Section 4

EXPERIMENTS

4A. Absorption of Rb resonance radiation by atomic Rb

In this first experiment, you will make an approximate measurement of the cross-section for the absorption of rubidium resonance radiation by atomic rubidium. The measured value will then be compared with the geometric cross-section and the value calculated from theory.

The apparatus should be arranged as shown in Figure 4A-1. The linear polarizer and the quarter wave plate should be removed since they will not be needed for this experiment. The cell heater should be off, and the apparatus allowed to come to equilibrium. It may be necessary to insert a neutral density filter before the absorption cell to prevent saturation of the detector amplifier.

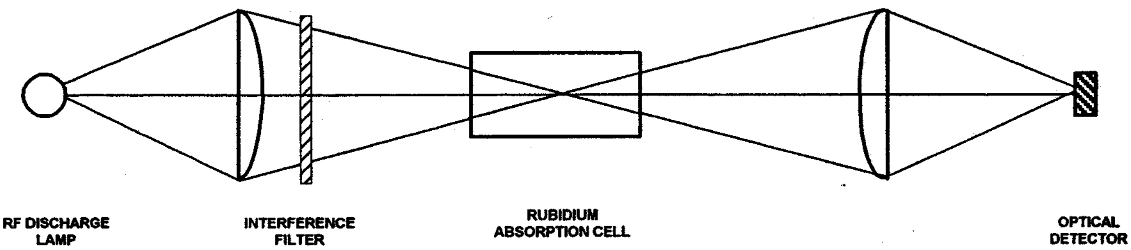


FIGURE 4A-1. Arrangement of the apparatus.

Set the cell heater to 300 K, and allow thermal equilibrium to be established. It will take about 30 minutes for the temperature to become stable. Measure the intensity of the optical signal taking care to record all amplifier gain settings. Repeat the measurement in temperature increments of 10 K, taking care that thermal equilibrium is reached between readings. Repeat the series of measurements as many times as possible both increasing and decreasing the temperature.

Determine the density of atomic rubidium in the cell as a function of temperature from Table 4A-1, and fit the data to an equation of the form

$$I = ae^{-b\rho} \qquad \textbf{4A-1}$$

where ρ is the density of atomic rubidium in the cell. From the value of b determine the cross-section for the absorption of rubidium resonance radiation by atomic rubidium.

Compare your result with the calculated value of the cross-section and with the geometrical cross-section.

Temperature, K	Density, atoms/cubic meter
290	3.3×10^{15}
300	1.1×10^{16}
310	2.9×10^{16}
320	7.5×10^{16}
330	1.8×10^{17}
340	4.3×10^{17}
350	8.3×10^{17}
360	1.5×10^{18}
370	3.7×10^{18}
380	6.3×10^{18}
390	1.2×10^{19}
400	2.4×10^{19}

TABLE 4A-1. Density of rubidium atoms over solid or liquid rubidium as a function of temperature [4A-1].

SAMPLE DATA

Temperature, K	Detector Output, Volts
300	1.57
310	1.31
320	1.06
330	0.72
340	0.52
350	0.24
360	0.17
370	0.14
380	0.13
390	0.12
400	0.12

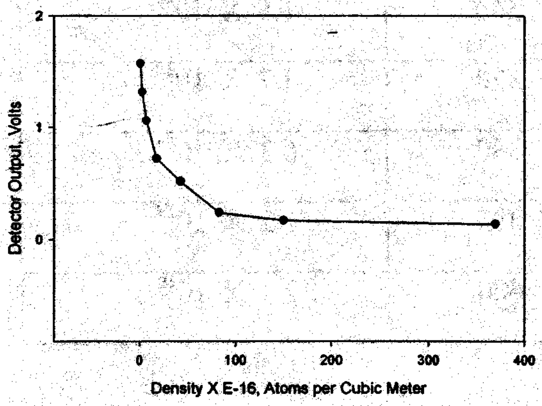


FIGURE 4A-2. Plot of Sample Data

It can be seen from the plot that above a density of about 200 X 10^{16} there is no further decrease in the intensity of the transmitted light. Ideally the cell should be optically thick, and no light should be transmitted. The light that is transmitted does not fall within the absorption profile of the rubidium in the cell, and hence gets through the cell and causes this background.

This radiation comes from the wings of the emission line and from the buffer gas in the discharge lamp. In order to correct for this a constant detector output voltage of 0.14 volt will be subtracted from all readings, and the plot and fit will be limited to the first seven points. The result is shown in Figure 4A-3.

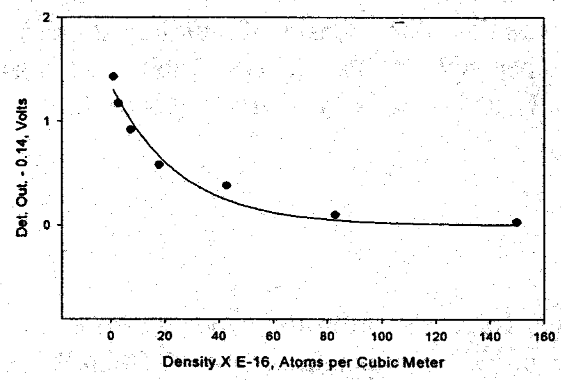


FIGURE 4A-3. Plot of Sample Data with Background Correction

Points are the data. Curve was fit using Sigma Plot© and nonlinear regression analysis to yield

$$I = 1.36e^{-0.040\rho} \quad \textbf{4A-2}$$

The length of the absorption path was about 2.5 cm giving a result

$$0.025\sigma X10^{16} = 0.040 \quad \textbf{4A-3}$$

and

$$\sigma = 1.6X10^{-16} \ \ \mathrm{m}^2 \quad \textbf{4A-4}$$

This can be compared with the result calculated from the equations in section 2C, using a Doppler width at 350K of about 550×10^6 MHz, and a center frequency of about 3.77×10^{14} Hz. This corresponds to a center wavelength of $795 \ X \ 10^{-9}$ m. The resulting maximum cross-section is $\sigma_0 = 15 \ X \ 10^{-16} \ \mathrm{m}^2$.

A more detailed calculation of the cross-section is in the literature [4A-2], and a value of about $10 \ X \ 10^{-16} \ \mathrm{m}^2$ is given there. The geometrical cross-section is about $(10^{-10})^2 = 10^{-20} \ \mathrm{m}^2$. Notice that the resonant cross-section is much larger than that normally associated with atomic scattering processes. As a point of interest the value of the absorption cross-section for sodium resonance radiation in atomic sodium is $12 \ X \ 10^{-16} \ \mathrm{m}^2$ [4A-3].

Care needs to be taken in the interpretation of these results, since the cross-sections involved are somewhat ambiguous. The cross-section is a function of the frequency distribution in the absorption profile of the rubidium atom, and the intensity of the absorbed light will depend on the relationship of the intensity profile of the incident light to the absorption profile of the atom. Therefore the measured result should be considered to be only approximate. These considerations are discussed in detail in the literature [4A-4]. The main point here is to realize that the cross-section for absorption of resonance radiation by an atom is much larger than what is usually taken as a measure of the geometrical cross-section.

The measured cross-section is about 10 times smaller than that calculated from theory. However this is not unreasonable considering the sources of error in the experiment. One of the largest of these is the rapid variation of the density of rubidium atoms in the cell as a function of temperature. This dependence, as shown in the Table 4A-1, was calculated from graphical data contained in [4A-1], and is subject to considerable error.

REFERENCES

[4A-1] Values of density calculated from the vapor pressure data tabulated in "The Characterization of High Temperature Vapors", (John Wiley & Sons, 1967).

[4A-2] A. M. van der Spek, J. J. L. Mulders and L. W. G. Steenhuysen, J. Opt. Soc. Am. 5, 1478 (1988).

