Assignment 3 - Data Estimation

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1 Aim of the Assignment

The objective of this assignment is to estimate various physical parameters, such as the temperature (T), speed of light (c), Planck's constant (h), and Boltzmann's constant (k), from given spectral radiance data. The estimation is done using curve fitting techniques based on Planck's law. The goal is to analyze the data, estimate the unknown parameters, and experiment with partial application to simplify the estimation process.

2 Knowledge Prerequisites

To understand and execute this assignment, the following concepts are required: - **Planck's Law**: Understanding the physical significance and mathematical formulation of the law for blackbody radiation. - **Python Programming**: Familiarity with Python, particularly the `matplotlib` and `scipy.optimize.curve_fit` libraries. - **Curve Fitting**: Basic understanding of curve fitting techniques for data estimation.

3 Code Layout

The code provided in the Python Notebook (`EE23B110.ipynb`) follows a structured approach for estimating the physical parameters from the data:

1. **Importing Data**: The datasets (`d1.txt`, `d2.txt`, `d3.txt`, `d4.txt`) are imported, and the spectral radiance data is plotted to visualize the initial data.
2. **Estimating All Parameters (T, h, c, k)**: Using the curve fitting method, the first step is to estimate all the parameters simultaneously from the data.
3. **Partial Application and Estimation**:
   - **Estimating T**: Assuming known values for `h`, `c`, and `k`, the temperature `T` is estimated.
   - **Estimating k**: Assuming known values for `T`, `h`, and `c`, the Boltzmann constant `k` is estimated.
   - **Estimating c**: Assuming known values for `T`, `h`, and `k`, the speed of light `c` is estimated.
   - **Estimating h**: Assuming known values for `T`, `c`, and `k`, Planck's constant `h` is estimated.

   Each of these sections implements a Python function based on Planck's law and then uses curve fitting to estimate the corresponding parameter.

4 How to Run the Code

To run the code, follow these steps:

1. Ensure the Jupyter Notebook (`EE23B110.ipynb`) and the datasets (`d1.txt`, `d2.txt`, `d3.txt`, `d4.txt`) are all located in the same directory.
2. Inside the notebook, select the dataset to use by modifying the following part of the code:

   ```
   # Open and read the contents of d1.txt (You can use any data file here)
   with open('d1.txt', 'r') as file:
       lines = file.readlines()
   ```

   You can change 'd1.txt' to any other dataset file name (e.g., 'd3.txt') to test different datasets.
3. Once the dataset is chosen, run all the cells in the notebook sequentially. The code will automatically process the data, perform the curve fitting, and generate the plots.
4. The notebook will print the estimated values of the parameters and display the plots showing the data points and fitted curves.

5 Findings

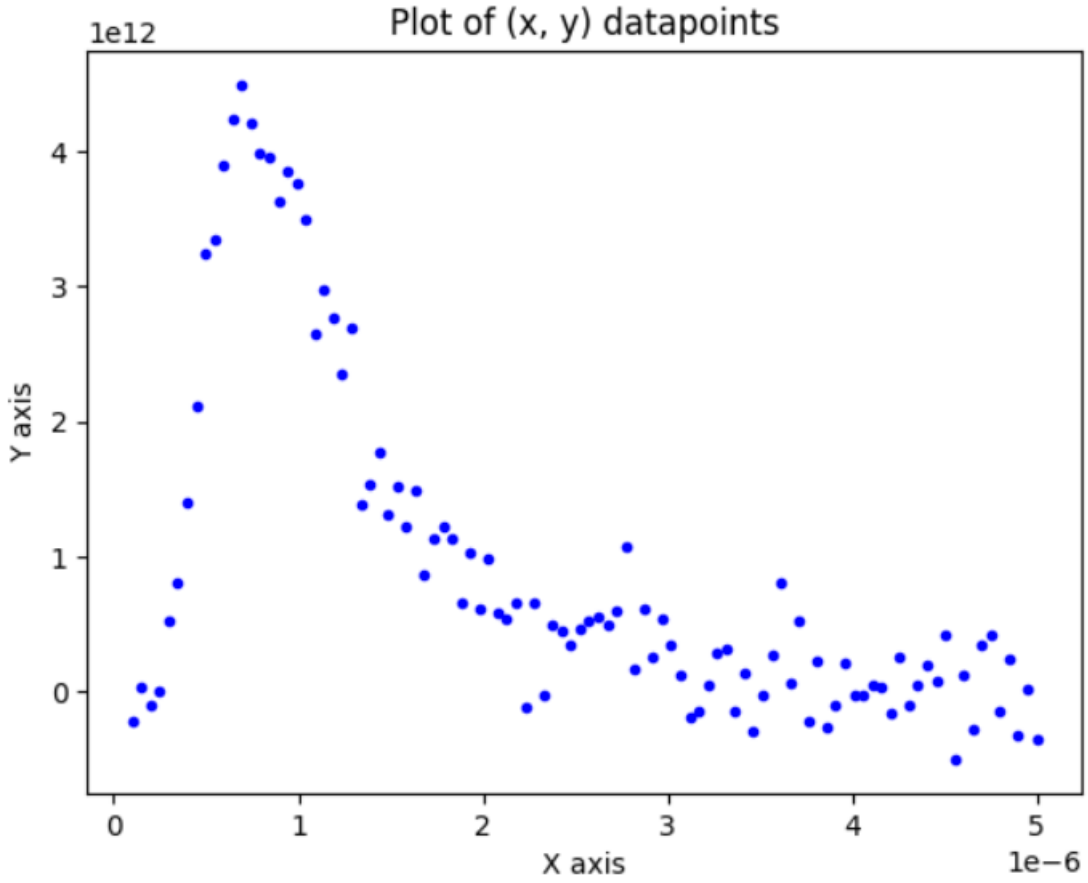
After performing the curve fitting and partial applications, the following were the key observations:

