Optical Pumping Data Analysis

March 12, 2016

```
In [9]: %pylab inline
        def fit_and_plot(x,y,xlabel="",ylabel="",title="",zeroed=False,annotate_fit= True,right_words =
            fig = plt.figure()
            ax1 = fig.add_subplot(111)
            ax1.plot(x,y,'{}'.format(marker))
            z = np.polyfit(x,y, 1)
            p = np.poly1d(z)
            if zeroed :
                a = np.linspace(0,max(x))
            else:
                a = np.linspace(min(x),max(x))
            ax1.plot(a, p(np.linspace(min(x),max(x))),color="red")
            if annotate_fit:
                slope = z[0]
                intercept = z[1]
                if right_words:
                    ax1.text(0.48,0.85,"y= %.5f x + %.5f"%(slope,intercept), fontsize=13,transform=ax1.
                else:
                    ax1.text(0.03,0.85,"y= %.5f x + %.5f"%(slope,intercept), fontsize=13,transform=ax1.
            if title !="":
                plt.title(title,fontsize=13 )
            plt.xlabel(xlabel,fontsize=12)
            plt.ylabel(ylabel,fontsize=12)
            if annotate!="":
                if right_annotate:
                    ax1.text(0.48,0.85,annotate, fontsize=13,transform=ax1.transAxes)
            if error_bar!="":
                ax1.errorbar(x, y, yerr=error_bar, fmt='o')
            if sci_lim:
                plt.ticklabel_format(style='sci', axis='x', scilimits=(0,0))
            plt.tick_params(axis='both', which='major', labelsize=12)
            plt.tick_params(axis='both', which='minor', labelsize=12)
            return p
```

```
Populating the interactive namespace from numpy and matplotlib
```

```
In [14]: freq_pos = np.array([3.904,3.500,3.000,2.500,2.000,1.500,1.000,0.7,0.5,0.2])
         I_pos = np.array([1.84,1.63,1.40,1.15,0.9,0.66,0.41,0.26,0.16,0.0])
         freq_neg = np.array([3.900,3.500,3.000,2.500,2.000,1.500,1.000,0.7,0.5,0.2,0.1])
         I_neg = -np.array([1.98,1.78,1.53,1.29,1.04,0.79,0.55,0.40,0.30,0.11,0.06])
         I_mega = list(I_neg)+list(I_pos)
         freq_mega = list(freq_neg)+list(freq_pos)
         freq2_neg = np.array([3.900,3.500,3.000,2.500,2.000,1.500,1.000,0.7,0.5,0.2])
         I2_neg = -np.array([1.35,1.21,1.05,0.88,0.71,0.55,0.38,0.28,0.21,0.06])
```