[4A-3] Alan Corney, "Atomic and Laser Spectroscopy", pp288, (Oxford University Press, 1986).

[4A-4] Allan C. G. Mitchell and Mark W. Zemansky, "Resonance Radiation and Excited Atoms", (Cambridge Univ. Press, 1961).

4B. Low Field Resonances

In all of the following experiments of this lab, it will be necessary to apply a weak magnetic field along the optical axis of the apparatus. In order to do this satisfactorily, the apparatus must be located where the local residual magnetic field is as uniform as possible. The proposed location should be surveyed with a compass to check for gross inhomogeneity in the local field, and the orientation of the horizontal component of the residual field should also be determined. All iron or steel objects should be removed from the vicinity of the apparatus. The instrument should be placed on a table made with no magnetic material, such as the one supplied for this experiment by TeachSpin.

The optical axis of the apparatus should be oriented such that the horizontal component of the residual field is along this axis. The apparatus should be set up as shown in Figure 4B-1, and the interference filter reinstalled. Be sure that the linear polarizer is ahead of the quarter-wave plate in order to obtain circularly polarized light, and that the two are oriented properly.

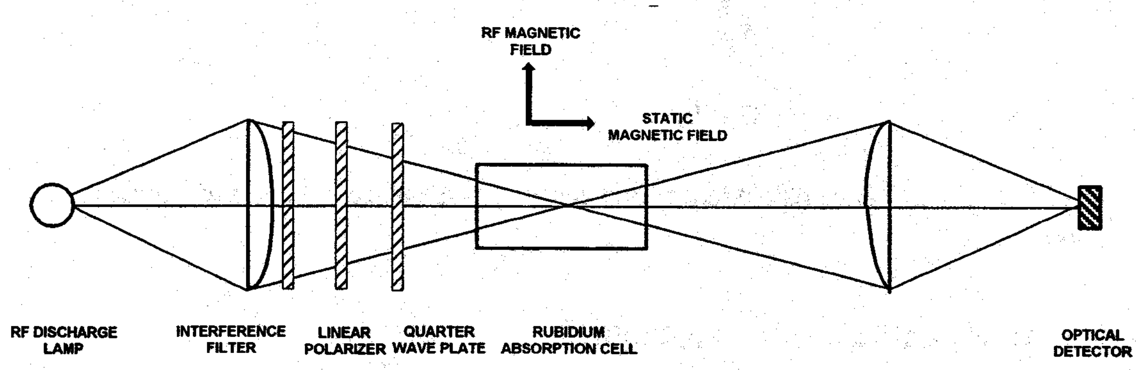


FIGURE 4B-1. Apparatus arrangement for optical pumping.

In order to observe the zero-field transition, no RF is applied and the magnetic field is swept slowly around zero. This is accomplished by varying the current in the sweep windings. The current through the main horizontal field coils should be set to zero. Adjust the current in the vertical compensating coils to achieve ***minimum width*** of the zero field transition. Also check the orientation of the apparatus along the horizontal component of the residual field by rotating the apparatus about the vertical axis and setting for minimum line width.

Set the cell temperature to 320 K and allow thermal equilibrium to be established. It is most convenient if the output of the optical detector is observed on the vertical axis of a storage oscilloscope, and a signal proportional to the current in the horizontal axis sweep coils is displayed on the horizontal axis. As will be shown later optical pumping is a slow process, and during these experiments it will be necessary to use a very slow sweep rate for the magnetic field current.

Figure 4B-2 shows the zero field resonance and the Zeeman resonances and at a frequency of 0.0134 MHZ.

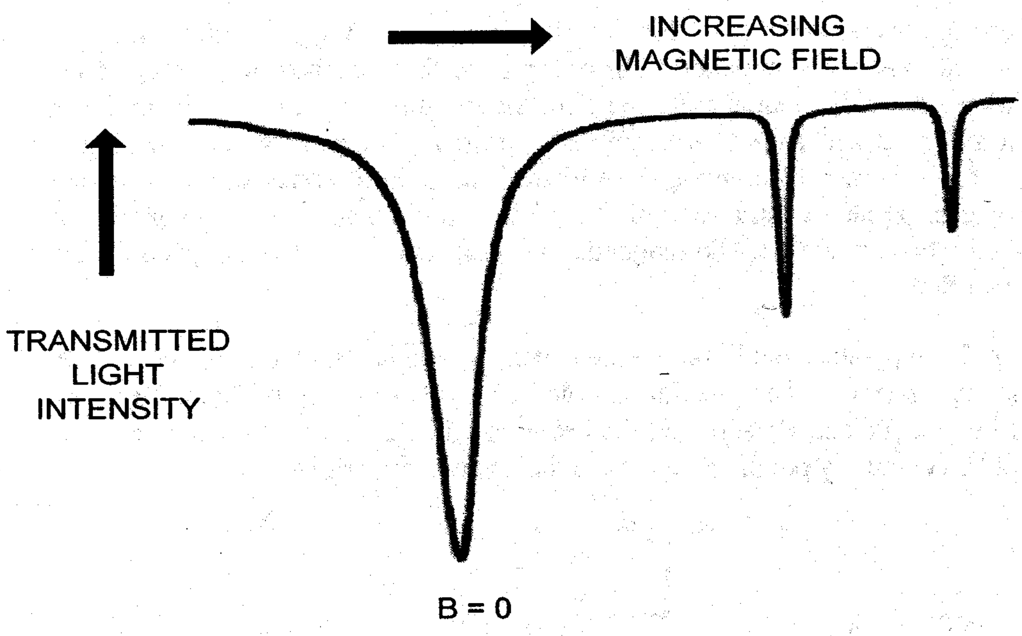


FIGURE 4B-2. Zeeman resonances and zero field resonance at very low magnetic fields.

MEASUREMENT OF THE NUCLEAR SPINS

There are two isotopes of rubidium, and they have different nuclear spins. We are going to pretend that we don't know their values, so we can measure them. In order to do this we must measure the g_F values from which the spins can be calculated. This can be done by measuring a single resonant frequency of each isotope at a known value of the magnetic field. The magnetic field will be determined approximately from the geometry of the field coils. Since nuclear spins are either integral or half-integral we need only an approximate value of the field.

We will use only the sweep field coils for this purpose, and their parameters are as follows:

Mean radius = 0.1639 m $B(\text{gauss}) = 8.991 \times 10^{-3}\, I N / \bar{R}$ **4B-1**
11 turns on each side

where I is the current in amps, N is the number of turns on each side, and $\bar{R}$ is the mean radius of the coils. The coils satisfy the Helmholtz condition. At the sweep monitor terminals on the front panel, a voltage is presented that is numerically equal to the current in amps (the current passes through a one ohm resistor). Use this voltage as a measure of the sweep coil current.

First, the residual magnetic field at the location of the absorption cell must be determined. Disconnect the main field coils so that there can be no current through them. Adjust the current in the sweep coils to center on the zero field resonance, and measure the current. From this and Equation 4B-1 calculate the value of the residual magnetic field. Be sure that there is no RF being applied.

An RF signal can now be applied to the RF coils, and its amplitude set to an arbitrary value. Later this amplitude will be adjusted for optimum transition probability. The frequency of the RF should be set to about 150 KHz. Sweep the horizontal magnetic field slowly increasing from zero, and search for the Zeeman resonances. Measure the current at which each resonance occurs.

An oscilloscope should be used to measure a signal proportional to the RF current at the connector on the cell holder. This signal is developed across a 50 ohm resistor that is in series with the RF coils, and therefore it is proportional to the amplitude of the RF magnetic field.

Measure the characteristics of the RF transitions as a function of the amplitude of the RF magnetic field, and determine the value that provides optimum transition probability [2G-2].

The remaining data in this section should be taken using that value of RF magnetic field.