- **Initial Estimation**: Estimating all parameters (T, h, c, k) simultaneously often led to poor results due to the complexity of fitting multiple variables.
- **Initial Guess Sensitivity**: The choice of the initial guess is crucial. For accurate estimations, the initial guess should be within a range of 10^-2 to 10^+2 of the correct value. If the initial guess is too far from the correct value, the scipy.curve_fit function tends to overflow, leading to incorrect or unstable results.
- **Partial Application**: By reducing the number of unknowns (fixing some parameters), the estimations became more accurate.
- **Accuracy**: The more parameters fixed during partial application, the more accurate the fitting results became. Also, simultaneous estimation of multiple unknowns led to instability and less reliable results.

Following are the observations and values of parameters when two of the datasets d1.txt and d3.txt are used.

5.1 Dataset d1.txt

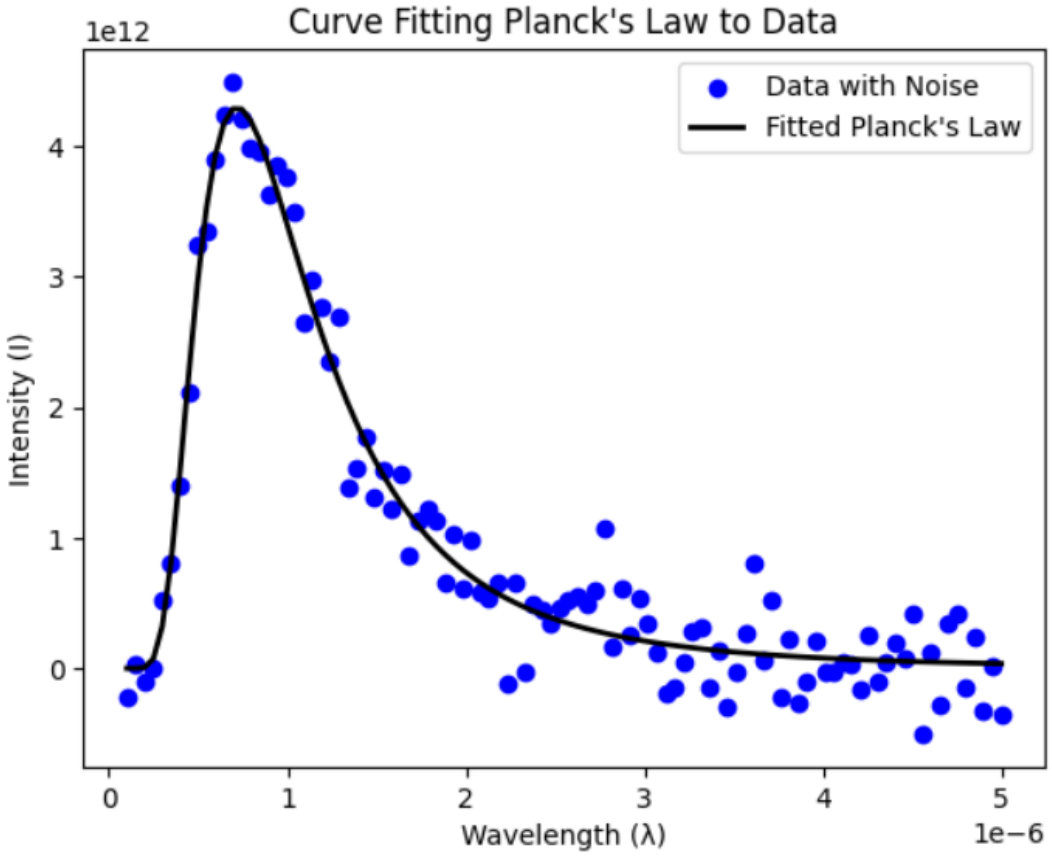
This dataset contains a 100 (x,y) points, with noise.



5.1.1 Values When All Parameters are Estimated Simultaneously

In this section, the parameter values estimated when all parameters (T, h, c, k) were fitted simultaneously. The results often exhibited significant deviations due to the complexity of fitting multiple variables.

