(Advanced) Experimental Physics V85.0112/G85.2075 Fall, 201210/16/2012

# **Optical Pumping Control Unit**

## Introduction

This document is gives an overview of the optical pumping control unit.

#### Magnetic Fields

**Magnetic Field Coils:** In the optical pumping experiment there are three sets of coils that allow one to control the magnetic fields seen by the atoms. Each set of coils is in a *Helmholtz* configuration, which consists of a pair of circular coils of radius R that are separated from each other along a line perpendicular to the plain of the coils by the distance R, as shown in Figure 1. With this configuration, the magnetic field



Figure 1: Helmholtz coil arrangement (from Wikipedia)

half way between the two coils and on the axis of symmetry, points along the symmetry axis (x-axis in the Figure 1) and is very homogeneous. (The magnetic field as a function of the distance from this point has no linear or quadratic variation).

Two of the four sets of coils in the experiment produce a horizontal magnetic field pointing along the direction of the optical axis of the experiment, as shown in Figure 2. We call this direction the z-direction, or the z-axis. In fact, both these sets of coils are wrapped around the same coil forms in the experiment, but the current through these two sets of coils is independently controlled by the control unit. A third set of coils is also in a Helmholtz configuration and produces a magnetic field that points along the vertical direction. Finally, a fourth set of "rf coils" produces a radio frequency magnetic field along the horizontal direction, perpendicular to the z-axis.

**Eliminating Unwanted Magnetic Fields:** In the optimal configuration of this experiment, there is only a magnetic field pointing along (or opposite) the z-axis (when there is no rf magnetic field). To achieve this configuration, one must eliminate any magnetic fields along the vertical direction (call this the y-axis), as well as along the horizontal direction that is perpendicular to the z-axis (call this the x-axis). There are two steps to do this.

In the first step, to eliminate the vertical component of the earth's magnetic field, one applies a current through the vertical field coils to produces a magnetic field that exactly cancels the vertical component of the earth's field. This is done by adjusting the 10-turn potentiometer knob labeled "VERTICAL MAGNETIC FIELD" on the control unit, shown in Figure 3.

To eliminate the magnetic field along the x-axis, the entire experiment is rotated about a vertical axis so that the horizontal component of the earth's magnetic field points along the z-axis of the experiment. One can use a compass needle to estimate the direction of the horizontal component of the earth's magnetic field.



Figure 2: Optical pumping apparatus (from TeachSpin)



Figure 3: Optical Pumping Control Unit

You may be wondering how one determines the position of the potentiometer that eliminates the vertical component of the field, especially since the center of the coils is not accessible (due to the presence of the oven and glass cell containing the Rb atoms). It turns out that one can use the atoms themselves (or more specifically, the light passing through the atomic vapor) to determine when the vertical component of the total magnetic field is zero. The procedure for doing this will be described later.

**Horizontal Magnetic Field:** Below the "VERTICAL MAGNETIC FIELD" control is a knob labeled "HORIZONTAL MAGNETIC FIELD", which allows one to set a constant magnetic field along the *z*-axis of the experiment.

Horizontal Magnetic Field Sweep: In addition to setting a static horizontal magnetic field, one can sweep the horizontal field using the controls in the area marked "HORIZONTAL MAGNETIC FIELD SWEEP". These controls produce a magnetic field who's strength follows a sawtooth shape as a function of time. That is, the field increases from some minimum value at a constant rate until it reaches a maximum value, and then quickly returns to the minimum value before ramping up again. The minimum field is set by the 10-turn potentiometer marked "START FIELD", and the range of the sweep, which is the difference between the maximum field and minimum field is determined by the potentiometer marked "RANGE". The duration of the sweep is set by the multi-position switch marked "TIME (SECONDS)". (Note that the toggle switch at the lower right of the "HORIZONTAL MAGNETIC FIELD SWEEP" section of the control panel should be set to 'CONTINUOUS', or the field will stop sweeping when it reaches its maximum value.)

