H2D2 Spectroscopy

James Amidei, Zach Stedman, And Max Markgraf

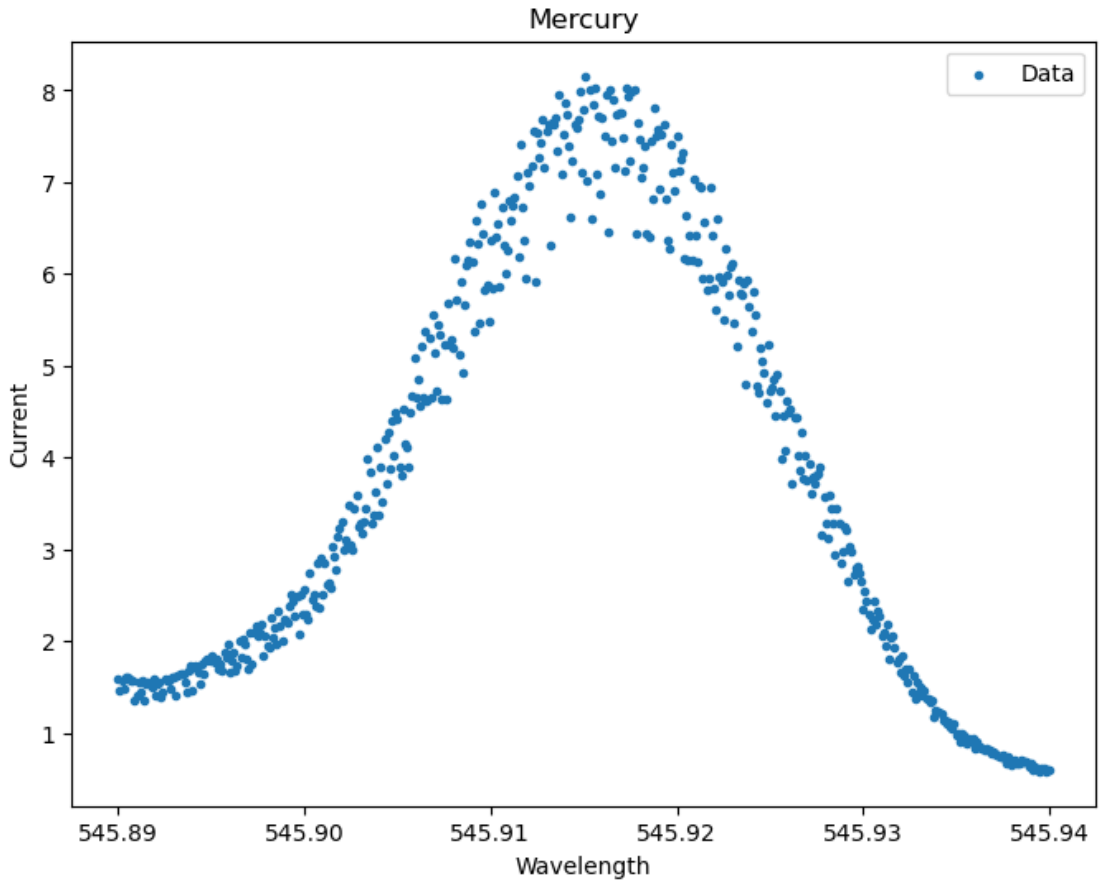
In [23]:

```
import numpy as np
import pylab as py
import matplotlib.pyplot as plt
from scipy.optimize import curve_fit
import scipy.stats as stats

def fgaussian(x, A, B, C, D):
    return A * np.exp(-((x - B) ** 2) / (2 * C ** 2)) + D

def ftwogaussian(x, A1, A2, B1, B2, C1, C2, D):
    return (A1 * np.exp(-((x - B1) ** 2) / (2 * C1 ** 2))
            + A2 * np.exp(-((x - B2) ** 2) / (2 * C2 ** 2)) + D)

def is_float(string):
    try:
        float(string)
        return True
    except ValueError:
        return False

# pull data
#data1 = np.genfromtxt('MercuryData.csv', delimiter=',', skip_header=22, d
datam = np.genfromtxt('DataFiles/MercuryData.csv', delimiter=',', dtype=st
datam_copy = np.genfromtxt('DataFiles/MercuryDataCopy.csv', delimiter=',',

data1 =  np.genfromtxt('DataFiles/H2D2Data1.csv', delimiter=',', dtype=str
data1_peak1 =  np.genfromtxt('DataFiles/H2D2Data1Peak1.csv', delimiter=','
data1_peak2 =  np.genfromtxt('DataFiles/H2D2Data1Peak2.csv', delimiter=','

data2 =  np.genfromtxt('DataFiles/H2D2Data2.csv', delimiter=',', dtype=str
data2_peak1 =  np.genfromtxt('DataFiles/H2D2Data2Peak1.csv', delimiter=','
data2_peak2 =  np.genfromtxt('DataFiles/H2D2Data2Peak2.csv', delimiter=','

data3 =  np.genfromtxt('DataFiles/H2D2Data3.csv', delimiter=',', dtype=str
data3_peak1 =  np.genfromtxt('DataFiles/H2D2Data3Peak1.csv', delimiter=','
data3_peak2 =  np.genfromtxt('DataFiles/H2D2Data3Peak2.csv', delimiter=','

data4 =  np.genfromtxt('DataFiles/H2D2Data4.csv', delimiter=',', dtype=str
data4_peak1 =  np.genfromtxt('DataFiles/H2D2Data4Peak1.csv', delimiter=','
data4_peak2 =  np.genfromtxt('DataFiles/H2D2Data4Peak2.csv', delimiter=','

data5 =  np.genfromtxt('DataFiles/Full_Data_copy.csv', delimiter=',', dtyp

# split columns from data into x and y values
x_data_m = [float(row[0]) if is_float(row[0]) else np.nan for row in datam
y_data_m = [float(row[1]) if is_float(row[1]) else np.nan for row in datam
x_data_m_Peak1 = [float(row[0]) if is_float(row[0]) else np.nan for row in
y_data_m_Peak1 = [float(row[1]) if is_float(row[1]) else np.nan for row in

x_data_1 = [float(row[0]) if is_float(row[0]) else np.nan for row in data1
y_data_1 = [float(row[1]) if is_float(row[1]) else np.nan for row in data1
x_data_1_peak1 = [float(row[0]) if is_float(row[0]) else np.nan for row in
y_data_1_peak1 = [float(row[1]) if is_float(row[1]) else np.nan for row in
x_data_1_peak2 = [float(row[0]) if is_float(row[0]) else np.nan for row in
y_data_1_peak2 = [float(row[1]) if is_float(row[1]) else np.nan for row in

x_data_2 = [float(row[0]) if is_float(row[0]) else np.nan for row in data2
```

```
y_data_2 = [float(row[1]) if is_float(row[1]) else np.nan for row in data2
x_data_2_peak1 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_2_peak1 = [float(row[1]) if is_float(row[1]) else np.nan for row ir
x_data_2_peak2 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_2_peak2 = [float(row[1]) if is_float(row[1]) else np.nan for row ir

x_data_3 = [float(row[0]) if is_float(row[0]) else np.nan for row in data3
y_data_3 = [float(row[1]) if is_float(row[1]) else np.nan for row in data3
x_data_3_peak1 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_3_peak1 = [float(row[1]) if is_float(row[1]) else np.nan for row ir
x_data_3_peak2 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_3_peak2 = [float(row[1]) if is_float(row[1]) else np.nan for row ir

x_data_4 = [float(row[0]) if is_float(row[0]) else np.nan for row in data4
y_data_4 = [float(row[1]) if is_float(row[1]) else np.nan for row in data4
x_data_4_peak1 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_4_peak1 = [float(row[1]) if is_float(row[1]) else np.nan for row ir
x_data_4_peak2 = [float(row[0]) if is_float(row[0]) else np.nan for row ir
y_data_4_peak2 = [float(row[1]) if is_float(row[1]) else np.nan for row ir

x_data_5 = [float(row[0]) if is_float(row[0]) else np.nan for row in data5
y_data_5 = [float(row[1]) if is_float(row[1]) else np.nan for row in data5
```