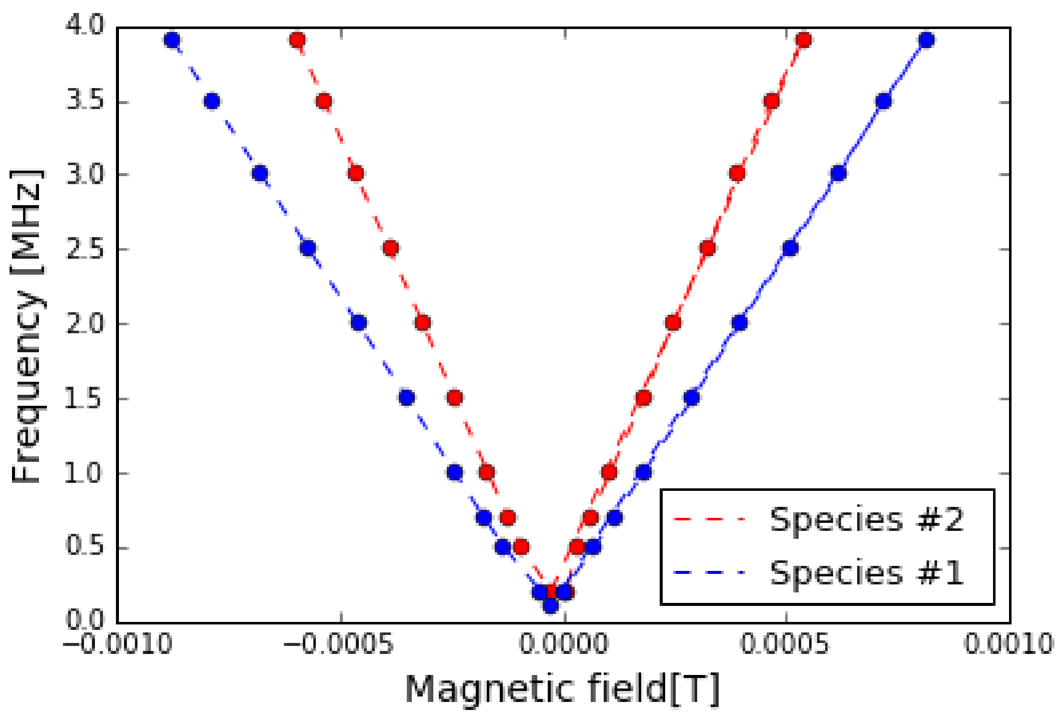
```
freq2_pos = np.array([3.904,3.500,3.000,2.500,2.000,1.500,1.000,0.7,0.5,0.2])
I2_pos = np.array([1.22,1.06,0.89,0.73,0.56,0.41,0.24,0.14,0.07,0.02])
I2_mega = list(I2_neg)+list(I2_pos)
freq2_mega = list(freq2_neg)+list(freq2_pos)
```

```
In [11]: def I_to_B(I):
             N = 135 #turns
             a = 0.275 #meters
             return 0.9e-6 * N*np.array(I)/a
```

```
In [12]: from matplotlib.legend_handler import HandlerLine2D
         N = 135 #turns
         a = 0.275 #meters
         B_mega = I_to_B(I_mega)
         B2_mega = I_to_B(I2_mega)

         plt.plot(B2_mega,freq2_mega,'o',color = "red")
         plt.plot(B2_mega,freq2_mega,'--',color = "red",label = "Species #2 ")
         plt.plot(B_mega,freq_mega,'o',color = "blue")
         plt.plot(B_mega,freq_mega,'--',color = "blue",label = "Species #1 ")
         plt.legend(loc='lower right',prop={'size':13},numpoints=1)
         plt.title("",fontsize=14)
         plt.xlabel("Magnetic field[T]" ,fontsize=14)
         plt.ylabel("Frequency [MHz]",fontsize=14)
```