When the "MAGNETIC FIELD MODULATION' toggle switch is set to 'START FIELD', the 'AMPLI-TUDE' knob allows one to fine tune the value of the start field for the magnetic field sweep. When the toggle switch is set to 'MOD', a magnetic field proportional to an external voltage applied to the 'INPUT' BNC connector is added to the magnetic field sweep.

Finally, one can monitor the value of the magnetic field generated by the horizontal magnetic field sweep by observing the voltage from the BNC connector in the 'MAGNETIC FIELD MODULATION' section in the lower panel. The 'RECORDER OFFSET' knob adds an offset voltage to the recorder output.

For some experiments, such as the determination the Landé g-factors, you will want to have a calibrated value of the magnetic field generated by the 'HORIZONTAL MAGNETIC FIELD SWEEP' coil. The current through the this coil can be determined by measuring the voltage across a precision 1  $\Omega$  resistor in series with the coil. This resistor can be accessed via the tip-jacks labeled 'MONITOR' in the 'HORIZONTAL MAGNETIC FIELD SWEEP' section on the lower panel. The magnetic field can be determined from the current using the calibration information in Section 3E. (page 3-14) of the TeachSpin Optical Pumping Guide. To obtain a calibrated value of the horizontal magnetic field, use the tip jacks labeled 'MONITOR' that are just to the left of the 'HORIZONTAL FIELD' output jacks.

**Reversing the Magnetic Fields:** The magnetic field controls only allow a current to pass through the coils in one direction. One can reverse the magnetic field in a particular coil by swapping the red and black connectors on the magnetic field outputs located on the lower section of the controller front panel.

# **RF** and **RF** Modulation

On the very left side of the control unit is an rf (radio frequency) amplifier. The output of this amplifier is sent to the rf coils (see Figure 2). These coils produce an oscillating magnetic field along a direction perpendicular to the z-axis. In the presence of a horizontal magnetic field  $B_z$ , the different Zeeman levels within a particular hyperfine level are shifted in energy by different amounts. The oscillating field produced by the rf-coils can produce transitions between these Zeeman levels if the relationship between the energy difference  $\Delta E$  between an adjacent pair of Zeeman levels and the applied rf frequency  $\omega$  satisfies the resonance condition  $\hbar \omega = \Delta E$ . These transitions can be observed because they "compete" with the optical pumping process and therefore affect the intensity of light that reaches the photodetector. When an rf field is applied (at constant frequency) while the horizontal magnetic field is swept through resonance, the resonance condition can be observed by the change the light intensity that reaches the photodetector. Recording the value of the magnetic field at which this occurs allows one to determine the g-factor of the transition.

A separate rf oscillator is available with this experiment. To connect it to the rf coils, run a cable from the oscillator output to the 'RF AMPLIFIER' input (lower left section of the front panel), and be sure the rf amplifier output is connected to the cable (going to the apparatus) labeled 'RF OUTPUT'. The 'GAIN' knob allows one to easily control the amplitude of the rf magnetic field.

For the last part of the experiment, the rf field is turned on and off suddenly. To turn on and off the rf, apply a square wave signal to the 'RF MODULATION' input. When the voltage to this input exceeds about 720 mV, the rf output turns off. So if one sends to the rf modulation input a square-wave signal

that oscillates between 0 V and about 1V, the rf output should be periodically turned on and off at the frequency of the square-wave signal. Observe this signal (from the 'RF AMPLIFIER OUTPUT' BNC) on an oscilloscope to verify the modulation.

If the resonance condition is met, interesting transient effects should be observable in the signal from the photodetector. This is the most difficult part of the experiment, because fluctuations in the magnetic field in the room (likely due to the subway) make it difficult to maintain the resonance condition. At the moment, this is dealt with by waiting for the magnetic field to satisfy the resonance condition, which one can see by observing the oscilloscope trace, and then pausing the scope before the next trace occurs.