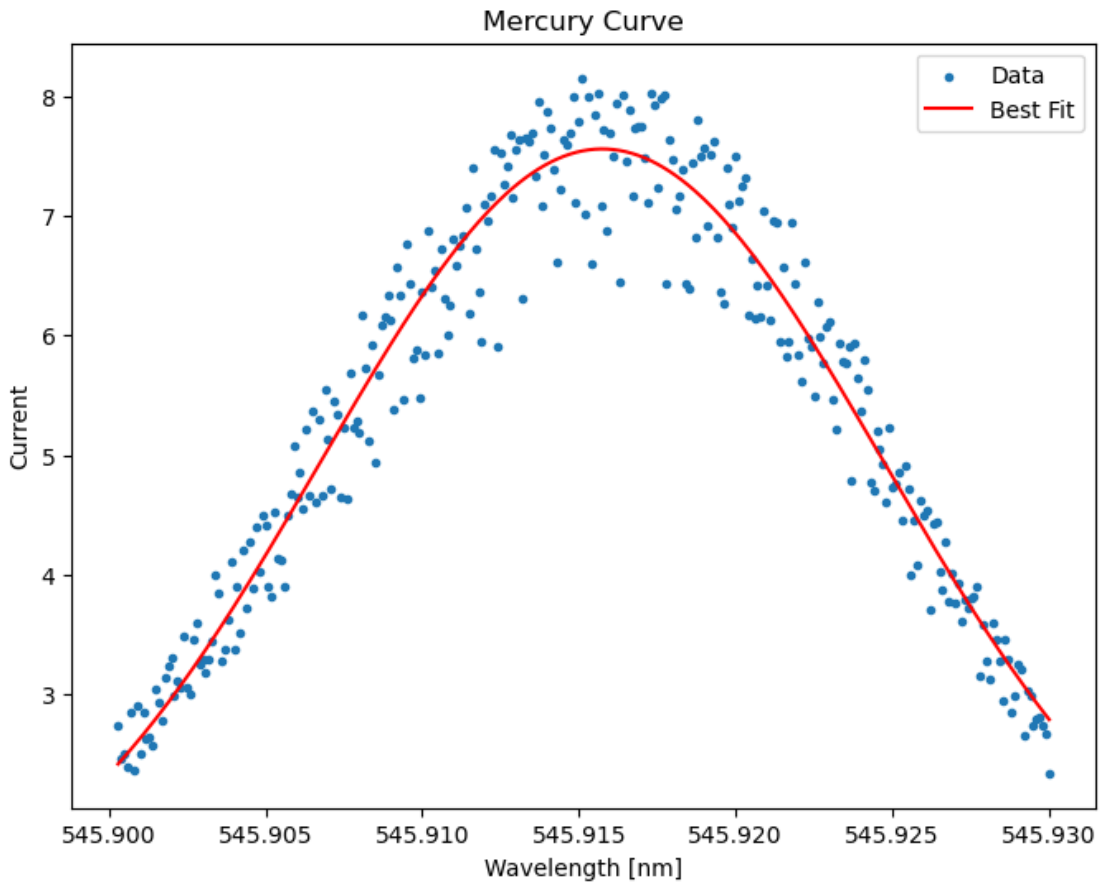
Mercury Calibration

In [24]:
```
# plot all data

plt.figure(figsize=(8, 6))
plt.scatter(x_data_m, y_data_m, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title('Mercury')
plt.legend()
plt.show()
```



In [25]:

```
#x_min = 545.901
#x_max = 545.93
A1 = 7
B1 = 545.91
C1 = 0.01
D = 1

params, covariance = curve_fit(fgaussian, x_data_m_Peak1, y_data_m_Peak1,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.figure(figsize=(8, 6))
plt.scatter(x_data_m_Peak1, y_data_m_Peak1, label='Data', marker='.')
plt.plot(x_data_m_Peak1, fgaussian(x_data_m_Peak1, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('Mercury Curve')
plt.legend()
plt.show()

print('Peak 1 (0.081 MeV):')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
print(f'D = {D_fit:.8f} ± {uncert[3]:.8f}')
```

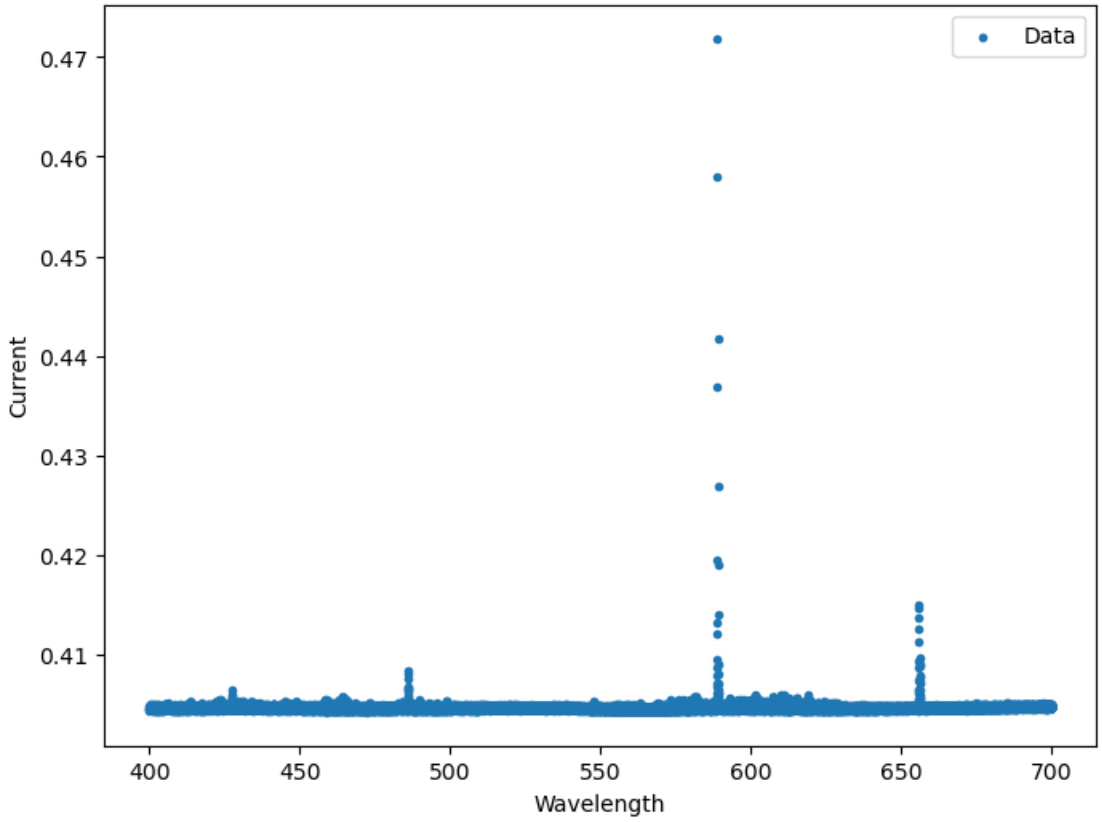


```
Peak 1 (0.081 MeV):

A1 = 6.68835828 ± 0.31518634
B1 = 545.91574142 ± 0.00006202
C1 = 0.00900771 ± 0.00038161
D = 0.87393753 ± 0.33408648
```

Full Spectrum

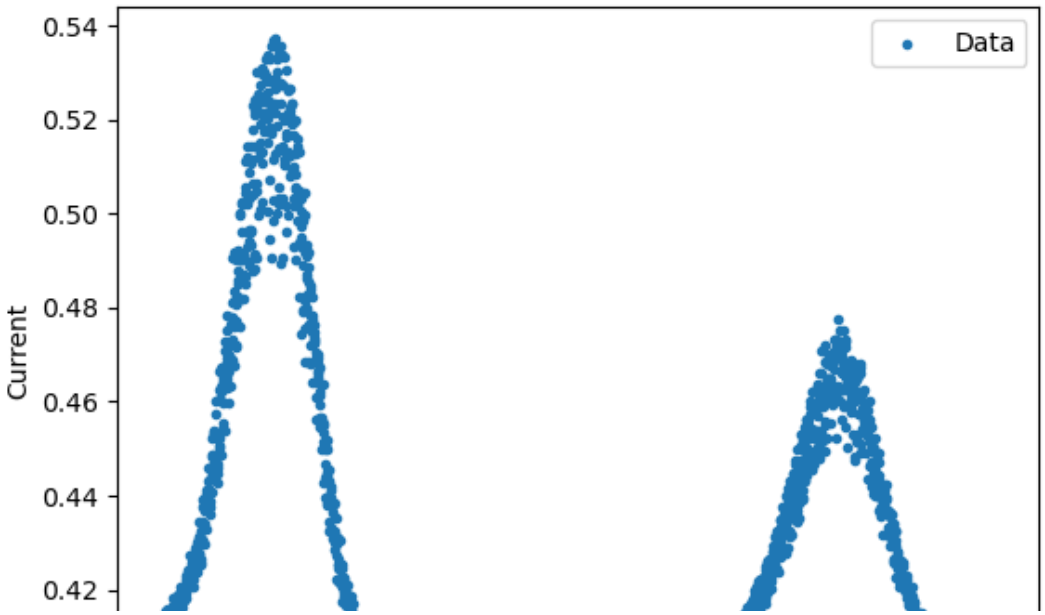
In [26]:

```
plt.figure(figsize=(8, 6))
plt.scatter(x_data_5, y_data_5, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title(' ')
plt.legend()
plt.show()
```



656.279 nm

In [27]:
```
plt.scatter(x_data_1, y_data_1, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title(' ')
plt.legend()
plt.show()
```