LOW FIELD ZEEMAN EFFECT

With the main coils still disconnected, measure the transition frequencies of each isotope as function of sweep coil current, and plot the results to determine that the resonances are indeed linear in the magnetic field. From the slope of the plots determine the ratio of the g_F-factors, and compare the measured ratio with that predicted by theory. 2F - 2 ?

SWEEP FIELD CALIBRATION

For the remainder of the experiment it will be necessary to have a more precise value of the magnetic field than can be obtained from the geometry of the coils. In this section we will calibrate the sweep coils using the known g_F values and the previous measurements.

From the previous measurements calculate the value of the magnetic field for each isotope from the resonance equation, and plot the magnetic field vs. the current in the sweep coils. Fit the data to a straight line using a linear regression to obtain an equation for the magnetic field vs. current.

It will now be necessary to make a calibration of the main field coils.

MAIN FIELD CALIBRATION

Connect up the main coils so that their field is in the same direction as that of the sweep coils. The current control for the main coils is too coarse to allow the resonances to be centered well using it alone. It will be necessary to use both the main coils and the sweep coils for this calibration. The voltage presented by the main coil monitor on the front panel (which is developed across a 0.5 ohm resistor) is one half of the main coil current in amps. Use this voltage as a measure of the main coil current.

Use both sets of coils to make measurements at resonance frequencies up to about 1 MHz, and use the sweep coil calibration to correct the measured fields for the residual field. Plot the data on a linear plot, and use a linear regression to obtain the best fit.

SAMPLE DATA

Residual magnetic field:

The zero field resonance was determined to be at a sweep field current of 0.323 amp. From this and the above coil parameters the residual field is 0.188 gauss. Since the rest of the experiment will be done with the magnetic field oriented opposite to the residual field, the above number must be subtracted from the values calculated from Equation 4B-1.

Nuclear spins:

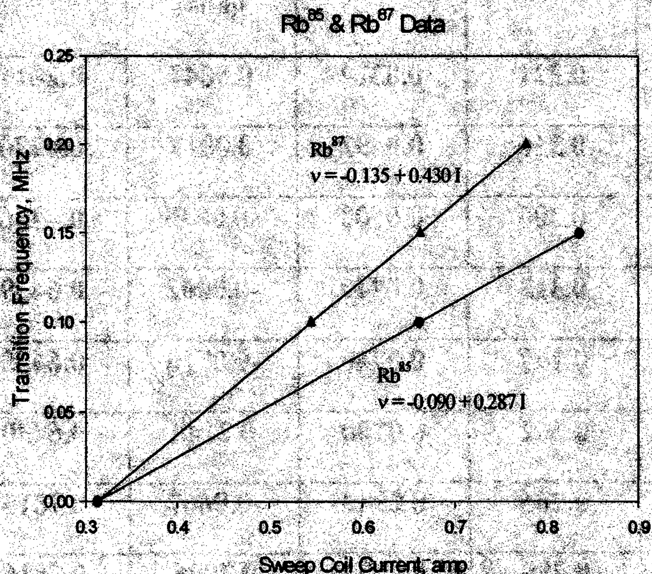
At an RF frequency of 150 KHz the measured currents for the two isotopes were 0.836 and 0.662 amp corresponding to magnetic field values of 0.504 and 0.400 gauss. From each of these values a residual field of 0.188 gauss must be subtracted yielding 0.316 and 0.212 gauss.

The resonant frequencies are determined from

$$\nu = g_F \mu_0 B / h \qquad \text{2F-2}$$

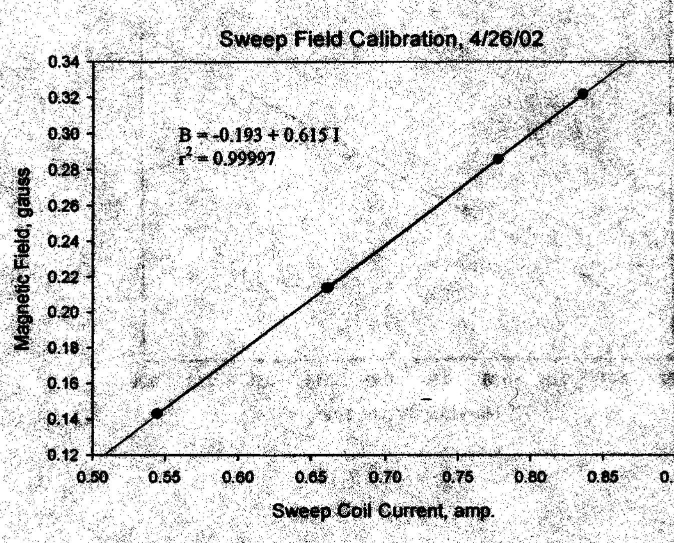
resulting in g_F values of 0.34 and 0.51. From Equation 2B-4 the corresponding nuclear spins are $I = 5/2$ and $I = 3/2$ with theoretical g_F values of 1/3 and 1/2 respectively.

Low field Zeeman effect:



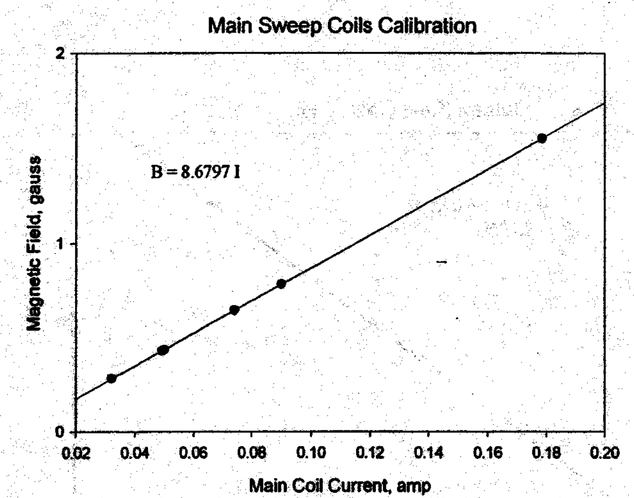
The slopes of the two plots are in the ratio of 0.430/0.287 which gives a value of 1.498. The theoretical ratio is 1.5.

Sweep field calibration



Main field calibration

Freq. MHz	Total field, gauss	Sweep current, amp	Main current, amp	B from sweep coils, gauss	B from main coils, gauss	Isotope
0.2000	0.2858	0.321	0.0322	0.0047	0.2811	Rb^{87}
0.2000	0.4287	0.316	0.0492	0.0017	0.4270	Rb^{85}
0.3003	0.4291	0.306	0.0500	-0.0045	0.4336	Rb^{87}
0.3003	0.6437	0.313	0.0740	-0.0002	0.6439	Rb^{85}
0.4002	0.5719	0.197	0.0740	-0.0716	0.6435	Rb^{87}
0.4002	0.8578	0.662	0.0740	0.2148	0.6430	Rb^{85}
0.5002	0.7148	0.205	0.0900	-0.0667	0.7815	Rb^{87}
0.5002	1.0722	0.785	0.0900	0.2906	0.7816	Rb^{85}
1.0001	1.4291	0.121	0.1786	-0.1185	1.6482	Rb^{87}



4C. Quadratic Zeeman effect

The RF resonances of both isotopes will now be studied as the applied magnetic field is increased into a region where the energy level splitting is no longer linear in **B**. Each of the zero field energy levels splits into 2F + 1 sublevels, whose spacing is no longer equal. In this region there are 2F resonances whose splittings can be resolved . Thus for I = 3/2 there are a total of six resonances with $\Delta F = 0$ and $\Delta M = \pm 1$, and for I = 5/2 a total of ten. These can all be observed. Their intensities depending on the pumping conditions.

The magnetic field at which these resonances can be observed can be approximately determined from the resonance equation

$$\nu = g_F \mu_0 B / h \qquad \text{2F-2}$$

and the current for the main field coils set from the previous calibration.