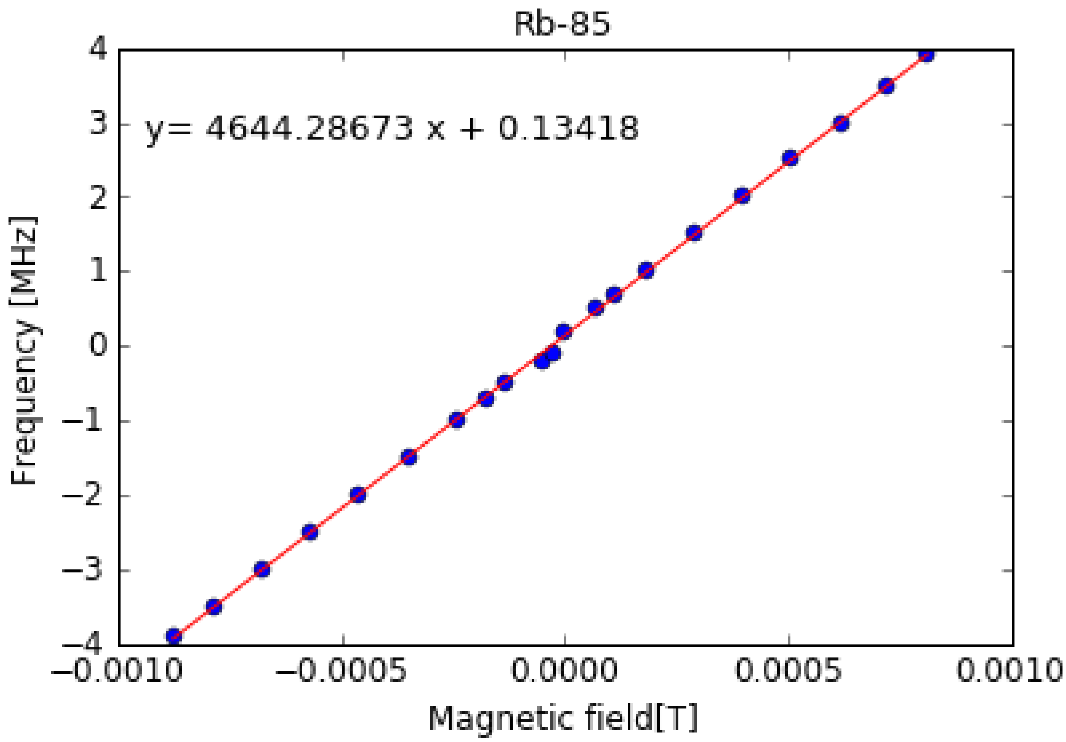
```
Out[12]: <matplotlib.text.Text at 0x7f1f17b55490>
```

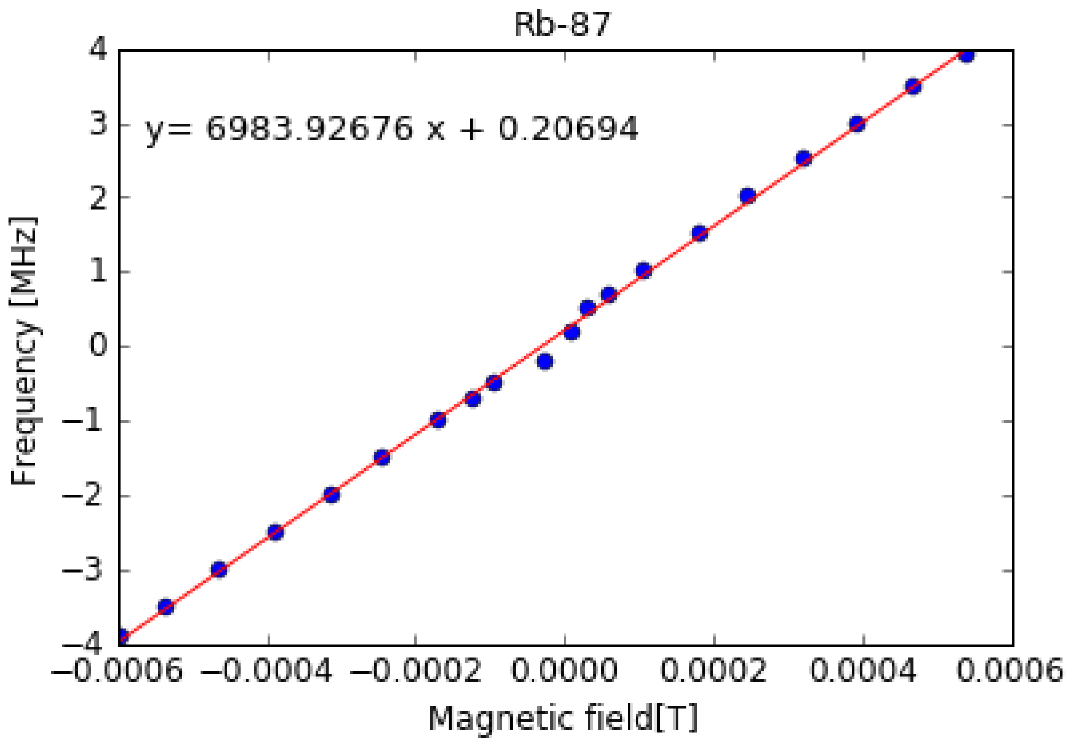



```
In [88]: I_mega_line = list(I_neg)+list(I_pos)
         freq_mega_line = list(-freq_neg)+list(freq_pos)
```

```
I2_mega_line = list(I2_neg)+list(I2_pos)
freq2_mega_line = list(-freq2_neg)+list(freq2_pos)

spec1_fit = fit_and_plot(I_to_B(I_mega_line),freq_mega_line,xlabel="Magnetic field[T]",ylabel=
spec2_fit = fit_and_plot(I_to_B(I2_mega_line),freq2_mega_line,xlabel="Magnetic field[T]",ylabel
```