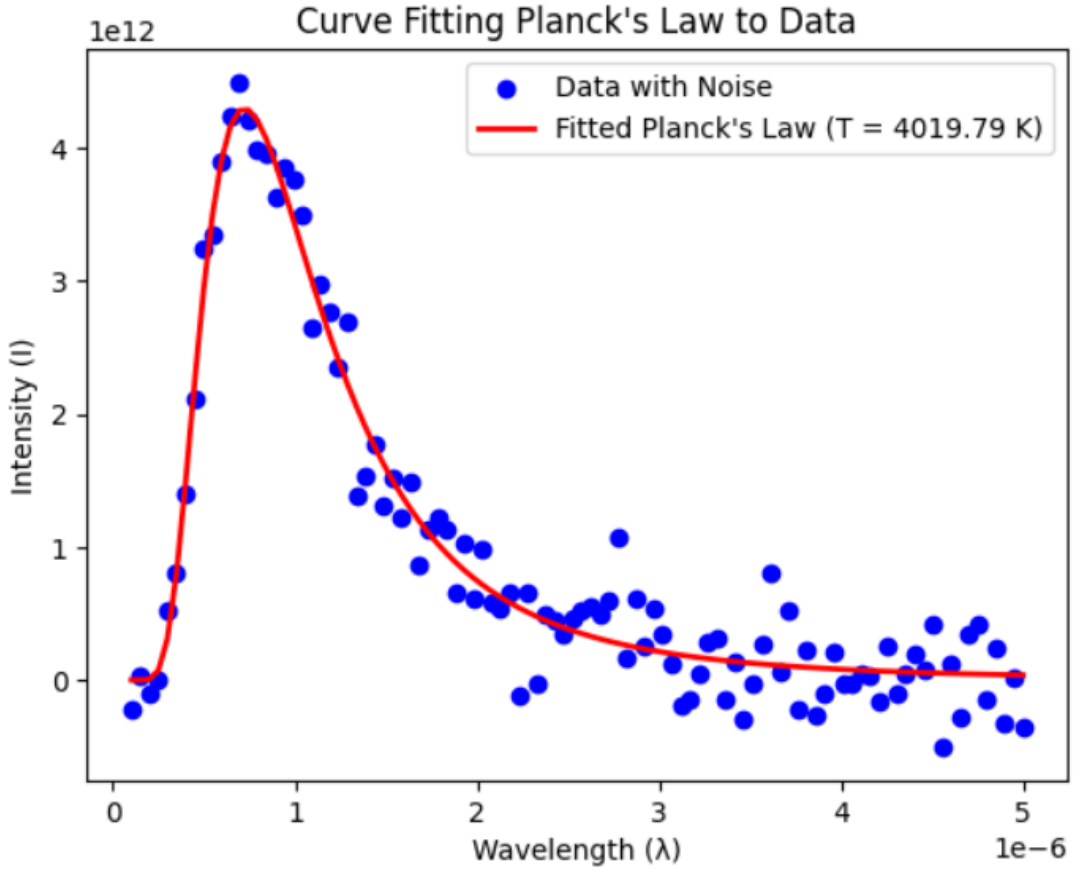
```
Fitted Temperature (T): 13346.31268361073 K
Fitted Planck Constant (h): 1.7301270700639533e-33 J·s
Fitted Speed of Light (c): -183024471.68006372 m/s
Fitted Boltzmann Constant (k): -6.665216923541398e-24 J/K
```



5.1.2 Value of T When h, c, k Fixed

Here, we present the estimated value of the temperature (T) when the Planck constant (h), speed of light (c), and Boltzmann constant (k) were kept fixed. This approach yielded a reasonable estimate of the temperature.

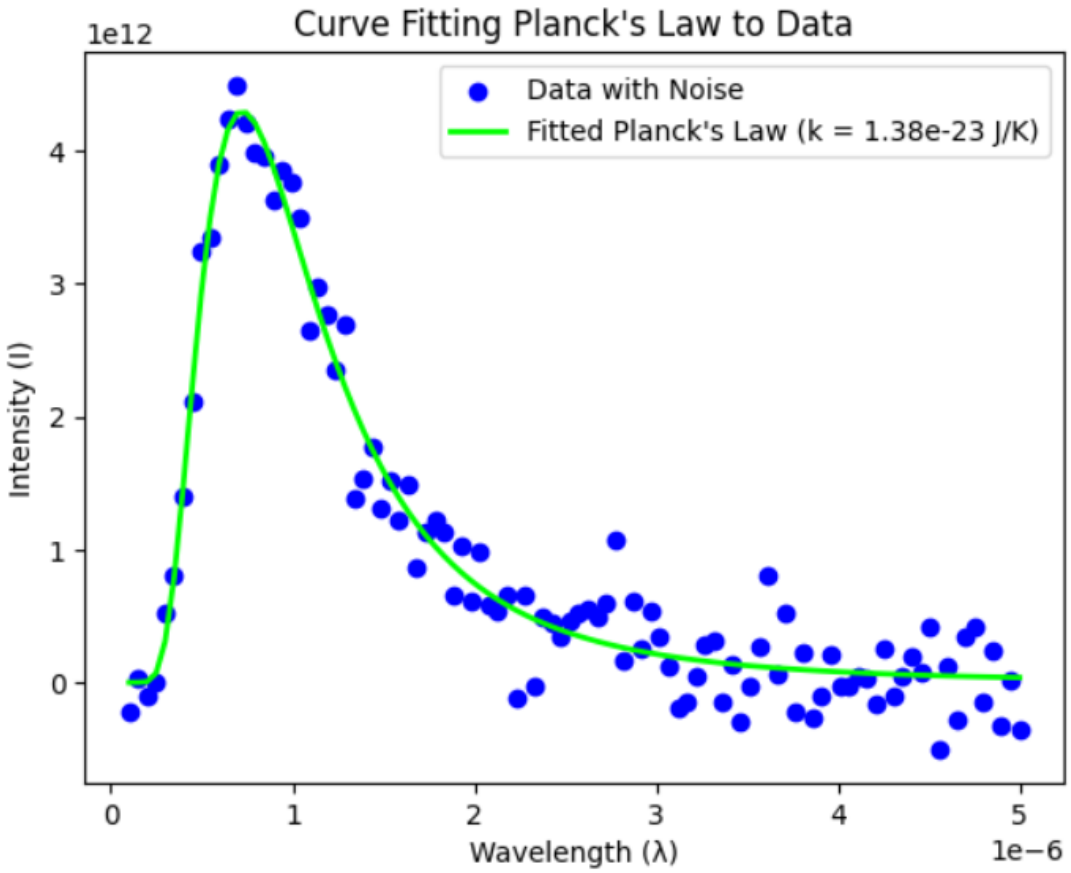
```
Fitted Temperature (T): 4019.794168790863 K
```