Start with the main field current at zero, and set the sweep current to the center of the zero field transition. Then set the main field current to the desired value, and use the sweep field to observe the resonances. For a given frequency, measure the sweep field current corresponding to each resonance, and calculate the total magnetic field. If the first frequency that you try does not yield resolved resonances go to a higher frequency.

SAMPLE DATA

Rb^{87}: Front Panel settings:

Output gain	= 20 X 10
ν	= 4.9874 MHz
RC	= 100 msec
RF amp gain	= 3 on dial
Sweep time	= 100 sec
Main field current	= 0.820 amp
Main field	= 7.117 gauss

The observed spectrum is shown in Figure 4C-1 and the calculated spectrum from the Breit-Rabi equation is shown in Figure 4C-2.

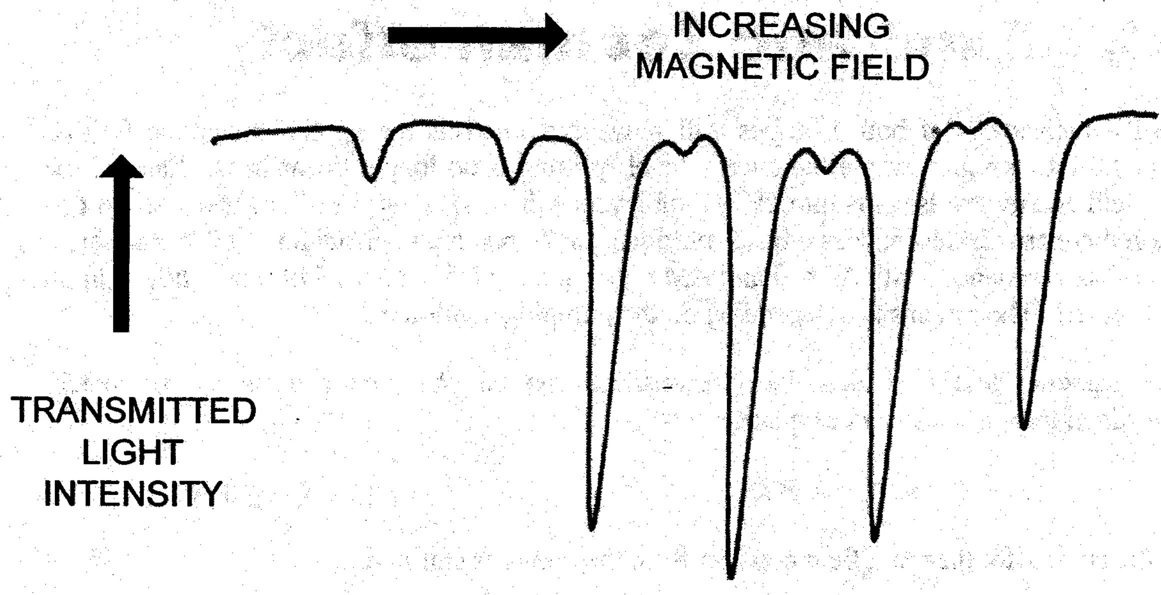


FIGURE 4C-1. Observed spectrum of Rb^{87} at optimum RF power.

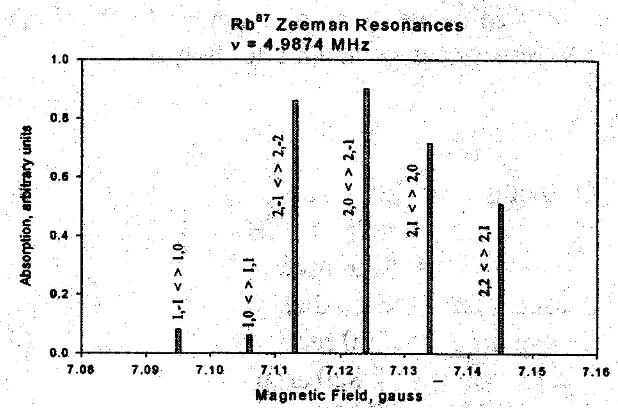


FIGURE 4C-2. Calculated spectrum of Rb^{87}.

The absorption intensities in Figure 4C-2 have been adjusted to match the observed spectrum. The Breit-Rabi equation can not be directly solved for x and hence B, but it can be easily solved by a computer program such as Maple or Mathmatica. The results in Figure 4C-2 were obtained using Maple 5.

The resonances occur at fields shown in the following table:

Sweep Field Current, amp	Sweep Field, gauss	Total Field from calibration, gauss	Total Field from BR eqn., gauss
0.292	-0.013	7.104	7.095
0.310	-0.002	7.115	7.106
0.321	0.004	7.121	7.113
0.339	0.016	7.133	7.124
0.355	0.025	7.142	7.134
0.373	0.036	7.153	7.145

There is a systematic difference of 0.009 gauss or about 0.14% between the calculated and measured total field values.

The Rb^{87} spectrum taken under the same conditions as above except at higher RF power is shown in Figure 4C-3. Here the double quantum transitions, which occur midway between the single quantum transitions, are shown. Notice that the single quantum transitions have become broader because they are being overdriven by the higher RF power.

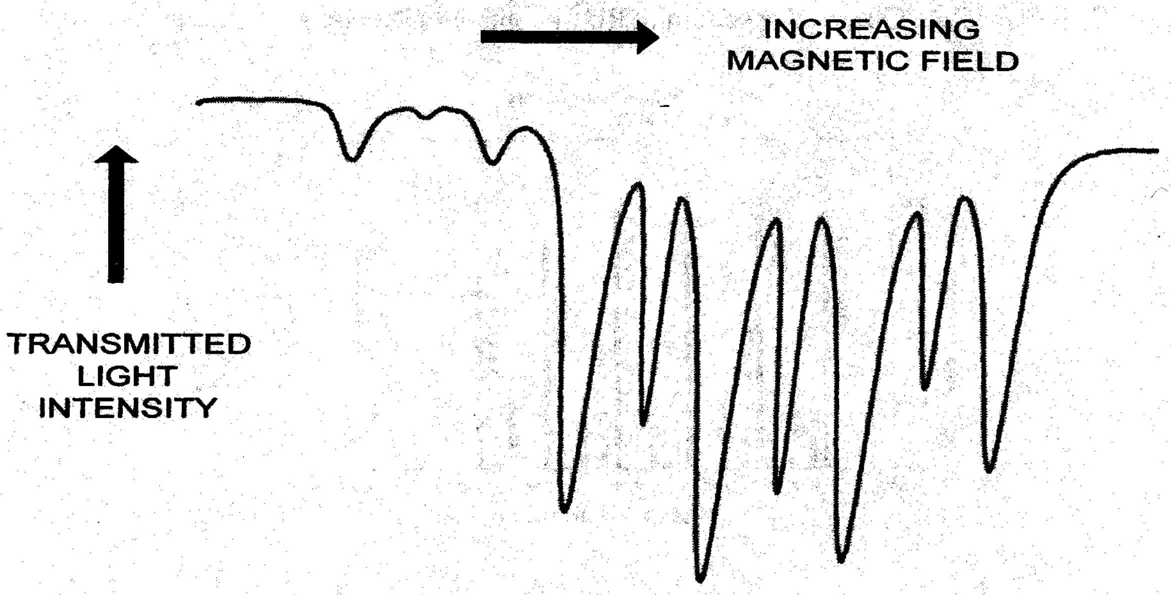


FIGURE 4C-3. Observed spectrum of Rb^{87} at higher RF power showing double quantum transitions.