0.0.1 Estimate of the Earth's magnetic field

At the zero current point, the magnetic field is zero and have no magnetic field contribution from the Helmholtz coil so $B_{total} = B_{earth}$. This could also be thought of as the y intercept of the linear regression:

$$B_H = \frac{(2I+1)}{2.799}\nu - B_e$$

.

```
In [21]: print  0.9e-6 * N*spec1_fit[0]/a ,"teslas"
         print  0.9e-6 * N*spec2_fit[0]/a ,"teslas"
```

```
5.92823442548e-05 teslas
9.1428498284e-05 teslas
```

The actual total magnetic field in Berkeley is 48.6 μT

In order to decrease the error on the parameters for linear regression (y = ax+b), we flipped the negative data along the x axis so that we could perform two linear fits so that we have double the size of the sample.

$$I = \frac{1}{2}\left(\frac{2.799}{a} - 1\right)$$

```
In [25]: spec1_fit[1]
```

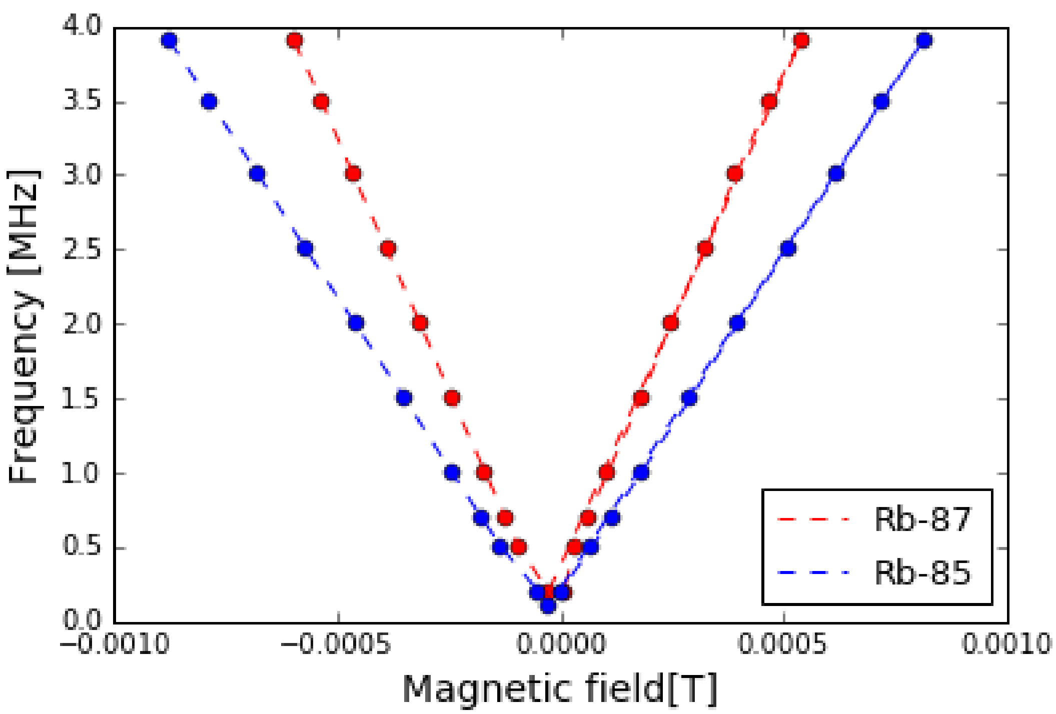
```
Out[25]: 4644.2867320091918
```

```
In [24]: print 0.5*( 2.799/spec1_fit[1] -1 )
         print 0.5*( 2.799/spec2_fit[1] -1 )
```

```
-0.499698662016
-0.499799611301
```