5.1.3 Value of k When T, h, c Fixed

This section shows the estimated value of the Boltzmann constant (k) when the temperature (T), Planck constant (h), and speed of light (c) were fixed. The results closely matched the known physical constant.

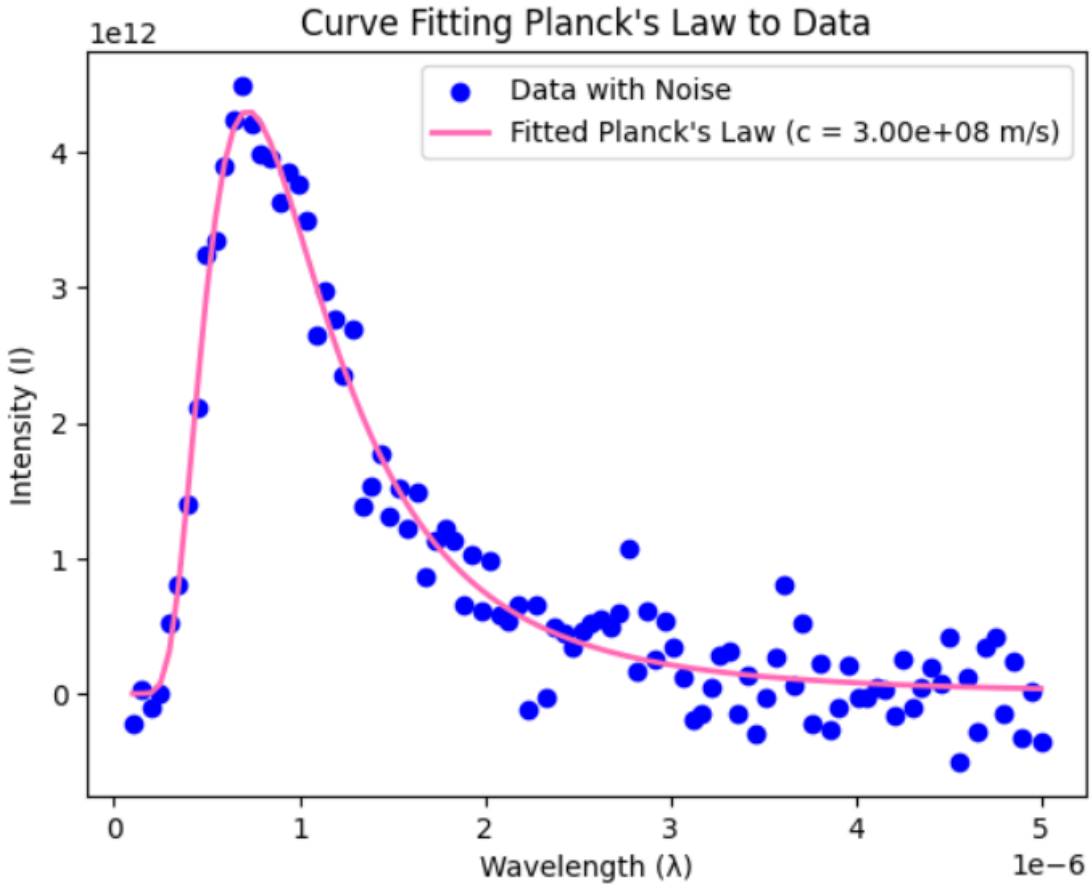
```
Fitted Boltzmann Constant (k): 1.380648999896279e-23 J/K
```



5.1.4 Value of c When T, h, k Fixed

The estimated value of the speed of light (c) when temperature (T), Planck constant (h), and Boltzmann constant (k) were fixed.