Rb[85]: Front Panel settings:

Output gain	=	20 X 10
ν	=	3.3391 MHz
RC	=	100 msec
RF amp gain	=	3 on dial
Sweep time	=	100 secs
Main field current	=	0.820 amp
Main field	=	7.117 gauss

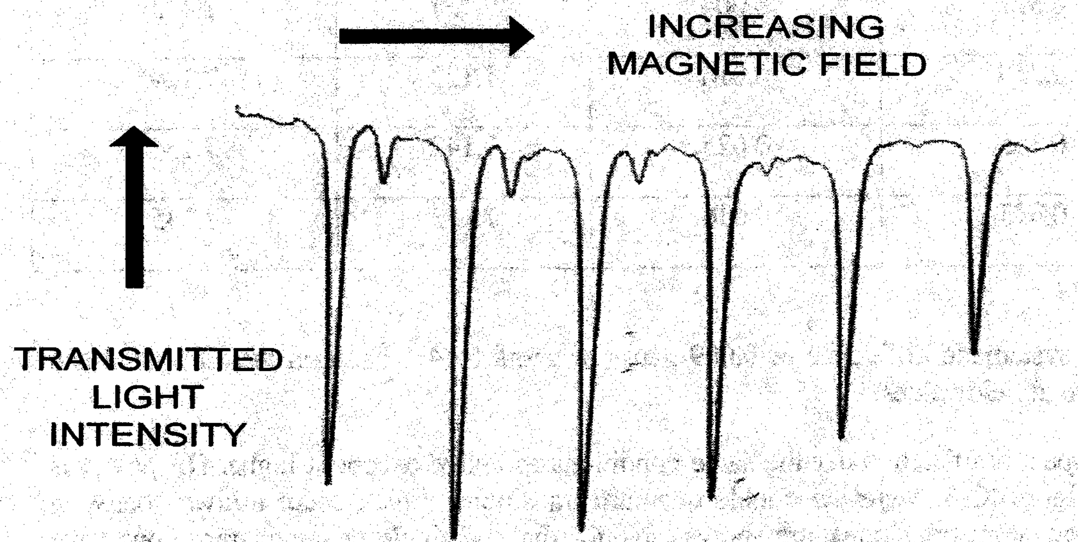


FIGURE 4C-4. Observed spectrum of Rb^{85} at optimum RF power.

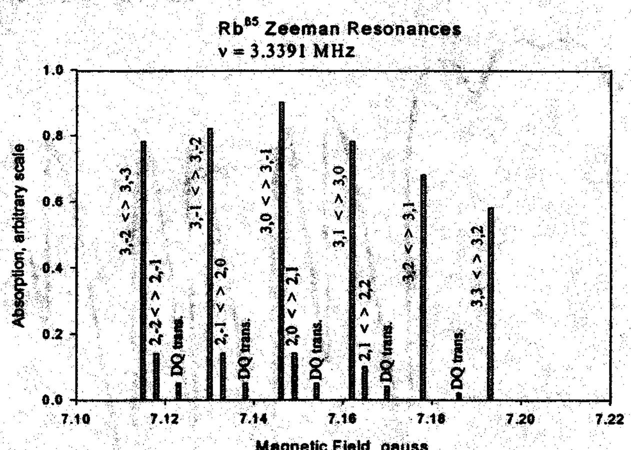


FIGURE 4C-5. Calculated spectrum of Rb^{85}.

The resonances occur at fields shown in the following table:

Sweep Field Current, amp	Sweep Field, gauss	Total Field from calibration, gauss	Total Field from BR eqn., gauss
0.318 amp	0.003	7.120	7.115
0.344	0.019	7.136	7.130
0.369	0.034	7.151	7.146
0.395	0.050	7.167	7.162
0.421	0.066	7.183	7.178
0.446	0.081	7.198	7.193

There is a systematic difference of 0.005 gauss or about 0.07% between the calculated and measured total field values.

The Rb^{85} spectrum taken under the same conditions as above except at higher RF power is shown in Figure 4C-6. Here the double quantum transitions, which occur midway between the single quantum transitions, are shown. Notice that the single quantum transitions have become broader because they are being overdriven by the higher RF power.

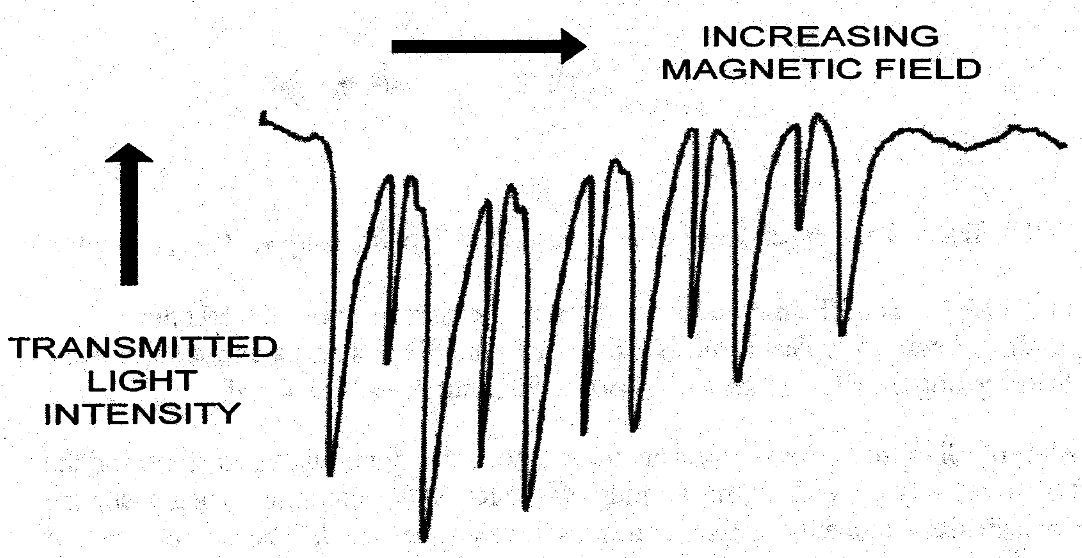


FIGURE 4C-6. Observed spectrum of Rb^{87} at higher RF power showing double quantum transitions.

4D. Transient Effects

In order to observe transient effects it is necessary to either turn the pumping light off and on rapidly or turn the RF on and off while tuned to the center of a resonance. Here we will do the latter while tuned to the center of a low field resonance, and observe the transmitted light intensity as a function of time.

SAMPLE DATA

A square wave pulse of about 0 to +5 volts amplitude is connected to the RF modulation input on the front panel, and the frequency of the square wave should be set to about 5 Hz. The falling edge of the square wave should be used to trigger the sweep of a storage scope, and the output of the detector monitored. The following data was taken at the resonance

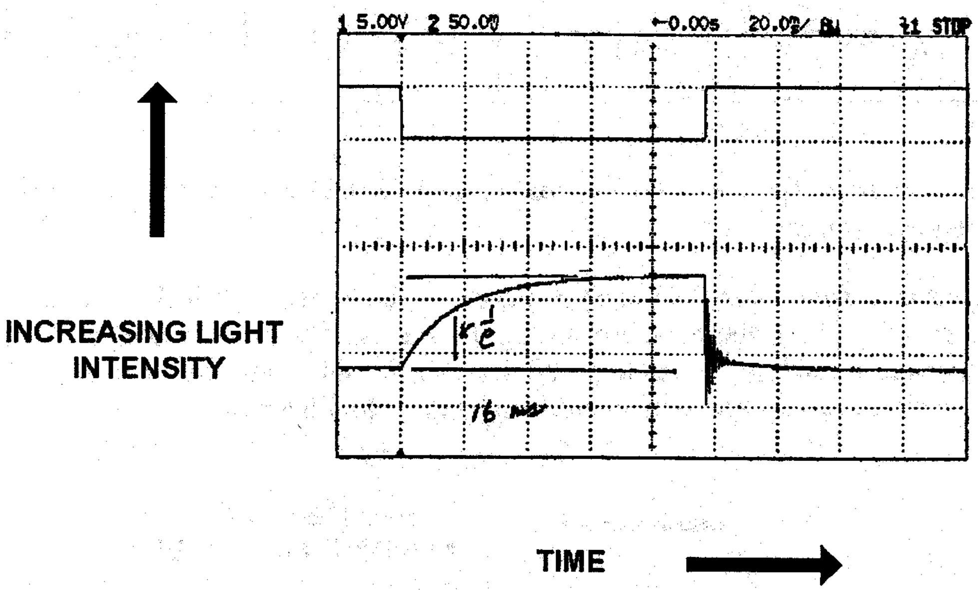


FIGURE 4D-1. Time dependence of the transmitted light intensity vs. RF amplitude.

frequency of 0.3 MHz. The RF amplitude was taken as the voltage across the 50 ohm resistor in series with the RF coil. A typical result is shown in Figure 4D-1. The upper trace shows the waveform that is gating the RF, and the lower shows the resulting optical signal.