In [83]:
```
plt.plot(B2_mega,freq2_mega,'o',color = "red")
# plt.plot(B2_mega,freq2_mega,'--',color = "red",label = "Species #2 ")
plt.plot(B2_mega,freq2_mega,'--',color = "red",label = "Rb-87")
plt.plot(B_mega,freq_mega,'o',color = "blue")
# plt.plot(B_mega,freq_mega,'--',color = "blue",label = "Species #1 ")
plt.plot(B_mega,freq_mega,'--',color = "blue",label = "Rb-85")
plt.legend(loc='lower right',prop={'size':13},numpoints=1)
plt.title("",fontsize=14)
plt.xlabel("Magnetic field[T]" ,fontsize=14)
plt.ylabel("Frequency [MHz]",fontsize=14)
```

Out[83]:
```
<matplotlib.text.Text at 0x7f1f175ab8d0>
```



In [28]:
```
np.array(freq_mega[:-1])/np.array(freq2_mega)
```

Out[28]:
```
array([ 1.        ,  1.        ,  1.        ,  1.        ,  1.        ,
        1.        ,  1.        ,  1.        ,  1.        ,  1.        ,
        0.02561475,  1.11542857,  1.16666667,  1.2       ,  1.25      ,
        1.33333333,  1.5       ,  1.42857143,  1.4       ,  2.5       ])
```

In [30]:
```
1./(B_mega[:-1]/B2_mega)
```

Out[30]:
```
array([  0.68181818,   0.67977528,   0.68627451,   0.68217054,
         0.68269231,   0.69620253,   0.69090909,   0.7       ,
         0.7       ,   0.54545455, -20.33333333,   0.57608696,
         0.54601227,   0.52142857,   0.48695652,   0.45555556,
         0.36363636,   0.34146341,   0.26923077,   0.125     ])
```

In [32]: 2/3.