Peak 1

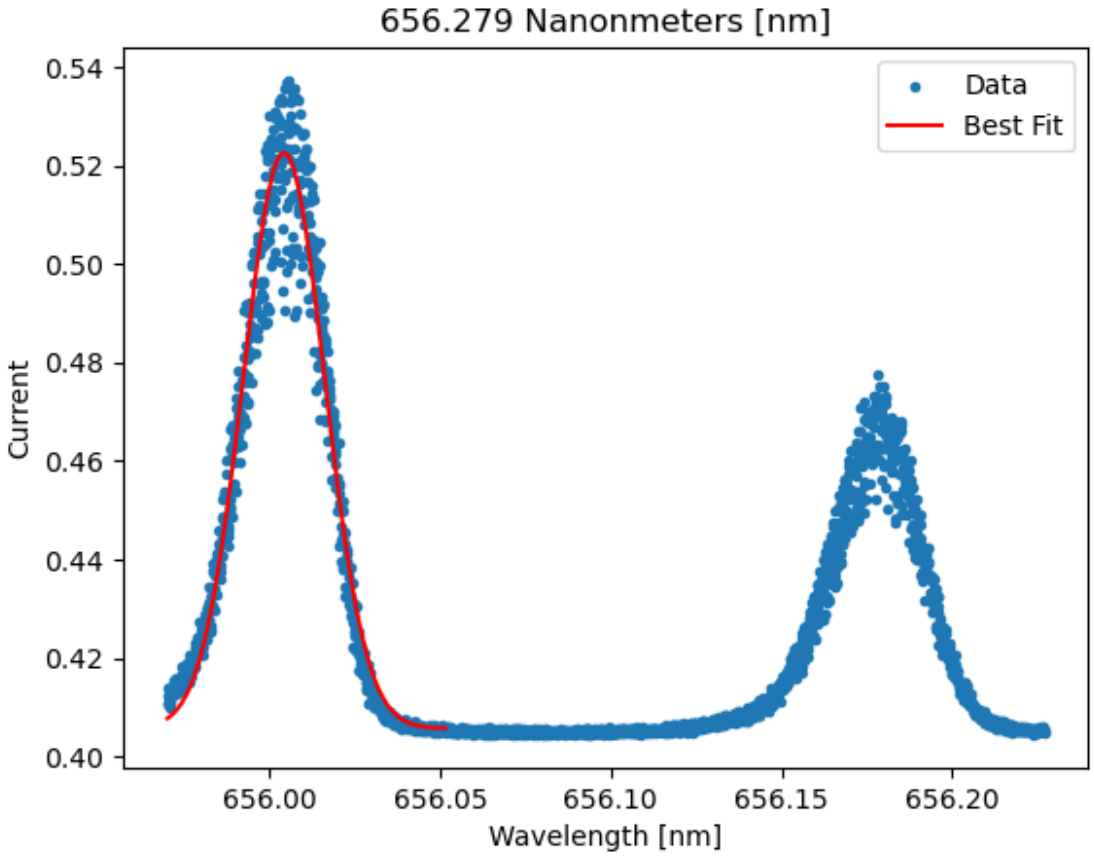
(655.95, 656.05)

Peak 2

(656.10, 656.25)

In [28]:

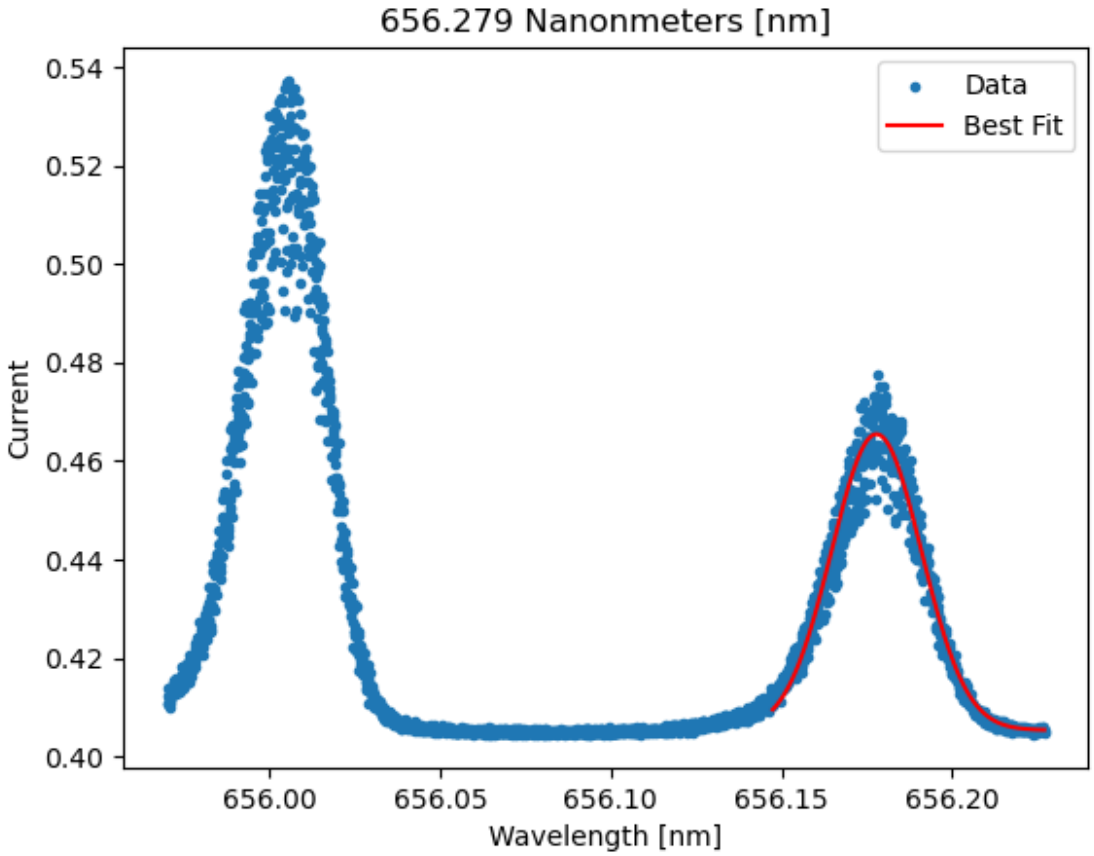
```
A1 = 0.54
B1 = 656
C1 = .01
D = 1

params, covariance = curve_fit(fgaussian, x_data_1_peak1, y_data_1_peak1,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_1, y_data_1, label='Data', marker='.')
plt.plot(x_data_1_peak1, fgaussian(x_data_1_peak1, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('656.279 Nanonmeters [nm]')
plt.legend()
plt.show()

print('656.279 Nanonmeters [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



```
656.279 Nanonmeters [nm]

A1 = 0.11682109 ± 0.00067805
B1 = 656.00413598 ± 0.00006824
C1 = 0.01199412 ± 0.00009666
```

In [29]:

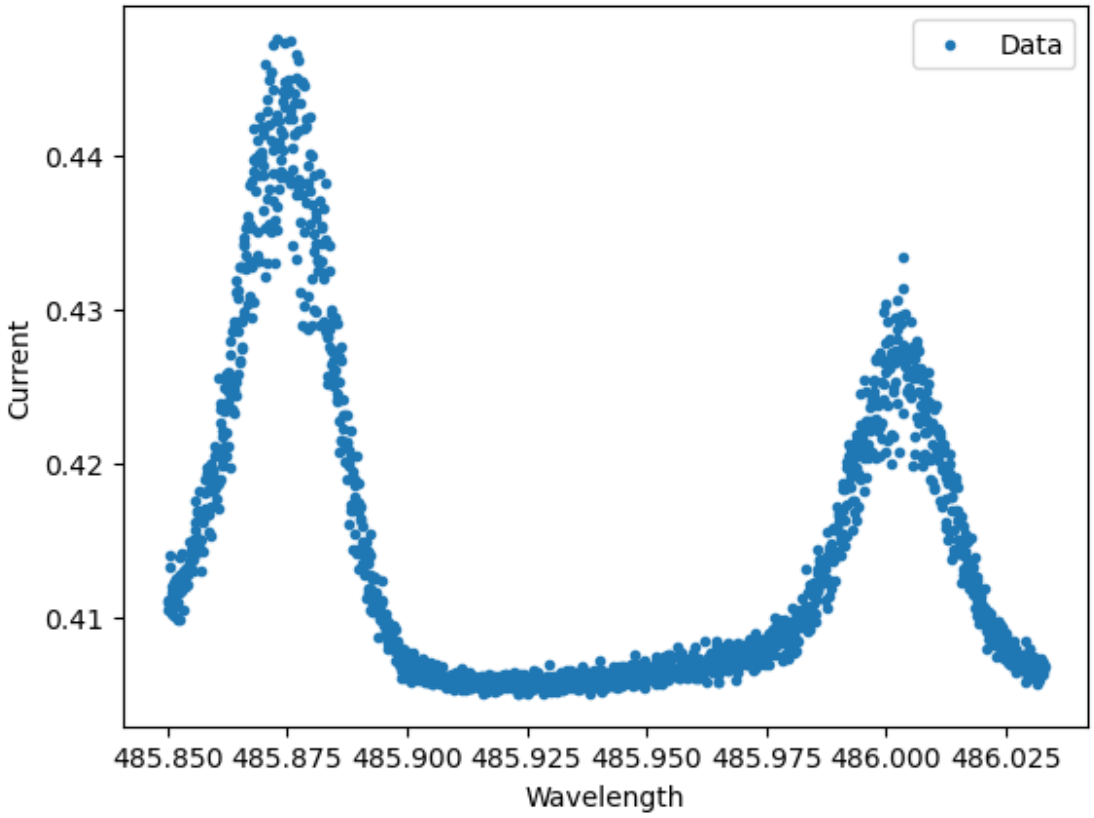
```
A1 = 0.54
B1 = 656.156
C1 = .05
D = 1