When the RF is on all of the Zeeman levels are mixed, no optical pumping takes place, and the transmitted light intensity is a minimum. Turning off the RF allows pumping to begin, and the light intensity increases exponentially until a maximum value is reached. The time constant of this exponential is a measure of the optical pumping time. The characteristic value of the time will be found to be proportional to the intensity of the pumping light.

When the RF is turned on transitions will occur between the Zeeman sublevels and the population of the levels will be driven toward equilibrium. If the rise time of the RF envelope is short enough the populations will overshoot giving rise to the ringing shown in Figure 4D-1. The ringing damps out, and the light intensity approaches that for the unpumped cell.

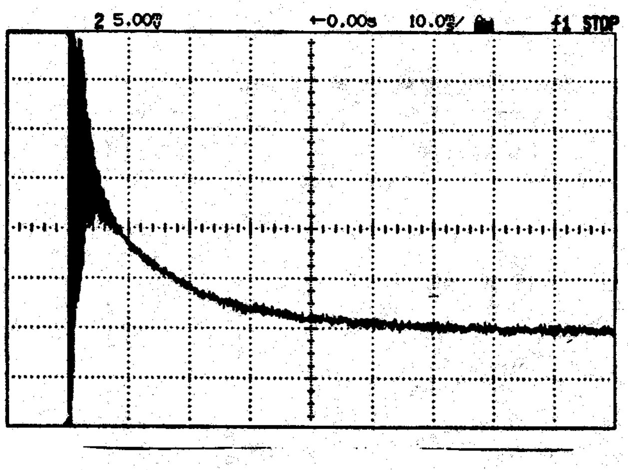


FIGURE 4D-2. Expanded region where the RF is turned on.

Figure 4D-2 shows an expanded region of Figure 4D-1 in the region of where the RF is turned on. It can be seen that the ringing is damped out followed by a longer damping time before the light returns to the unpumped value.

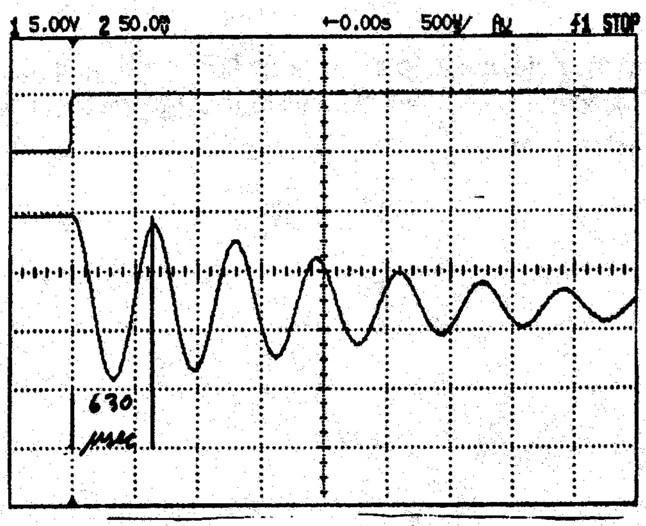


FIGURE 4D-3. Expanded region where the RF is turned on.

Further expansion of the region around the RF turn on time yields a result shown in Figure 4D-3. Here the ringing can be clearly be seen, and its period measured. According to the earlier discussion this period should be linearly proportional to the reciprocal of the amplitude of the RF, since it corresponds to a precession of **F** about the RF magnetic field. Figure 4D-4 shows this to be the case for both isotopes where the fit has been done by regression analysis in SigmaPlot.

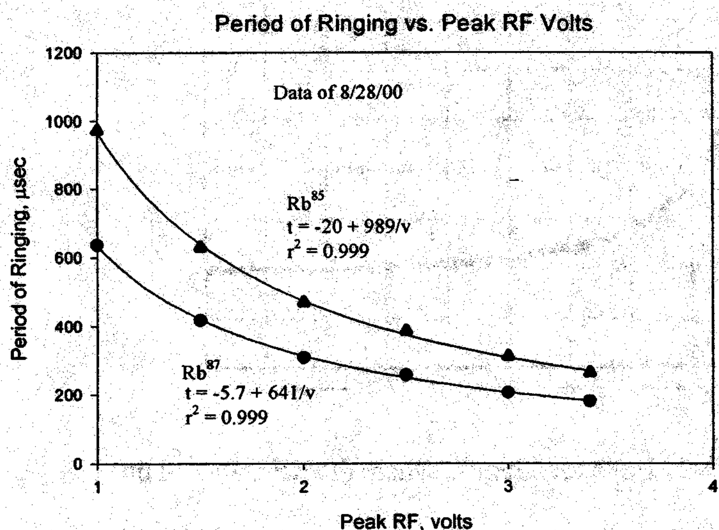


FIGURE 4D-4. Period of ringing vs. peak RF volts.

At a given value of the RF magnetic field, the ratio of the periods of the ringing is goes inversely as the g_F factors, and the above data shoes that this ratio is 989/641 = 1.54 to be compared with a theoretical value of 1.50.

Section 5

5. Getting Started

a.) Before unpacking the optical pumping apparatus you will need to find a good place to set up your instrument.

Magnetic Environment: You need a location with relatively uniform DC magnetic fields. It should be well away (several feet) from any iron (steel tables, shelves, radiators etc.) or other magnetic material. You will also need to align the optical axis of the instrument along the horizontal component of the Earth's Magnetic field. You will also need a non-magnetic table on which to place the instrument. AC Magnetic fields at the power line frequency (50/60Hz.) will also effect the performance of the instrument. AC magnetic fields are believed to limit the low field line width, and large AC fields can lead to strange line shapes.

Room lights: It is useful (though not essential) to be able to dim or turn off the room lights during some of the optical alignment. TeachSpin does provide a black cloth to cover the optics while taking data, however a little stray light always does seem to get into the detector. This can be particularly annoying when there are large changes in the ambient light level.

Thermal Environment: DC drifts in the signal level are due in large part to temperature changes in the lamp and experimental cell. Though both the lamp and cell are in regulated ovens, changes in the ambient temperature will invariably lead to drifts in the signal level.

b.) Once you have selected a site for your instrument, remove it from the box. Place the experiment platform on the table and align the optical axis with the Earth's magnetic field. (you will need a compass for this). Place the Electronics box several feet away from the experiment platform. (AC magnetic fields from the power supply transforms will affect the line widths)

c.) Before you start to place the optics on the rail, you will need to remove two pieces of shipping foam from inside the cell oven. With a small flat blade screw driver remove the three screws that hold the end caps onto each end of the cell oven. Place the end caps aside. Inside each side of the cell oven you will see a white doughnut shaped (annulus) piece of foam insulation and a black piece of shipping foam. Leave the white doughnut pieces in place. Remove the black shipping foam piece from each side of the oven.