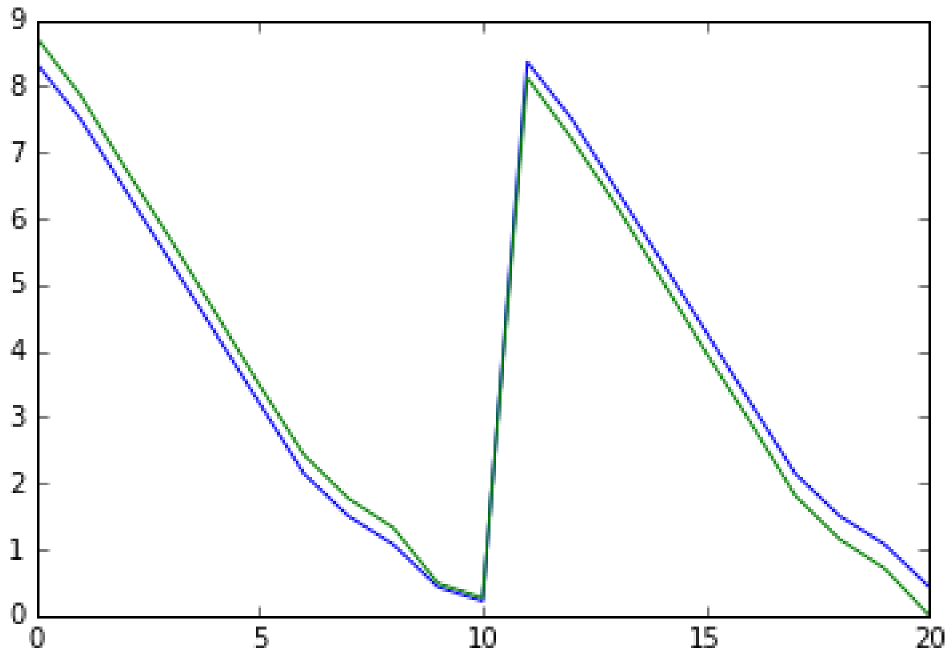
Out[32]: 0.6666666666666666

For species 1 :

```
In [68]: I = 2.5
         B_guess = (2*I+1)/2.799*np.array(freq_mega)-48.6e-6
         B_actual = abs(B_mega)*1e4
```

```
In [69]: plt.plot(B_guess)
         plt.plot(B_actual)
```

Out[69]: [<matplotlib.lines.Line2D at 0x7f1f1773b310>]




```
In [70]: mean((B_guess-B_actual)**2)
```

Out[70]: 0.091511448991768482

For species 2 :

```
In [79]: I = 1.5
         B2_guess = (2*I+1)/2.799*np.array(freq2_mega)-48.6e-6
         B2_actual = abs(B2_mega)*1e4
         # plt.plot(B_guess)
         # plt.plot(B_actual)

         mean((B2_guess-B2_actual)**2)
```

Out[79]: 0.097268324274124823

```
In [82]: (B_guess*1e-4*a/N/I_mega)[:-1]
```

```
/anaconda/lib/python2.7/site-packages/IPython/kernel/__main__.py:1: RuntimeWarning: divide by zero encou
  if __name__ == '__main__':
```

```
Out[82]: array([ -8.60090537e-07,  -8.58603207e-07,  -8.56197231e-07,
                 -8.46240170e-07,  -8.39728727e-07,  -8.29096116e-07,
                 -7.93916342e-07,  -7.64137054e-07,  -7.27740146e-07,
                 -7.93844342e-07,  -7.27608146e-07,   9.26481477e-07,
                  9.37615772e-07,   9.35701260e-07,   9.49260713e-07,
                  9.70353195e-07,   9.92402927e-07,   1.06500973e-06,
                  1.17559547e-06,   1.36451277e-06])
```

```
In [80]: mean(B2_guess*1e-4*a/N/I_mega[:-1])
```

```
Out[80]: -9.9626112557009977e-07
```

error on the fit:
$\sigma_a^2 = S_{xx}/\triangle$
$\sigma_b^2 = S/\triangle$

```
In [98]: S_x = sum(B_mega/0.001**2)
         S_xx = sum(B_mega**2/0.001**2)
         S = sum(1/0.001**2)
         delta = S*S_xx-S_x**2
         # print delta
         print "For species 1 : "
         print "error on fitted slope =", S_xx/delta
         print "error on intercept =", S/delta
```

```
For species 1 :
error on fitted slope = 1.09089761621e-06
error on intercept = 0.230934403605
```

```
In [100]: S_x = sum(B2_mega/0.001**2)
          S_xx = sum(B2_mega**2/0.001**2)
          S = sum(1/0.001**2)
          delta = S*S_xx-S_x**2
          # print delta
          print "For species 2 : "
          print "error on fitted slope =", S_xx/delta
          print "error on intercept =", S/delta
```

```
For species 2 :
error on fitted slope = 1.20071091637e-06
error on intercept = 0.572630173934
```

```
In [110]: fc1  = np.poly1d([4644.29, 0.1342])
          fc2  = np.poly1d([ 6983.93,0.2069])
          print sum((fc1(B_mega) - freq_mega)**2/freq_mega)/len(freq_mega)
          print sum((fc2(B2_mega) - freq2_mega)**2/freq2_mega)/len(freq2_mega)
```

```
3.57085081353
3.72395743657
```

```
In [ ]:
```