#### **Detector Amplifier Section**

The right side of the upper part of the control unit contains the detector section, which allows one to monitor the amount of light striking the photo-detector. The signal from the detector is first amplified, after which, a voltage (determined by the position of potentiometer marked "DC OFFSET") is subtracted. This difference voltage is then multiplied by factor determined by the "GAIN" and "GAIN MULTIPLIER" switches, after which it is sent through a low-pass filter whose cutoff frequency is determined by the "TIME CONSTANT" switch. The purpose of this setup is to allow one to measure small changes in the amount of light hitting the detector. Note that if you are looking at transient signals, the "TIME CONSTANT" switch should be set to a value *smaller* than the time over which the signal changes. Setting the time constant too large will "wash out" the signal.

The resulting signal can be observed by the deflection of the needle on the galvanometer, or by recording the voltage form the "DETECTOR AMPLIFIER OUTPUT' BNC connector on the lower part of the control panel. This voltage is usually monitored using an oscilloscope.

#### **Temperature Controller**

When the temperature controller is in 'RUN' mode, you see the current temperature. The desired temperature is determined by the parameter value *set-point 1*, or 'SP1'. By repeatedly pressing the O button (just below the display), the display cycles through a set of parameters that can be changed:

## RUN $\bigodot$ SP1 $\bigodot$ SP2 $\bigodot$ CNFG $\bigodot$ RUN.

When 'SP1' appears on the display, push the O button, and you will see the value of the set-point temperature (the .1's digit should be flashing.) To change the value of the set-point temperature, press the up or down arrows (O and O) until the temperature you want appears on the display. Then press the O key, and the display will briefly flash 'StRd' (for 'stored') and then 'SP2' will appear on the display. Then press the O button repeatedly until you see 'RUN' briefly flash on the screen and then the current temperature. If you get lost, just push the O button repeatedly until you see 'RUN' flash, and then the temperature.

#### How to Eliminate Unwanted Magnetic Fields:

In the section titled "Eliminating Unwanted Magnetic Fields", it was mentioned that there is a procedure for determining whether the magnetic components perpendicular to the z-axis are zero. This will be done now.

First, define the y-axis be along the vertical direction, and the x-axis to be the horizontal direction perpendicular to the z-axis. (Remember that the z-axis is the propagation direction of the light.)

Once the polarizers are in place (linear polarizer followed by the quarter-wave plate) and properly aligned, one can observe the intensity of the light reaching the detector as the horizontal field is swept (as determined by the 'HORIZONTAL MAGNETIC FIELD SWEEP' controls). This intensity as a function of time can be monitored on the oscilloscope by connecting cable from the 'RECORDER OUTPUT' BNC connector to Channel 1 of the oscilloscope, and from the 'DETECTOR AMPLIFIER' output to Channel 2 of the scope. Set the scope to trigger on Channel 1 with a negative slope, and adjust the trigger level until you see a the sweep on the scope. Make sure you can also see the output of the detector amplifier on the oscilloscope. By adjusting the 'HORIZONTAL MAGNETIC FIELD' with the 10-turn potentiometer, and possibly reversing the banana plugs at the 'HORIZONTAL FIELD' output, one should find that there is a time during the sweep when the z-component of the magnetic field is zero. It turns out that at this time, the amount of light reaching the detector will be at a minimum. Therefore, as the horizontal field is swept, you should see a dip on oscilloscope channel 2. If you don't, you need to change the value of the 'HORIZONTAL FIELD', and/or reverse the banana plugs driving the horizontal field.

Once you see a dip in the detector signal, the next step is to make the width of the dip as small as possible. To do this, first adjust the 'VERTICAL MAGNETIC FIELD' (10-turn pot) until the dip is as narrow as possible. Next gently rotate the entire apparatus about a vertical axis to narrow the dip even further. (You shouldn't have to rotate it by more than about 20 degrees.) Once you have done this, the magnetic field has only small components along the x and y axes. You will notice that the width of the dip will change as a function of time even when you are not doing anything the the experiment. This is because the magnetic fields in the room are changing as a function of time.

One of the goals of the experiment is to understand why the dip is narrow when there is a magnetic field only along the z-axis, and why it is wider when the field also has components in directions perpendicular to z. The answer has to do with how the optical pumping process works, and how the presence of fields perpendicular to the z-axis can compete with the optical pumping.