On one side of the oven you will see the thermocouple temperature sensor covered with black heat shrink tubing. The Thermocouple wire is only 5 μm in diameter and very delicate. In the center of the oven you will see the experimental cell held in place by a white foam support. You should confirm that the cell is still in the center of the oven. If you need to move the cell push gently on the foam support, make sure that the cylindrical cell does not become tilted in the support. If for some reason you need to replace or change the cell, remove the cell and the foam support together. ***Push gently from the side with the thermocouple towards the side without the thermocouple. Once the cell is properly placed in the center of the oven, make sure that the thermocouple is touching or at least close to the experimental cell.*** For an accurate measure of the cell temperature you do not want the thermocouple to be touching the heater element.[1] Now replace the white doughnut shaped foam pieces of insulation and then the end caps.

If you think you would find it easier to work on the cell oven if it was not between the magnet coils, you may remove the cell oven as follows: Remove the black anodized (1/2 " diameter 5.94" long) spacer from the top of the Horizontal magnet coils. It is held in place by two ¼-20 brass screws. Remove the cable tie downs from the wooden base, so that you can get some slack in the heater and RF cables. Loosen the nylon screws that hold the Cell Oven to the optical rail and then remove the Cell Oven from between the magnet coils. Be careful feeding the cable between the coils. Follow these steps in reverse to put the Cell Oven back on the rail.

d.) Placing Optics: Note that the magnet coils are not located in the center (wrt length) of the optical rail. The long part of the optical rail is for the Lamp and it's associated optics. The experimental cell is centered 3.5″ above the optical rail. (See Figure 2D-1) in Apparatus)

1) Place the Lamp near the end of the long section of optical rail. Adjust the height of the lamp such that the bulb is centered 3.5″[2] above the rail.

2) Place the 50mm plano-convex lens after the lamp, with the flat side facing the lamp and with the distance between the lamp bulb and the center of the lens equal to about 50 mm.(This placement is not crucial and we will adjust the lens position for maximum signal later)

3) Place the Interference filter with the reflecting side towards the lamp.

4) Place the Linear Polarizer after the interference filter with axis of the polarizer at 45° (The alignment mark on the holder indicates the direction of the axis).

5) Adjust the ¼ wave plate so that its axis is at 0° and place it after the Linear Polarizer.

[1] The heater element is the glass cylinder in which the cell and it's foam support slide.
[2] A standard business card is 3.5″ in length which we use for quick alignment.

6) On the other side of the Magnet coils place the remaining plano-convex lens (curved side towards the cell) and then the detector. Set the height of the detector so that the diode is centered 3.5″ above the rail.

e.) **Connect the Electronics**. You now need to make the following connections.

1.) Plug Lamp power into back panel connector
2.) Plug blue Thermocouple into lower front panel and blue heater banana plugs.
3.) Plug Black plastic Pre-amp power and Detector BNC into lower front panel.
4.) Plug in Vertical Field banana plugs into lower front panel. (red plug in red jack)[3]
5.) Plug the Horizontal Sweep Field banana plugs into the lower front panel. The horizontal fields are wired such that if the red plug is in the red jack the field will point in the direction of the light, (from the lamp to the detector). If you have oriented the experimental platform such that the lamp is on the south end then put the red plug in the red jack. Don't worry about this too much, simply plug it in and if you don't see the zero field transition then reverse the plugs. At this point you do not have to connect the Horizontal field. ***If you do connect it make sure that the current is set to zero***

Turn on the power switch on the back panel power entry module. After a few seconds of setup the temperature regulator will display the cell temperature. Check that the set point of the regulator is 50°C. Push the SCROLL key twice. SP will be displayed for 1.5 seconds and then the value of the set point will be displayed. If the value is not 50°C then push the UP or DOWN keys till it is. Push the SCROLL key twice again. PROC will be displayed for 1.5 seconds and then the current temperature. If you have question please refer to the Temperature section of the Apparatus or the controller manual.

f.) The lamp should turn on after a few minutes of warm up. You will see a purplish pinkish glow. The Lamp and the Cell Oven will take 10-20 minutes to thermally stabilize.

g.) Optical alignment. You will now adjust the optics for a maximum signal. It is best if you turn off the room lights for this alignment, but leave enough light so that you can see what you are doing and also observe the detector meter. Set the preamp gain for 10MΩ (toggle switch on preamp in middle position). On the Detector Amplifier set the Gain = 1, Gain Mult. = x1, Time Constant = 100ms, Meter Multiplier = x1, and DC Offset = 0. There should be a signal on the meter. Use a card to block the lamp and make sure this signal is from the lamp and not the room lights. If the signal is off scale change the meter multiplier to x2. If the signal is still off scale then you are probably saturating the preamp and you will need to change the preamp gain to 3MΩ (toggle switch in up position).

h.) You have set the Detector and Lamp height equal to the experimental Cell height. Maximizing the optical signal is now only a matter of adjusting the height of the two lenses and the spacing between the first lenses and the Lamp and the second lens and the

[3] This assumes you live in the Northern Hemisphere.

Detector. Loosen the nylon thumb screw on the side of the optical carriers to move the lenses along the optical rail. Loosen the nylon thumb screw on the side of the support holder to adjust the height of the lenses. Watch the meter on the Detector Amplifier while you do this and maximize the signal. If you are a perfectionist you can use the gain and DC offset control to zoom in on the maximum signal. The Lamp bulb is not always perfectly centered over the optical rail and you may find that slightly rotating the first lens about the vertical axis will steer the beam back to the center of the Cell and give you a little more signal.

i.) Zero Field Transition. Having maximized the DC signal, we are now ready to find the zero field signal. The purpose is to adjust the horizontal and vertical coils so that the magnetic field at the cell is zero. We take care of the third component of the local field by aligning the instrument so that the axis is parallel with the local field.

It is very useful (though not necessary) to have an X-Y storage oscilloscope for this experiment. Make sure that there is no RF on the RF coils by unplugging the coils from the RF amplifier. Make sure the main Horizontal filed is either set to zero or unplugged. Cover the optics with the black cloth. Adjust the DC offset so that the meter reads zero and turn up the gain to 20. You can adjust the gain as necessary if you have too much or too little signal. You may also have to adjust the DC offset if the signal drifts out of range.

We find that the cell can take along time to thermally equilibrate within the oven. The simple act of placing the cloth over the instrument is enough to temporarily change the temperature and cause a DC drift. Using a compass approximately align the instrument with the local field. Set the vertical field current to 0.33 A (3.3 on the dial).[4] If you are using a X-Y storage scope attach the Y axis to the Detector output and the X-axis to the Horizontal Sweep field Recorder Output and turn the Recorder offset to zero (full CCW). Set the Y-axis gain to 0.5 V/div and the X-axis to 1.0 V/div. Make sure that both inputs are DC coupled. Now on the Horizontal Sweep Field control put the Start/Reset toggle to Reset and starting from zero slowly increase the horizontal sweep field by turning the Start Field potentiometer.

You expect to see a broad dip in the transmitted light signal. In Buffalo, NY this dip is centered at a current of about 0.3 Amperes (Dial reading of 3.0). If you see no dip, try reversing the polarity of the Horizontal Sweep field (reverse the banana plugs). Then try changing the Vertical field. Turn the potentiometer one turn and try sweeping the horizontal field again. It is not inconceivable (if you are in a building with a lot of steel) that the local vertical field is in the opposite direction, try reversing the polarity of the vertical field. If all else fails do not hesitate to contact TeachSpin. We will be happy to help you.

[4] This is the approximate setting to cancel the vertical component of the Earth's Field in Buffalo, NY. USA. If you are further north you may need to a larger current and further south a smaller current. Of course it is really the local field that you must cancel out and the building you are in may make much more of a difference than your latitude.

j.) Once you have found the dip, you will adjust the vertical field and position of the experimental platform for a minimum width. The easiest way to do this is to adjust the field to the side of the dip (using the Start Field control) and then adjusting both the vertical field and the angle platform for a maximum signal.[5] You will have to adjust the oscilloscope gain and offsets during this iterative process. For the X-axis offset you can use the recorder offset On the Horizontal Field Sweep control to keep the signal centered.