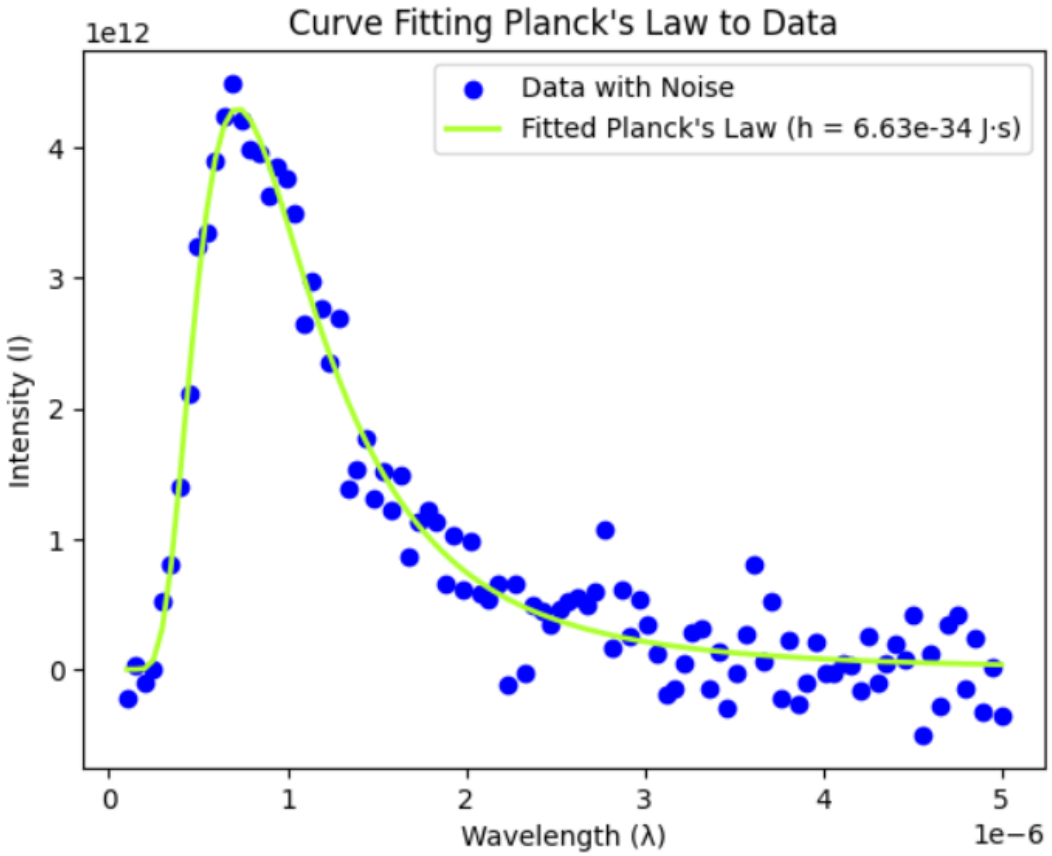
```
Fitted Speed of Light (c): 299608659.3961178 m/s
```



5.1.5 Value of h When T, c, k Fixed

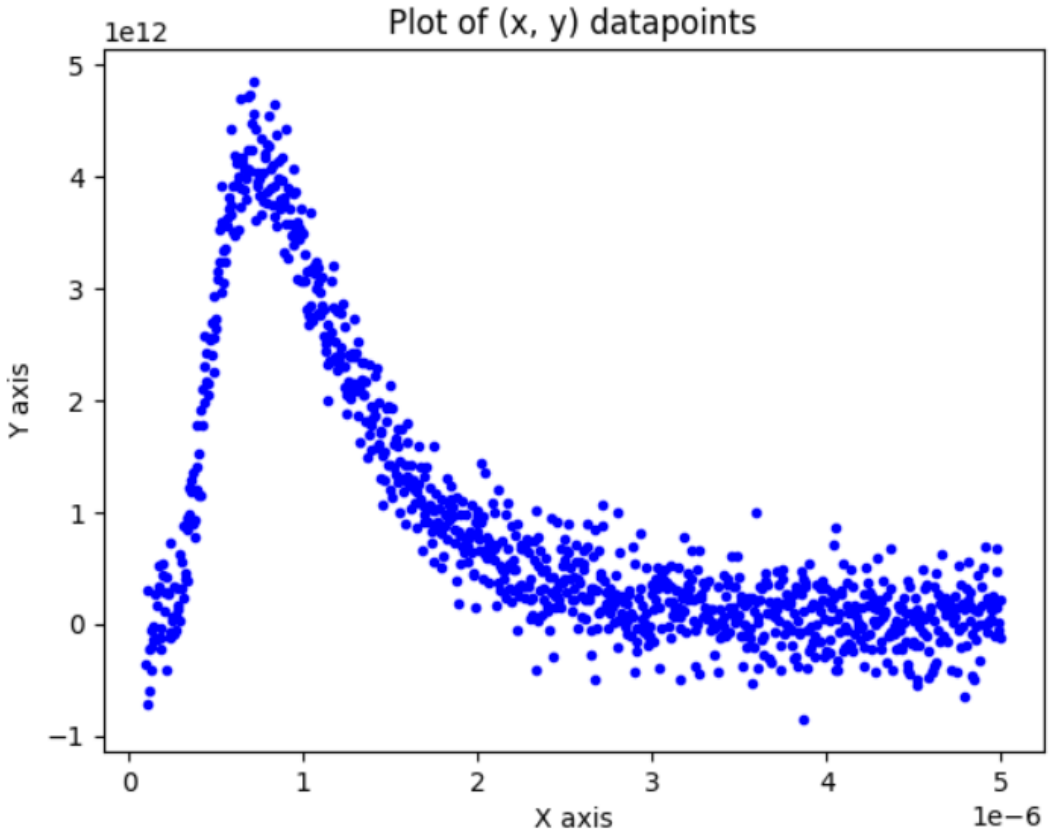
This section includes the estimated value of Planck's constant (h) when temperature (T), speed of light (c), and Boltzmann constant (k) were fixed.

```
Fitted PLanck Constant (h): 6.627958096836758e-34 J·s
```



