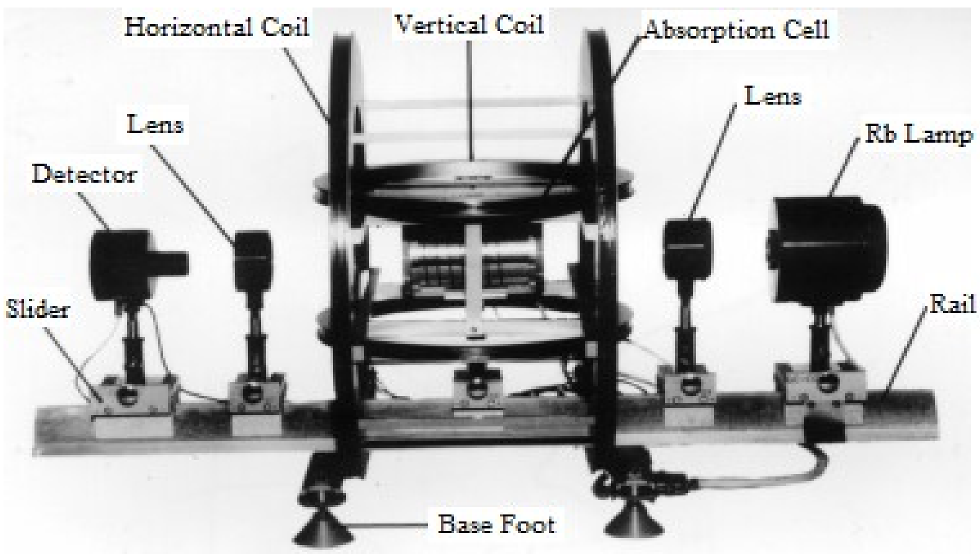
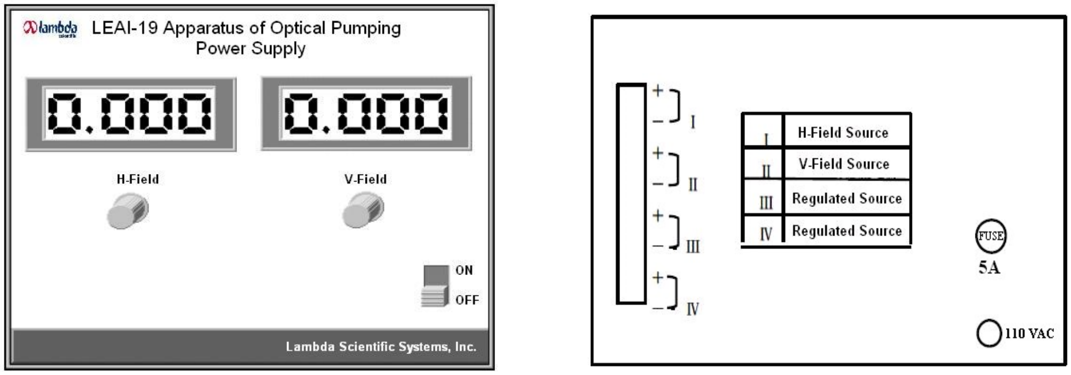