params, covariance = curve_fit(fgaussian, x_data_1_peak2, y_data_1_peak2,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_1, y_data_1, label='Data', marker='.')
plt.plot(x_data_1_peak2, fgaussian(x_data_1_peak2, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('656.279 Nanonmeters [nm]')
plt.legend()
plt.show()

print('656.279 Nanonmeters [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



```
656.279 Nanonmeters [nm]

A1 = 0.06007533 ± 0.00037762
B1 = 656.17789794 ± 0.00007609
C1 = 0.01316435 ± 0.00011315
```

486.135 nm

In [30]:
```
plt.scatter(x_data_2, y_data_2, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title('')
plt.legend()
plt.show()
```



Peak 1

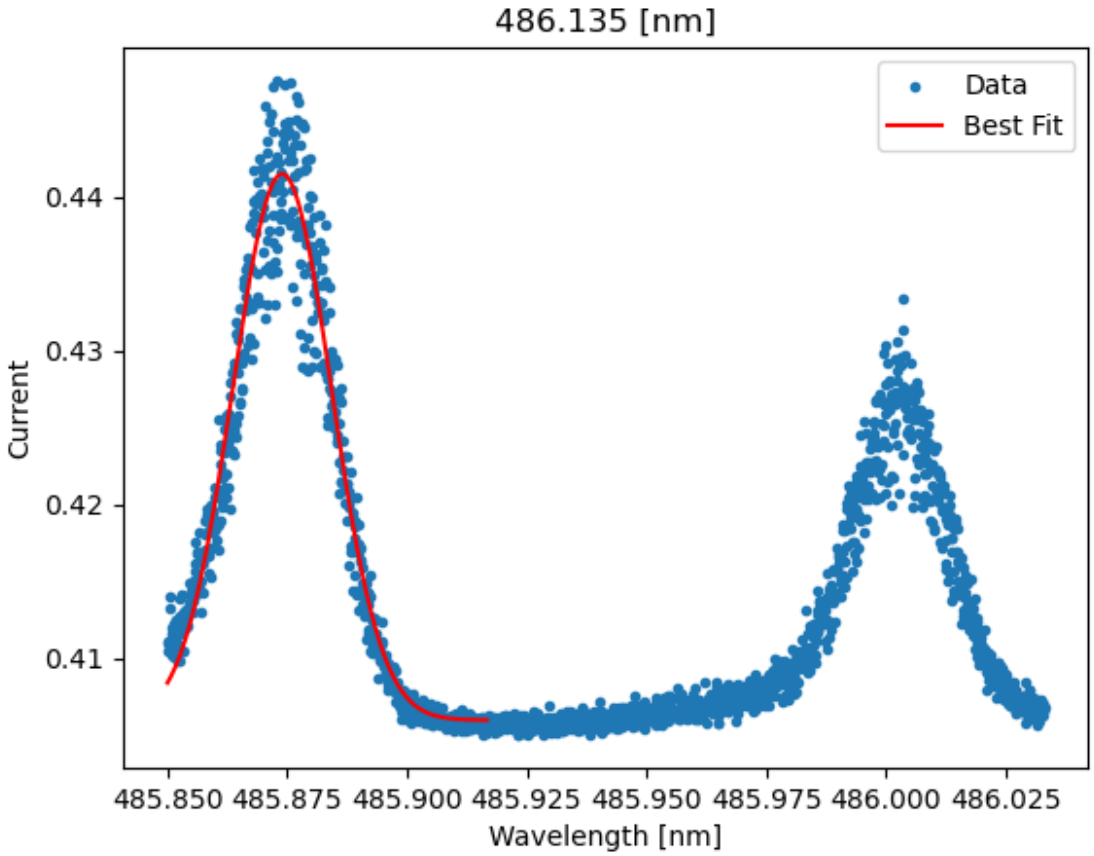
(485, 485.9)

Peak 2

(485.975, 486.025)

In [31]:

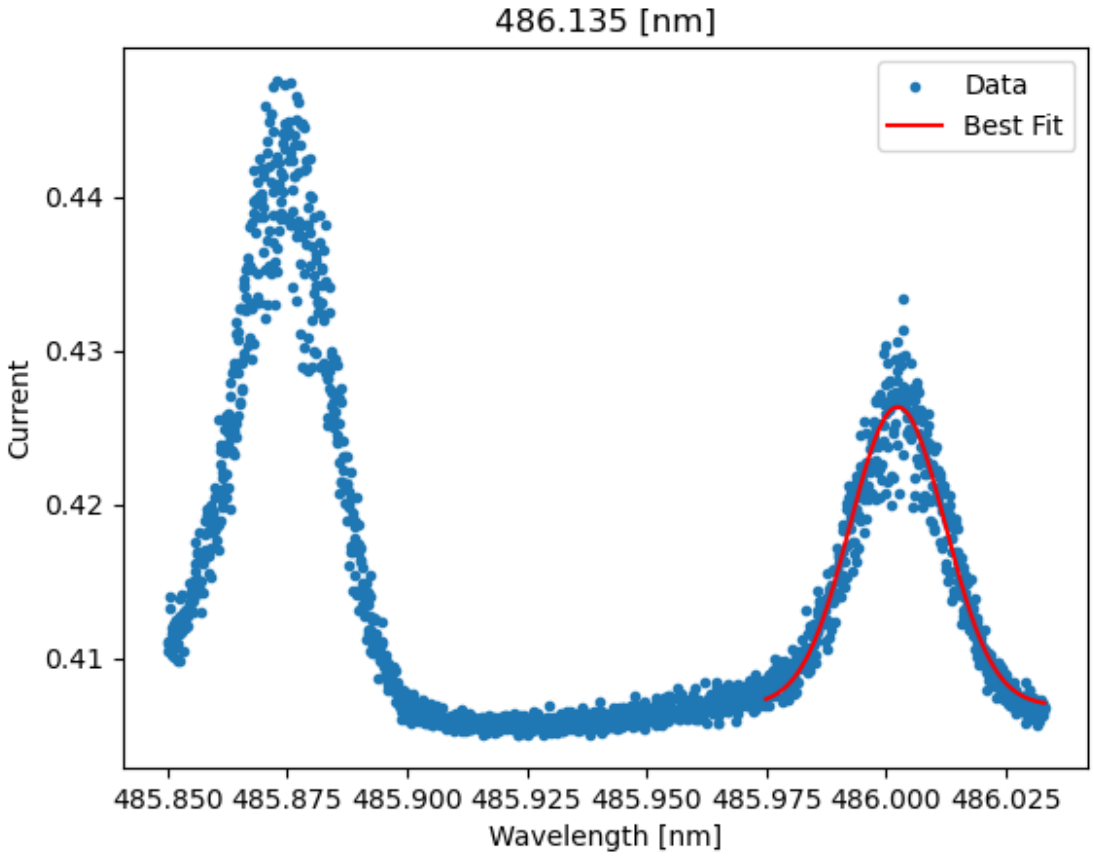
```
A1 = 0.45
B1 = 485.8
C1 = .05
D = 0

params, covariance = curve_fit(fgaussian, x_data_2_peak1, y_data_2_peak1,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_2, y_data_2, label='Data', marker='.')
plt.plot(x_data_2_peak1, fgaussian(x_data_2_peak1, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('486.135 [nm]')
plt.legend()
plt.show()

print('486.135 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



```
486.135 [nm]