5.1.6 Dataset d3.txt

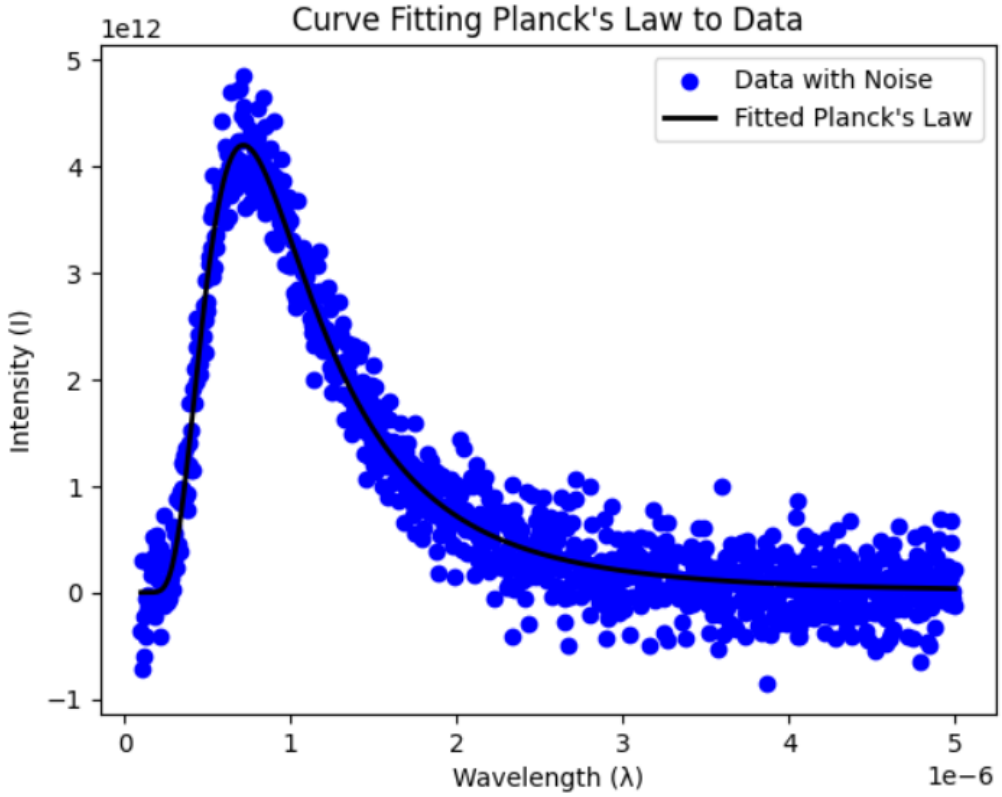
This dataset has more points than d1.txt, 1000 to be exact. Noise is also present in them.



5.1.7 Values When All Parameters are Estimated Simultaneously

In this section, the parameter values estimated when all parameters (T, h, c, k) were fitted simultaneously. The results often exhibited significant deviations due to the complexity of fitting multiple variables.

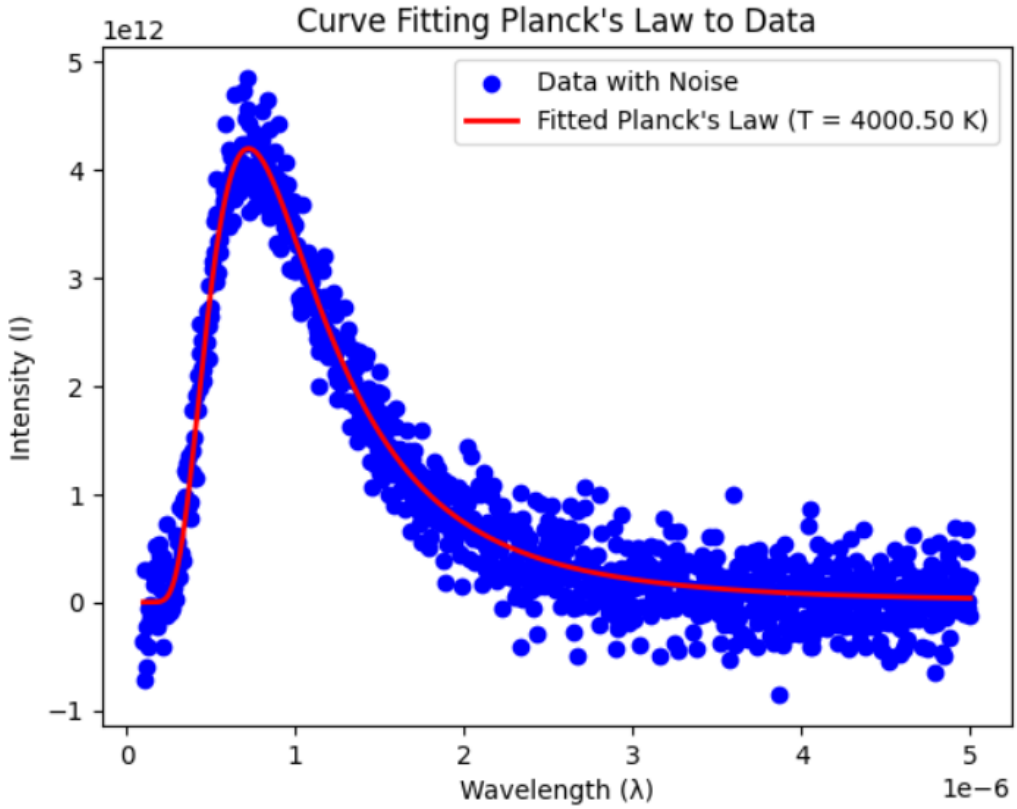
```
Fitted Temperature (T): 2104.1730345410124 K
Fitted Planck Constant (h): 5.4322131273475935e-34 J·s
Fitted Speed of Light (c): 322551827.170667 m/s
Fitted Boltzmann Constant (k): 2.3399357161802472e-23 J/K
```