Figure 4 Configuration of components of main unit

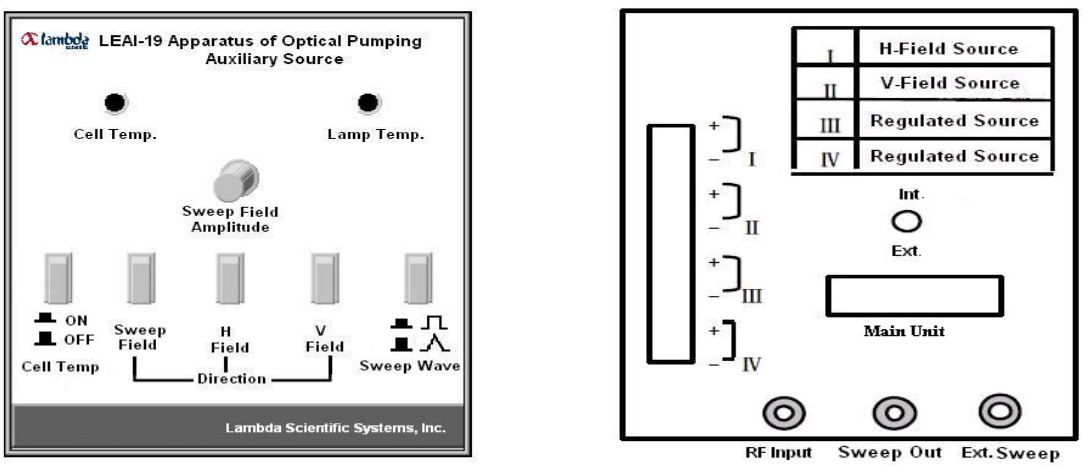
To promote hands-on learning, the main unit of this apparatus is designed with an open structure as seen in Figure 4. Discrete components such as *Rb* spectral lamp, absorption cell, photodetector, and other optical components are placed on an optical rail that can be easily installed and aligned. All parts of the main unit are made of non-magnetic materials. A light-proof cloth cover is provided to cover the apparatus to minimize the impact of ambient light on the system. An observing window is located on the rear of the *Rb* lamp, through which light of rose purple color can be seen under working conditions.

The power supply has two digital current displays, one for the horizontal field and the other for the vertical field. Its front and rear panels are shown in Figures 5(a) and 5(b), respectively. The auxiliary source has direction control switches of the horizontal, vertical and sweep fields as well as temperature control indictors of the absorption cell and *Rb* spectral lamp. Its front and rear panels are shown in Figures 6(a) and 6(b), respectively.



(a) (b)

Figure 5 Front (a) and rear (b) panels of power supply



(a) (b)

Figure 6 Front (a) and rear (b) panels of auxiliary source

5. Setup and Adjustment

1) Setup and adjustment of main unit

a. The coils and base feet were assembled as a whole piece before delivery. When setting up the apparatus, place the rail along the N-S direction determined by the included compass. When adjusting the base foot, first loose the upper nut, next rotate the lower big nut. When done, tighten the upper nut.

b. Place the absorption cell (GC4) with its slider in the central region of the two pairs of coils on the rail as per Figure 4.

c. Place the alignment plate on the two hanging pins on one of the inside walls of the horizontal field coil, adjust the absorption cell to the center of the horizontal coil according to the circular aperture and cross mark on the alignment plate, its three directions XYZ can be adjusted through the slider.

d. Place the *Rb* spectral lamp (GC2), collimating lens (including polarizer and $\lambda/4$ plate) (GC3), condenser (GC7), and photo detector (GC8) with corresponding sliders (marked with numbers) on the rail as per Figure 4. And, adjust them to be coaxial to the central axis of the absorption cell.

e. Loose the large fixing nut of the polarizer on the front side of the collimating lens, and rotate it to adjust polarization direction. After adjustment is done, tighten the nut.

f. The focal length of the two lenses is 77 mm. Refer this to approximately determine the locations of the photo detector and the *Rb* lamp.

2) Wiring

a. Connect the power supply and the auxiliary source using the small 8-wire bundle. Junction tables are given on the back panels of both power supply and auxiliary source. Connect the four sets of power sources according to the tables. **Warning: ensure correct connections!**

b. Connect the main unit and the auxiliary source using the 24-core cable.

c. The "RF Input" and "Sweep Out" sockets on the back panel of the auxiliary source should be connected to the output port of the RF signal generator and the lower trace of the dual-channel oscilloscope, respectively, using the provided Q9 (BNC) cables.

d. There are three small sockets on the side of one support beam of the main unit, labeled as "A", "B" and "C", respectively. Insert the corresponding plugs of absorption cell (A), coils (B) and *Rb* lamp (C) according to the labels marked on the sides of these plugs. Connect the L6 connector on the main unit to the socket of the photo detector labeled with "Power". **Warning: ensure correct connections!**

e. Connect the "Output" socket of the photo detector to the upper trace of the dual-channel oscilloscope using the L6-Q9 coaxial cable.

f. If the sawtooth signal of the oscilloscope is used for the sweep modulation field, then a Q9 cable can be used to connect the “Sweep output” of the oscilloscope and the “Ext. Sweep” socket on the back panel of the auxiliary source, and the sweep switch on the back panel of the auxiliary source should be set to “Ext.”.