A1 = 0.03550120 ± 0.00025833
B1 = 485.87392625 ± 0.00007253
C1 = -0.01032817 ± 0.00010056
```

In [32]:

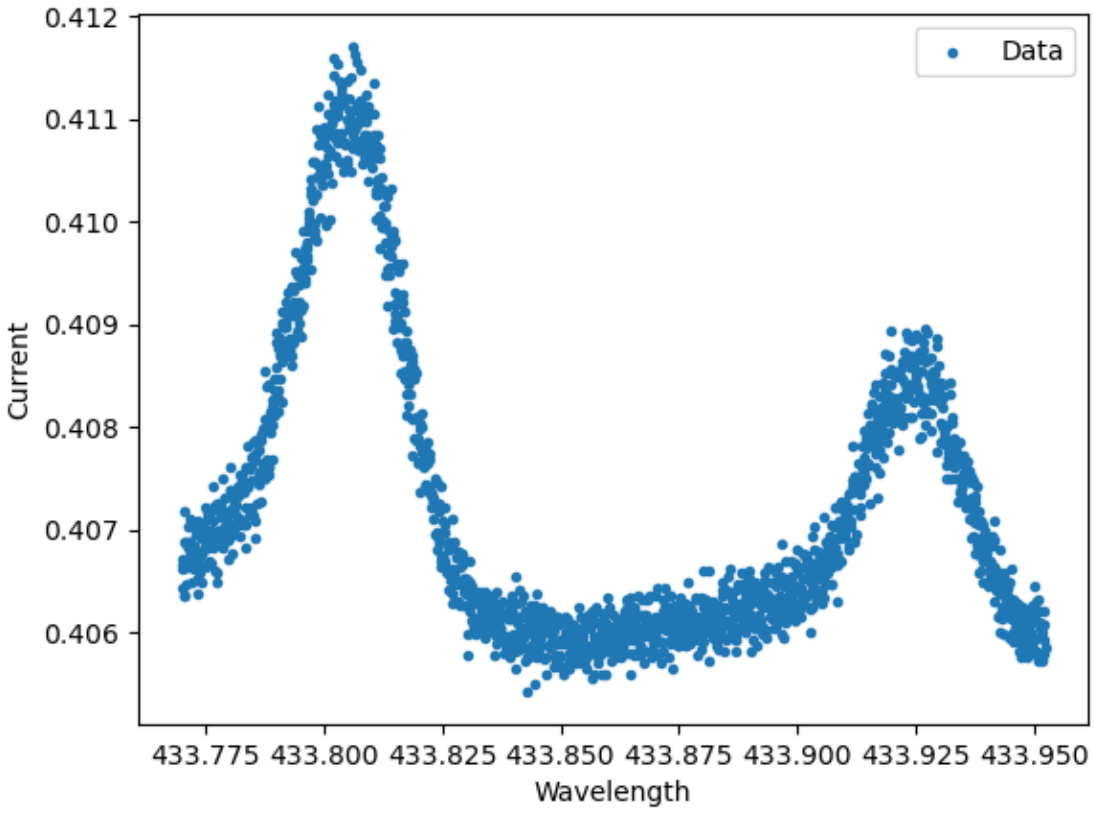
```
A1 = 0.43
B1 = 486
C1 = .02
D = 0

params, covariance = curve_fit(fgaussian, x_data_2_peak2, y_data_2_peak2,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_2, y_data_2, label='Data', marker='.')
plt.plot(x_data_2_peak2, fgaussian(x_data_2_peak2, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('486.135 [nm]')
plt.legend()
plt.show()

print('486.135 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



```
486.135 [nm]

A1 = 0.01939941 ± 0.00020042
B1 = 486.00249349 ± 0.00008774
C1 = -0.00992384 ± 0.00015021
```

434.0472 nm

In [33]:
```
plt.scatter(x_data_3, y_data_3, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title('')
plt.legend()
plt.show()
```



Peak 1

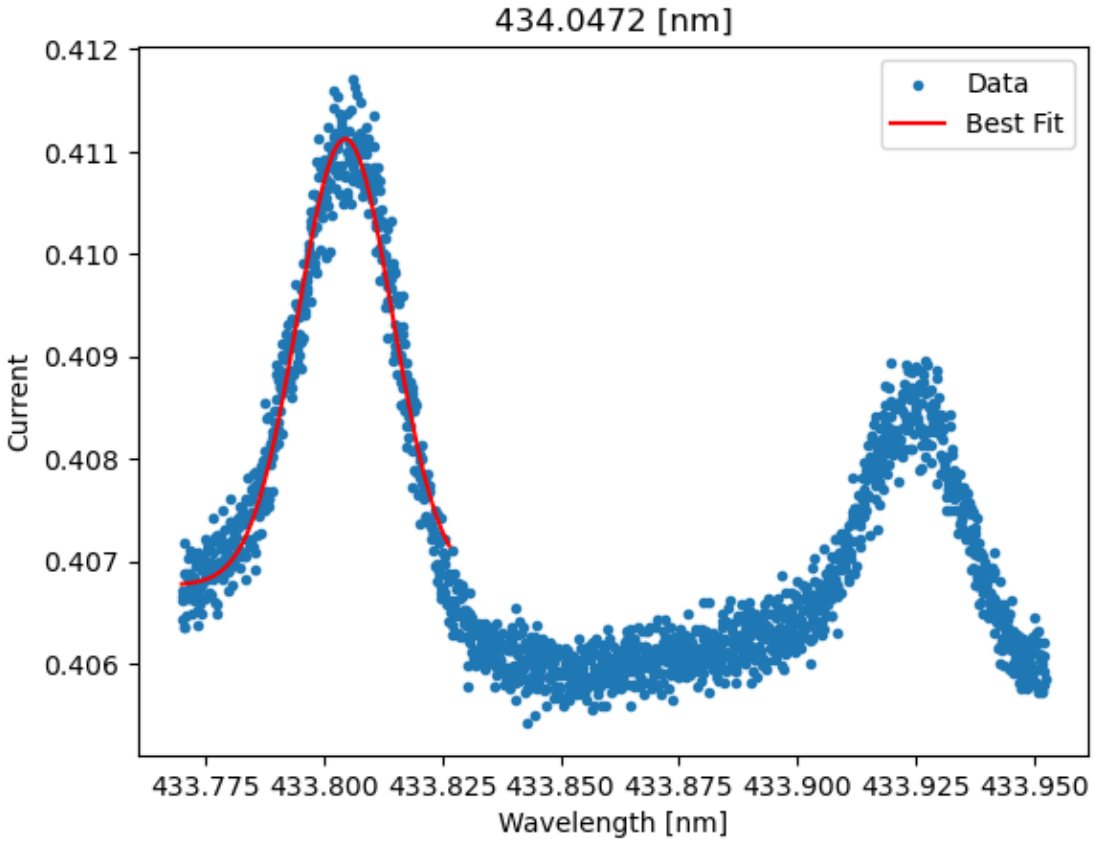
(433.775, 433.820)

Peak 2

(433.900, 433.950)

In [34]:

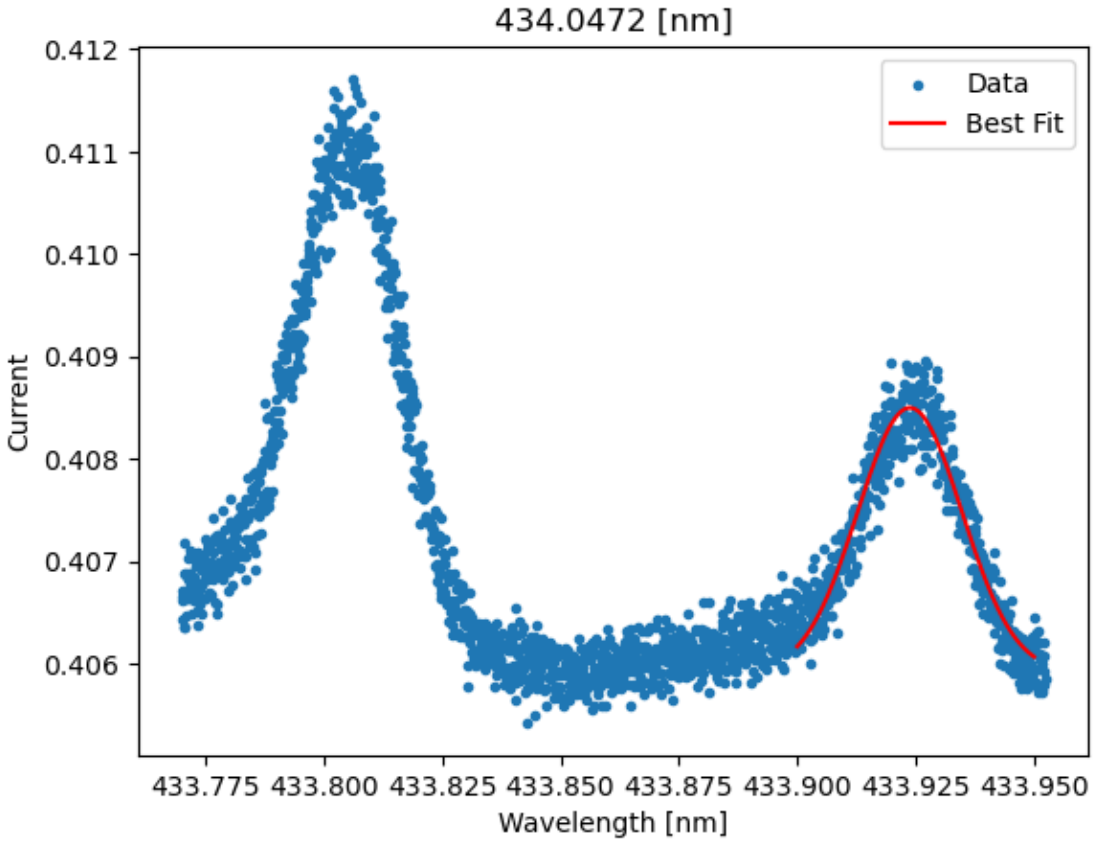
```
A1 = 0.412
B1 = 433.8
C1 = .1
D = 0

params, covariance = curve_fit(fgaussian, x_data_3_peak1, y_data_3_peak1,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_3, y_data_3, label='Data', marker='.')
plt.plot(x_data_3_peak1, fgaussian(x_data_3_peak1, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('434.0472 [nm]')
plt.legend()
plt.show()

print('434.0472 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