5.1.8 Value of T When h, c, k Fixed

Here, we present the estimated value of the temperature (T) when the Planck constant (h), speed of light (c), and Boltzmann constant (k) were kept fixed. This approach yielded a reasonable estimate of the temperature.

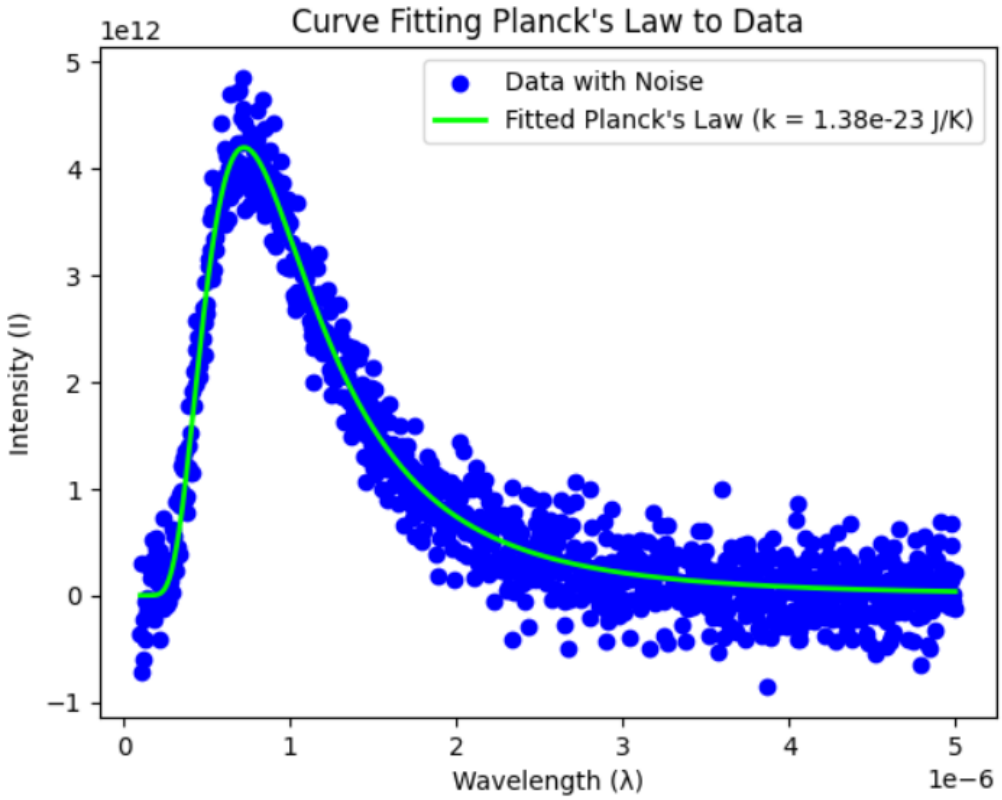
```
Fitted Temperature (T): 4000.503459457205 K
```



5.1.9 Value of k When T, h, c Fixed

This section shows the estimated value of the Boltzmann constant (k) when the temperature (T), Planck constant (h), and speed of light (c) were fixed. The results closely matched the known physical constant.