When you have finally finished aligning the magnetic fields you should find that the zero field transition corresponds to an intensity change of about 2% of the DC signal and that it has a line width of about 3 mG (30 μT) (The gain of the recorder output has been set so that 50mV $\approx$ 1 mG (10 μT).

You are now ready to do other experiments turn to section 4.

[5] There might be some confusion about what is meant by maximum signal. When you sweep through the zero field signal the dip corresponds to less light getting to the detector. This is a minimum signal. When sitting on the side of the dip and looking for a maximum signal, that is more light going to the detector.

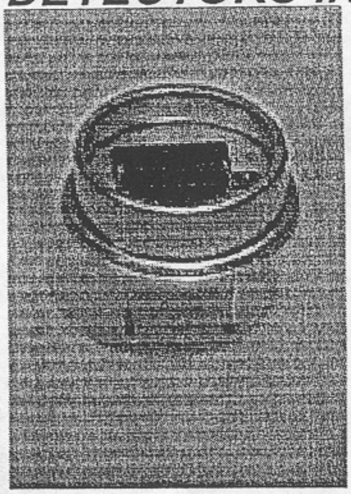
PID Tuning Parameters versus Temperature

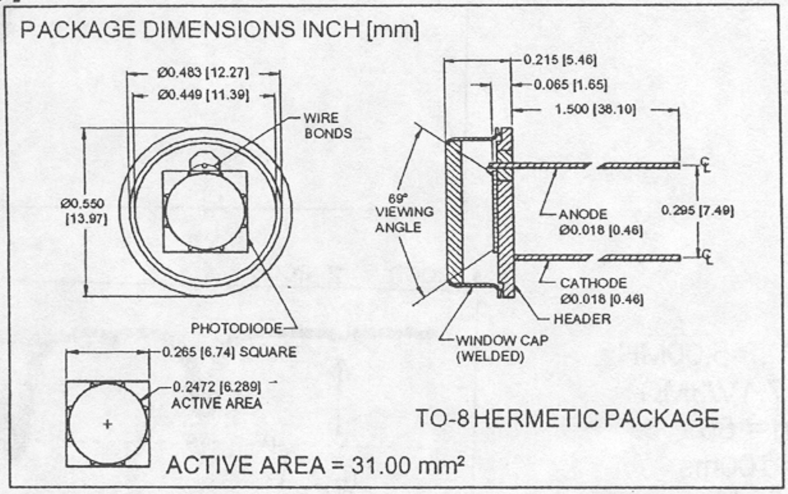
Temperature °C	Proportional Band Pb	Reset rSEt	Rate rAtE
30	6.2	13.28	2.14
40	5.3	9.52	1.38
50	4.4	8.14	1.22
60	3.7	6.32	1.05
70	3.0	5.17	0.52
80	2.5	4.09	0.35
90	2.0	3.35	0.35
100	1.7	3.12	0.32
110	1.2	2.31	0.25

The units for the reset and rate are xx.yy where xx are in minutes and yy are seconds. It should be noted that the Gain is inversely proportional the Proportional Band. If you express both the rate and reset in seconds then you can show that there exists the following relationships between the parameters; reset/PB $\approx$ 110 and reset/rate $\approx$ 6.04

PHOTONIC DETECTORS INC.

Silicon Photodiode, Blue Enhanced Photoconductive
Type PDB-C108





FEATURES
- High speed
- Low capacitance
- Blue enhanced
- Low dark current

DESCRIPTION
The **PDB-C108** is a silicon, PIN planar diffused, blue enhanced photodiode. Ideal for high speed photoconductive applications. Packaged in a hermetic TO-8 metal can with a flat window.

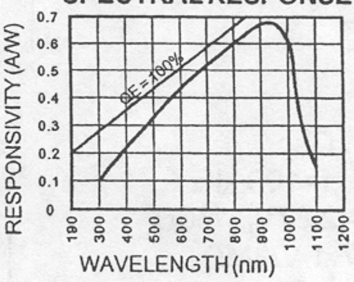
APPLICATIONS
- Instrumentation
- Industrial controls
- Photoelectric switches
- Flame sensors

ABSOLUTE MAXIMUM RATING (TA=25°C unless otherwise noted)

SYMBOL	PARAMETER	MIN	MAX	UNITS
V_{BR}	Reverse Voltage		100	V
T_{STG}	Storage Temperature	-55	+150	°C
T_O	Operating Temperature Range	-40	+125	°C
T_S	Soldering Temperature*		+240	°C
I_L	Light Current		0.5	mA

*1/16 inch from case for 3 secs max

SPECTRAL RESPONSE



ELECTRO-OPTICAL CHARACTERISTICS (TA=25°C unless otherwise noted)

SYMBOL	CHARACTERISTIC	TEST CONDITIONS	MIN	TYP	MAX	UNITS
I_{SC}	Short Circuit Current	H = 100 fc, 2850 K	400	460		μA
I_D	Dark Current	H = 0, V_R = 10 V		5	15	nA
R_{SH}	Shunt Resistance	H = 0, V_R = 10 mV	65	120		MΩ
TC R_{SH}	R_{SH} Temp. Coefficient	H = 0, V_R = 10 mV		-8		% / °C
C_J	Junction Capacitance	H = 0, V_R = 10 V**		75		pF
λrange	Spectral Application Range	Spot Scan	350		1100	nm
λp	Spectral Response - Peak	Spot Scan		950		nm
V_{BR}	Breakdown Voltage	I = 10 μA	100	125		V
NEP	Noise Equivalent Power	V_R = 10 V @ Peak		8×10^{-13}		W/ $\sqrt{Hz}$
tr	Response Time	RL = 1 KΩ V_R = 50 V		20		nS

 **f = 1 MHz

[FORM NO. 100-PDB-C108 REV B]

TEACH SPIN

Instruments Designed for Teaching

TeachSpin, Inc.
WARRANTY

****Do not attempt to repair this instrument while under warranty****

TeachSpin, Inc. is proud of the quality and workmanship of it teaching apparatus. We offer a warranty, which is unique in the industry because we are confident of the reliability of our instruments.

This instrument is warranted for a period of **two (2) years** from the date of purchase. We will pay for all labor and parts to repair the instrument to new working specification due to defects in components, workmanship or ordinary use.

Should an electronic module malfunction, TeachSpin, Inc. will ship to you within one work week a replacement module at no charge. TeachSpin, Inc. will accept phone or fax requests for such replacement. You are responsible to ship to TeachSpin, Inc. the malfunctioning module, fully insured, within a period of three (3) weeks. Failure to do so will result in charging you full retail price for the replacement module. Your defective module will be repaired and returned to you at no charge. You are obligated to return, fully insured, the replacement module originally sent by TeachSpin, Inc. This one week replacement program assures your students that they can finish the experiments assigned without significant interruption. This warranty is void under the following circumstances:

a) The instrument has been dropped, damaged, or mutilated.
b) Repairs or attempted repairs not authorized by TeachSpin, Inc. have been done to the module.
c) Instrument has been subjected to high voltages, plugged into 210 volts AC or otherwise electrically abused.
d) Instrument has been dropped or damaged by impact or extreme heat.

TeachSpin, Inc. makes no expressed warranty other than the warranty set forth herein, and all implied warranties are excluded. TeachSpin, Inc.'s liability for any defective product is limited to the repair or replacement of the product at our option. TeachSpin, Inc. shall not be liable for:

1) Damage to other properties caused by any defects, for damages caused by inconvenience, loss of use of the product, commercial loss, or loss of teaching time.
2) Any other damages, whether incidental, consequential or otherwise.

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