```
434.0472 [nm]

A1 = 0.00435986 ± 0.00003734
B1 = 433.80452053 ± 0.00007416
C1 = 0.00997645 ± 0.00011759
```

In [35]:

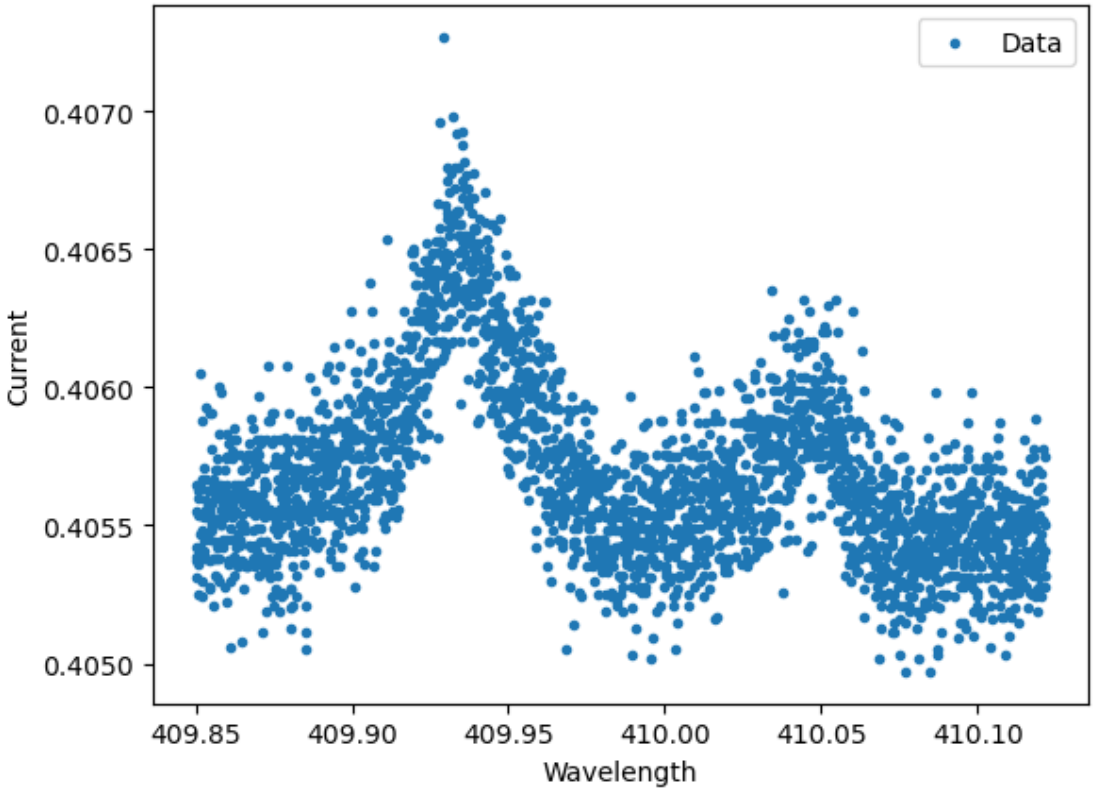
```
A1 = 0.43
B1 = 433.925
C1 = .02
D = 0

params, covariance = curve_fit(fgaussian, x_data_3_peak2, y_data_3_peak2,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_3, y_data_3, label='Data', marker='.')
plt.plot(x_data_3_peak2, fgaussian(x_data_3_peak2, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('434.0472 [nm]')
plt.legend()
plt.show()

print('434.0472 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```



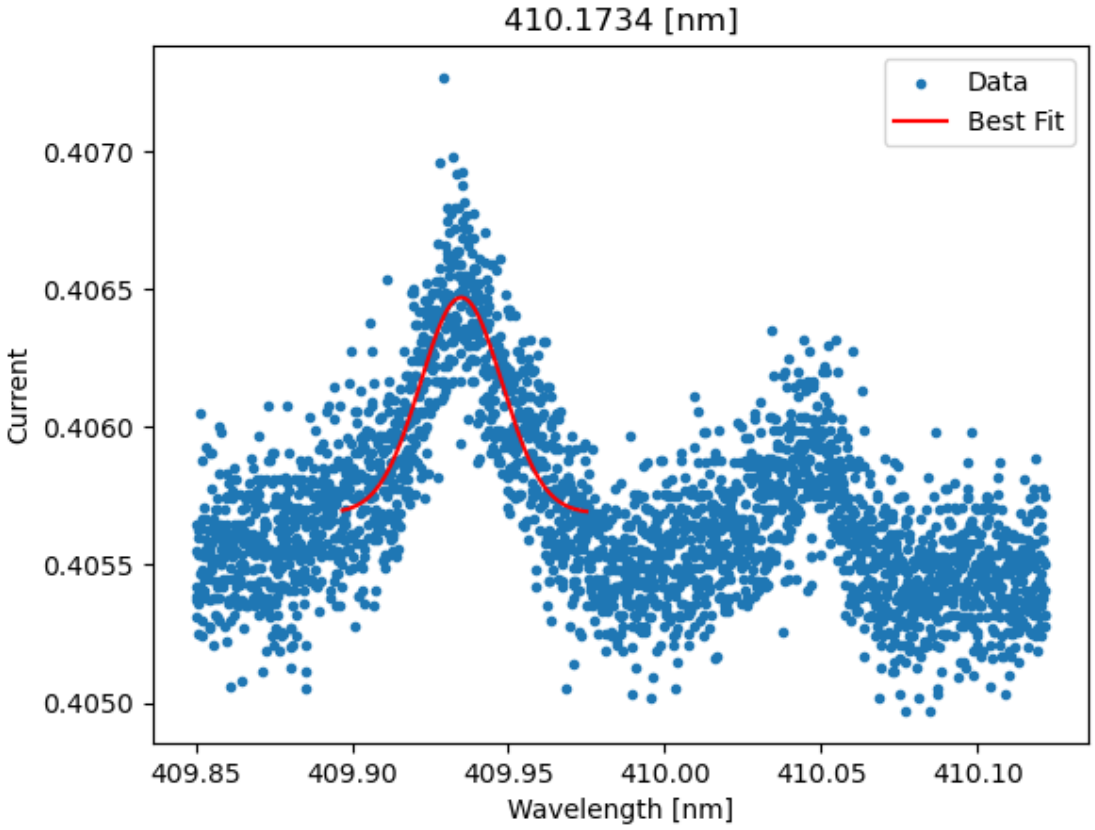
```
434.0472 [nm]

A1 = 0.00258533 ± 0.00005235
B1 = 433.92375671 ± 0.00010745
C1 = 0.01102500 ± 0.00029061
```

410.1734 nm

In [36]:
```
plt.scatter(x_data_4, y_data_4, label='Data', marker='.')
plt.xlabel('Wavelength')
plt.ylabel('Current')
plt.title('')
plt.legend()
plt.show()
```