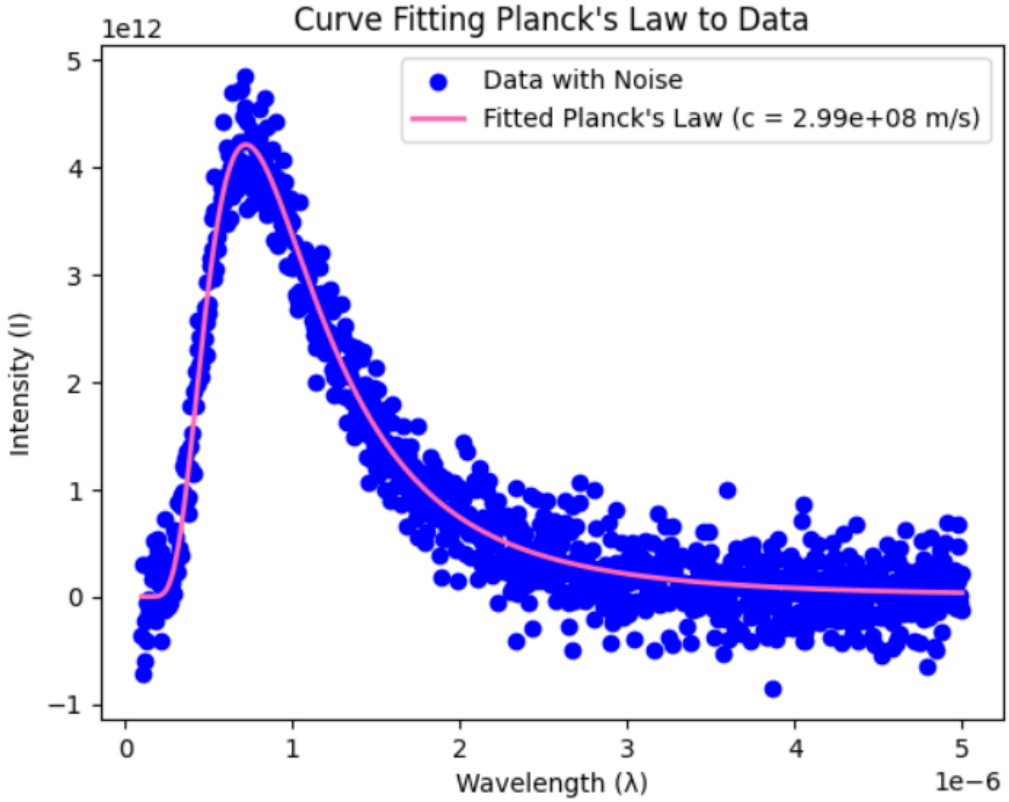
```
Fitted Boltzmann Constant (k): 1.3806490005508238e-23 J/K
```



5.1.10 Value of c When T, h, k Fixed

The estimated value of the speed of light (c) when temperature (T), Planck constant (h), and Boltzmann constant (k) were fixed.

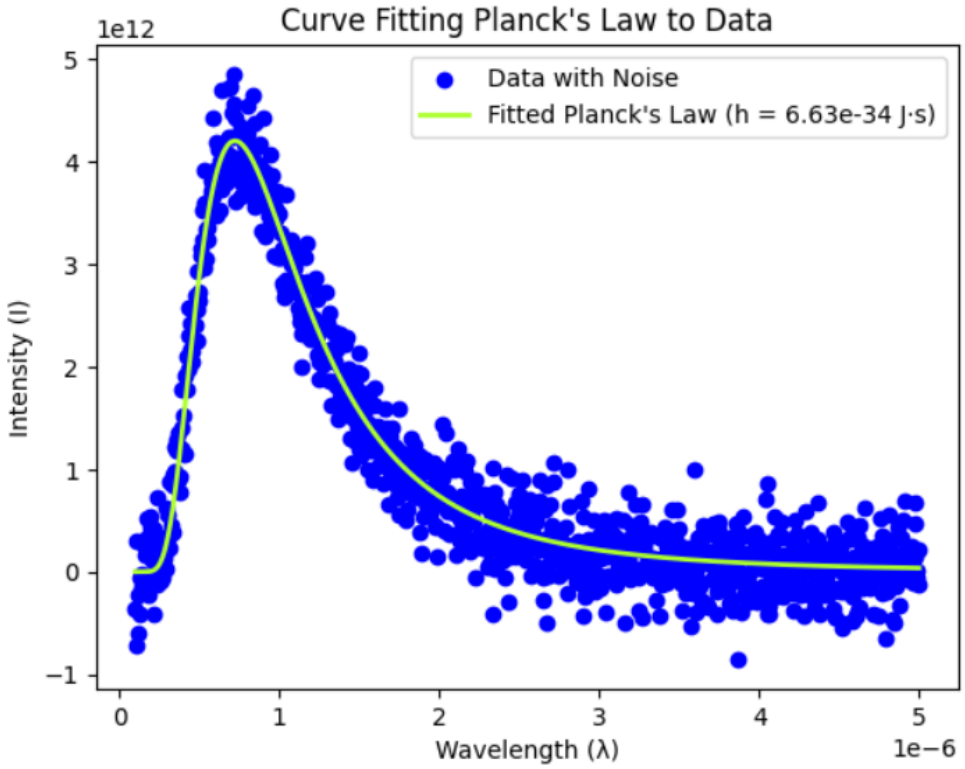
```
Fitted Speed of Light (c): 299439504.3463055 m/s
```



5.1.11 Value of h When T, c, k Fixed

This section includes the estimated value of Planck's constant (h) when temperature (T), speed of light (c), and Boltzmann constant (k) were fixed.

```
Fitted PLanck Constant (h): 6.6296923204652425e-34 J·s
```



6 Conclusion

In this assignment, we successfully applied Planck's law to estimate physical constants from raw data. Through curve fitting techniques and partial application, we observed that fixing certain parameters improved the estimation process significantly. The assignment highlights the importance of simplifying models to improve the accuracy of data estimation, especially in complex physical systems.

7 Instructions for Reproducing the Results

1. Ensure all the required data files (`d1.txt`, `d2.txt`, `d3.txt`, `d4.txt`) are available in the same directory as the notebook.
2. Select the dataset by modifying the file name in the code section for data import.
3. Run all cells in the notebook to generate the plots and fitted values.