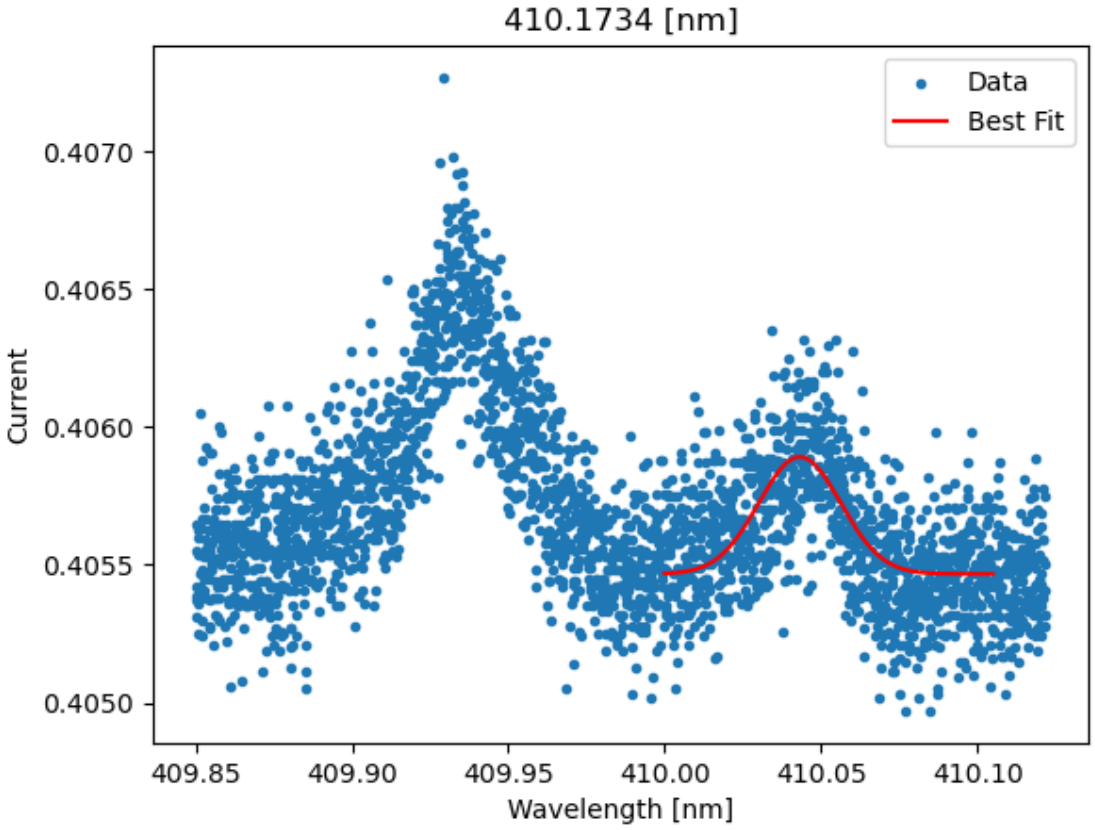


In [37]:
```
A1 = 0.407
B1 = 409.925
C1 = .01
D = 0

params, covariance = curve_fit(fgaussian, x_data_4_peak1, y_data_4_peak1,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_4, y_data_4, label='Data', marker='.')
plt.plot(x_data_4_peak1, fgaussian(x_data_4_peak1, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('410.1734 [nm]')
plt.legend()
plt.show()

print('410.1734 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```




```
410.1734 [nm]

A1 = 0.00078410 ± 0.00002220
B1 = 409.93494744 ± 0.00032382
C1 = 0.01299440 ± 0.00053964
```

In [38]:
```
A1 = 0.43
B1 = 410.05
C1 = .01
D = 0

params, covariance = curve_fit(fgaussian, x_data_4_peak2, y_data_4_peak2,
                               p0=[A1, B1, C1, D])

A1_fit, B1_fit, C1_fit, D_fit = params
uncert = np.sqrt(np.diag(covariance))

plt.scatter(x_data_4, y_data_4, label='Data', marker='.')
plt.plot(x_data_4_peak2, fgaussian(x_data_4_peak2, *params), label='Best F
plt.xlabel('Wavelength [nm]')
plt.ylabel('Current')
plt.title('410.1734 [nm]')
plt.legend()
plt.show()

print('410.1734 [nm]')
print()
print(f'A1 = {A1_fit:.8f} ± {uncert[0]:.8f}')
print(f'B1 = {B1_fit:.8f} ± {uncert[1]:.8f}')
print(f'C1 = {C1_fit:.8f} ± {uncert[2]:.8f}')
```




```
410.1734 [nm]

A1 = 0.00042482 ± 0.00001670
B1 = 410.04316769 ± 0.00053846
C1 = 0.01310418 ± 0.00068792
```

Plot

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$$

$$y = \frac{1}{\lambda} \qquad x = \frac{1}{n_i^2}$$

$$y = R\left(\frac{1}{2^2} - x\right) \rightarrow y = \frac{R}{4} - Rx$$

Note: Rydberg Constant for an Infinitely Massive Nucleus

$$R_\infty = \frac{1}{hc}\frac{E_0}{2} = \frac{1}{2}\frac{1}{hc}a^2 m_e c^2 = \frac{1}{1240\ \text{eV nm}}\frac{1}{137^2}(0.511 \times 10^6\ \text{eV}) = 0.01097\ \text{nm}^{-1}$$

Rydberg Constant for Deuterium and Hydrogen:

$$R_D = \frac{\mu_D}{m_e} R_\infty$$

$$R_H = \frac{\mu_H}{m_e} R_\infty$$

You can use these to find the reduced mass/electron mass ratio by dividing the specific Rydberg constant by the Rydberg constant for an infinitely massive nucleus.

$$\text{e.g.} \qquad R_D = \frac{\mu_D}{m_e} R_\infty$$

$$\frac{\mu_D}{m_e} = \frac{R_D}{R_\infty}$$

In [39]:

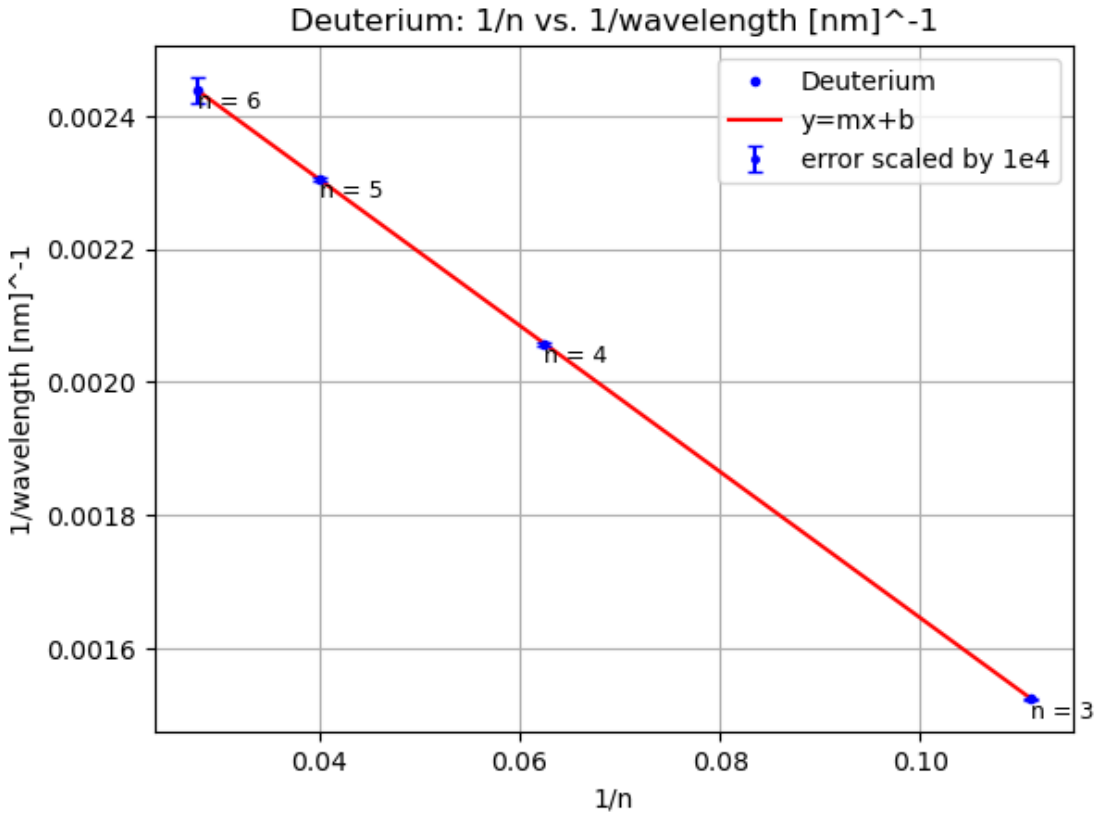
```
R_inf = 0.01097 # nm^-1

i = np.array([1.000224458, 1.000186905,
              1.000228641, 1.000228751]) # indices of refraction

ld = np.array([656.00413598, 485.87392625,
               433.80452053, 409.93494744]) # wavelengths for deuterium

yd = 1/(ld*i) # y for deuterium

ud = np.array([0.00006824, 0.00007253,
               0.00007416, 0.00032382]) # deuterium uncert

lh = np.array([656.17789794, 486.00249349,
               433.92375671, 410.04316769]) # wavelengths for hydrogen

yh = 1/(lh*i) # y for hydrogen

uh = np.array([0.00007609, 0.00008774,
               0.00010745, 0.00053846]) # hydrogen uncert

n = np.array([3, 4, 5, 6]) # energy level number

x_n = 1/n**2 # x

yd_u = 1/(i*(ld-ud)) # upper end of the error for deuterium

yh_u = 1/(i*(lh-uh)) # upper end of error for hydrogen

yd_err = abs(yd - yd_u) # error for y deuterium
yh_err = abs(yh - yh_u) # error for y hydrogen

print(yd)
print()
print(yd_u)
print()
print(yd_err)
print()
print(yh_err)
```

```
[0.00152404 0.00205776 0.00230466 0.00243885]

[0.00152404 0.00205776 0.00230466 0.00243886]

[1.58536198e-10 3.07177492e-10 3.93987427e-10 1.92652562e-09]

[1.76679828e-10 3.71397990e-10 5.70532496e-10 3.20180975e-09]
```

Deuterium

In [40]:

```
slope, intercept, r_value, p_value, std_err = stats.linregress(x_n, yd)

result = stats.linregress(x_n, yd)

data_labels = ['n = 3', 'n = 4',
               'n = 5', 'n = 6']

for x, y, label in zip(x_n, yd, data_labels):
    plt.text(x, y, label, fontsize=9, ha='left', va='top')

res = stats.linregress(x_n, yd)
plt.plot(x_n, yd, '.', color='b', label='Deuterium')
plt.plot(x_n, res.intercept + res.slope*x_n, 'r', label='y=mx+b')
plt.errorbar(x_n, yd, yerr=1e4*yd_err, fmt='.', color='b',
             label='error scaled by 1e4', markersize=5, capsize=3)

plt.xlabel('1/n')
plt.ylabel('1/wavelength [nm]^-1')
plt.title('Deuterium: 1/n vs. 1/wavelength [nm]^-1')
plt.grid(True)
plt.legend()
plt.show()

# chi_sq = np.sum((yd-(res.intercept+res.slope*x_n))**2/yd_err**2)

print(f"Linear fit: y = ({res.slope:.8f}+/-{result.stderr:.8f})x + ({res.i
#print()
#print(f'Chi-squared: {chi_sq}')
```




```
Linear fit: y = (-0.01097763+/-0.00000087)x + (0.00274380+/-0.00000006)
```

In [41]:

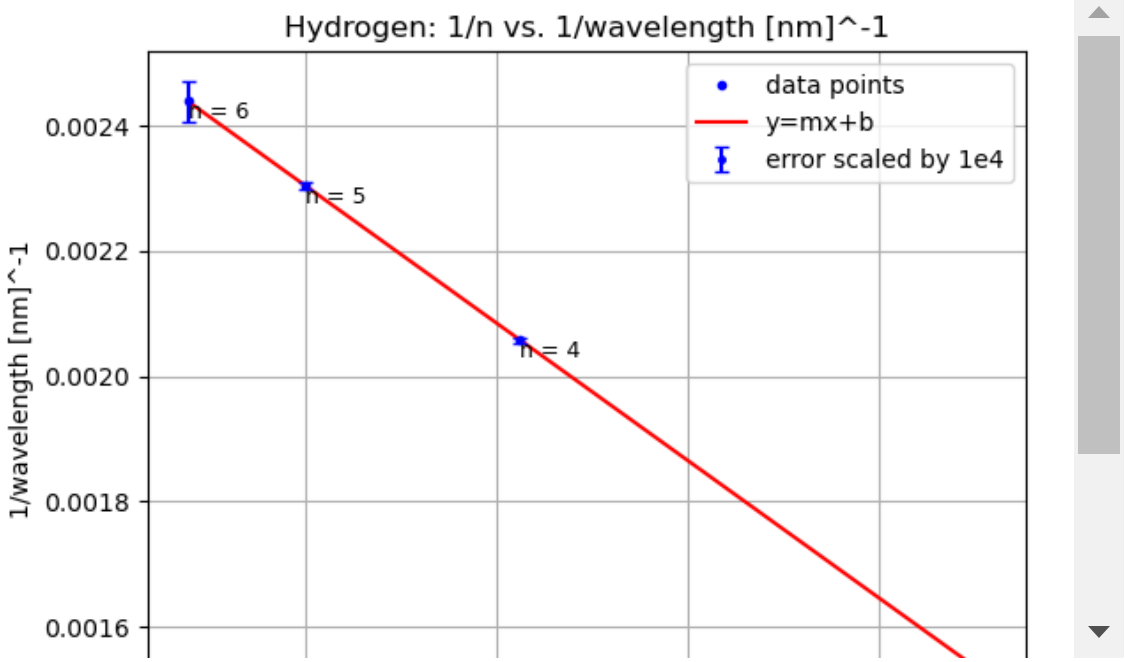
```
Rd = 0.01097763 # nm^-1
sigma_Rd = 0.00000087
Rd_r = 0.999728

print(f'Rydberg constant for Deuterium: {Rd}')
print()
print(f'Calculated reduced mass/electron mass ratio: {Rd/R_inf}')
print()
print(f'Actual reduced mass/electron mass ratio: {Rd_r}')
print()
print(f'Absolute error for reduced mass/electron mass ratio: {abs(Rd - Rd_
```

```
Rydberg constant for Deuterium: 0.01097763

Calculated reduced mass/electron mass ratio: 1.0006955332725616

Actual reduced mass/electron mass ratio: 0.999728

Absolute error for reduced mass/electron mass ratio: 0.98875037
```

Hydrogen

In [42]:

```
slope, intercept, r_value, p_value, std_err = stats.linregress(x_n, yh)

result = stats.linregress(x_n, yh)

data_labels = ['n = 3', 'n = 4',
               'n = 5', 'n = 6']

for x, y, label in zip(x_n, yh, data_labels):
    plt.text(x, y, label, fontsize=9, ha='left', va='top')

res = stats.linregress(x_n, yh)
plt.plot(x_n, yh, '.', color='blue', label='data points')
plt.plot(x_n, res.intercept + res.slope*x_n, 'r', label='y=mx+b')
plt.errorbar(x_n, yh, yerr=1e4*yh_err, fmt='.', color='blue',
             label='error scaled by 1e4', markersize=5, capsize=3)

plt.xlabel('1/n')
plt.ylabel('1/wavelength [nm]^-1')
plt.title('Hydrogen: 1/n vs. 1/wavelength [nm]^-1')
plt.grid(True)
plt.legend()
plt.show()

print(f"Linear fit: y = ({res.slope:.8f}+/-{result.stderr:.8f})x + ({res.i
```



In [43]:
```
Rh = 0.01097462 # nm^-1
sigma_Rh = 0.00000100
Rh_r = 0.999457

print(f'Rydberg constant for Hydrogen: {Rh}')
print()
print(f'Reduced mass/electron mass ratio: {Rh/R_inf}')
print()
print(f'Actual reduced mass/electron mass ratio: {0.999457}')
print()
print(f'Absolute error for reduced mass/electron mass ratio: {abs(Rh - Rh_
```

```
Rydberg constant for Hydrogen: 0.01097462

Reduced mass/electron mass ratio: 1.0004211485870556

Actual reduced mass/electron mass ratio: 0.999457

Absolute error for reduced mass/electron mass ratio: 0.98848238
```

$$\frac{R_D}{R_H} = \frac{\frac{\mu_D}{m_e}R_\infty}{\frac{\mu_H}{m_e}R_\infty} = \frac{\frac{1}{1+\frac{m_e}{M_D}}R_\infty}{\frac{1}{1+\frac{m_e}{M_H}}R_\infty} = \frac{1+\frac{m_e}{M_H}}{1+\frac{m_e}{M_D}} \approx \left(1+\frac{m_e}{M_H}\right)\left(1-\frac{m_e}{M_D}\right)$$

Neglecting second order terms.

$$\frac{R_D}{R_H} \approx 1 + m_e\left(\frac{1}{M_H} - \frac{1}{M_D}\right) = 1 + \frac{m_e}{M_H}\left(1 - \frac{M_H}{M_D}\right)$$

$$\frac{m_e}{M_H} \approx \frac{\frac{R_D}{R_H} - 1}{1 - \frac{M_H}{M_D}}$$

From pre-lab writeup:

$$\frac{M_D}{M_H} = 1.999$$

$$\frac{m_e}{M_H} \approx \frac{\frac{R_D}{R_H} - 1}{1 - 1.999} = 2.001\left(\frac{R_D}{R_H} - 1\right)$$

In [60]:
```
print(f'Ratio of the Rydberg constant for Deuterium and the Ryderg constar
print()
print(f'Electron/proton (Hydrogen nucleus) mass ratio: {2.001*((Rd/Rh)-1)}
print()
print(f'Proton/electron mass ratio: {1/(2.001*((Rd/Rh)-1))}')
print()
print(f'Our proton/electron mass ratio is within {(abs(1/(2.001*((Rd/Rh)-1
```

```
Ratio of the Rydberg constant for Deuterium and the Ryderg constant for
Hydrogen: Rd/Rh = 1.0002742691774296

Electron/proton (Hydrogen nucleus) mass ratio: 0.000548812624036559

Proton/electron mass ratio: 1822.1155203116928

Our proton/electron mass ratio is within 0.8% the published value of 183
6.
```

In [ ]:
```
```