# Assignment 1

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# Question 1 - Electron Modeling

A simple model was created that ran for 10,000 electrons. The electrons were all set to have the same speed (the thermal velocity) but in different directions.

The thermal velocity was calculated using the equation:

$$v_{th} = \sqrt{\frac{2kT}{m_n}}$$

The mean free path was calculated using the equation:

$$MFP = v_{th}\tau_{mn}$$

The simulation was run:

```
electron_box_3modes(1)
```

```
The theoretical thermal velocity is: 187019.126 m/s.
The theoretical mean free path is: 3.740e-08 m.
```

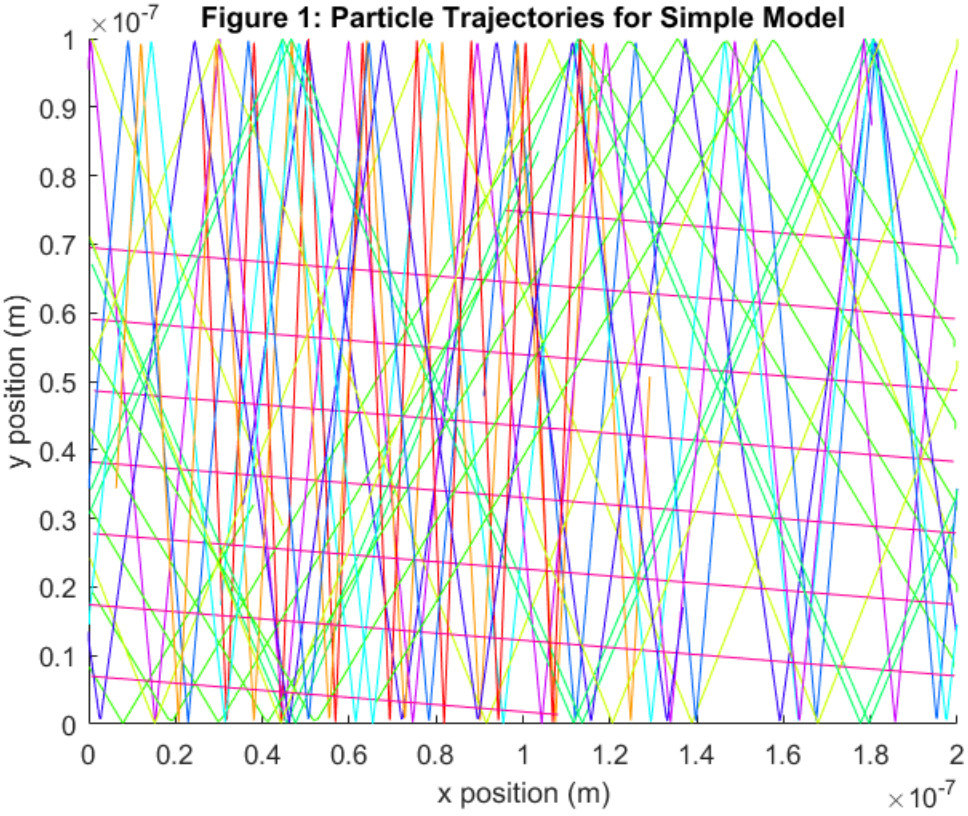


Figure 1: Particle Trajectories for Simple Model
×10^-7
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y position (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
x position (m)
×10^-7

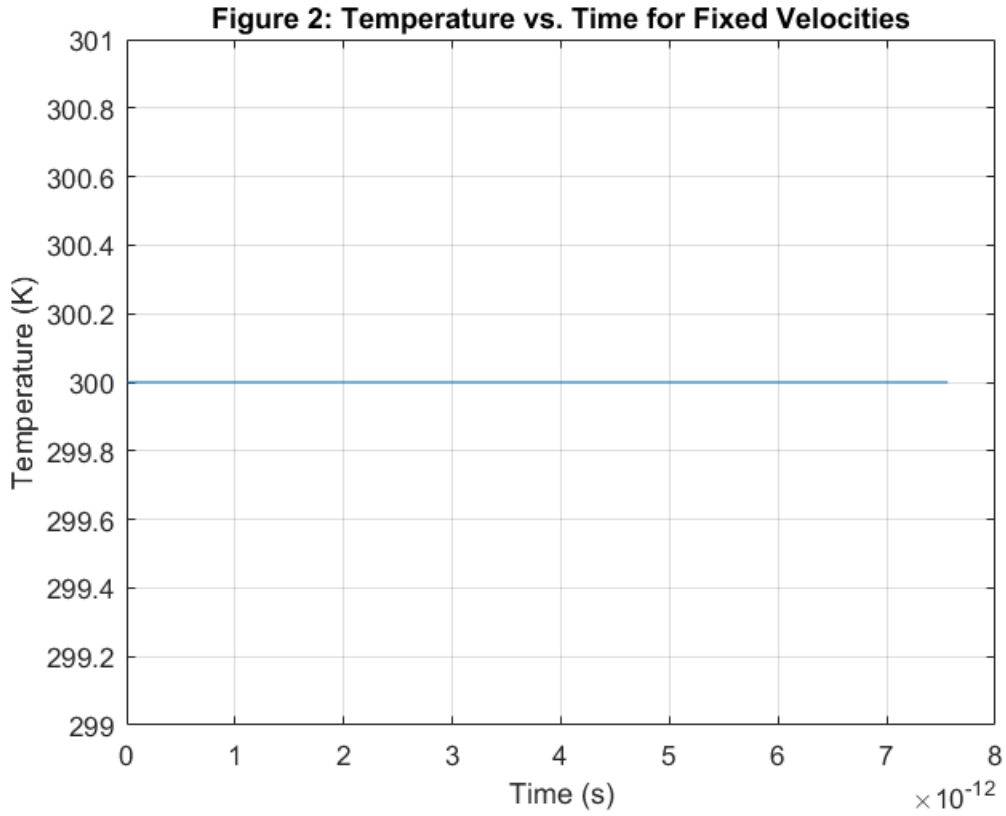


Figure 2: Temperature vs. Time for Fixed Velocities
301
300.8
300.6
300.4
300.2
300
299.8
299.6
299.4
299.2
299
Temperature (K)
0
1
2
3
4
5
6
7
8
Time (s)
×10^-12

a) The theoretical thermal velocity (as calculated above) is $187019.126$ m/s.

b) The theoretical mean free path (as calculated above) is $3.740 \times 10^{-8}$ m.

c)

i) As seen in the Figure 1, the particles move in straight lines. They bounce off the top and bottom. The x-direction has a periodic boundary as electrons pass from one side to the other.

ii) Figure 2 shows the temperature of the system over time. The temperature remains constant over all time. This makes sense because the velocities of the electrons are fixed.

# Question 2 - Collisions with Mean Free Path

Some changes where made to the initial simulation. Each particle was assigned a random velocity based on a normal distribution and the thermal velocity. The particles scatter randomly and are reassigned new velocities based on a normal distribution and the thermal velocity.

The experimental mean time between was calculated was calculated using the equation:

$$\tau_{mn} = \frac{\sum_i^{\#collisions}(\#steps\ since\ last\ collsion)(time\ step)}{\#collisions}$$

The thermal speed was calculated using the equation:

$$MFP = \frac{\sum_i^{\#collisions}(speed)(\#steps\ since\ last\ collsion)(time\ step)}{\#collisions}$$

The simulation was run:

```
electron_box_3modes(2)
```

```
The measured mean time between collisions is: 1.942e-13 s.
The measured mean free path is: 3.225e-08 m.
```

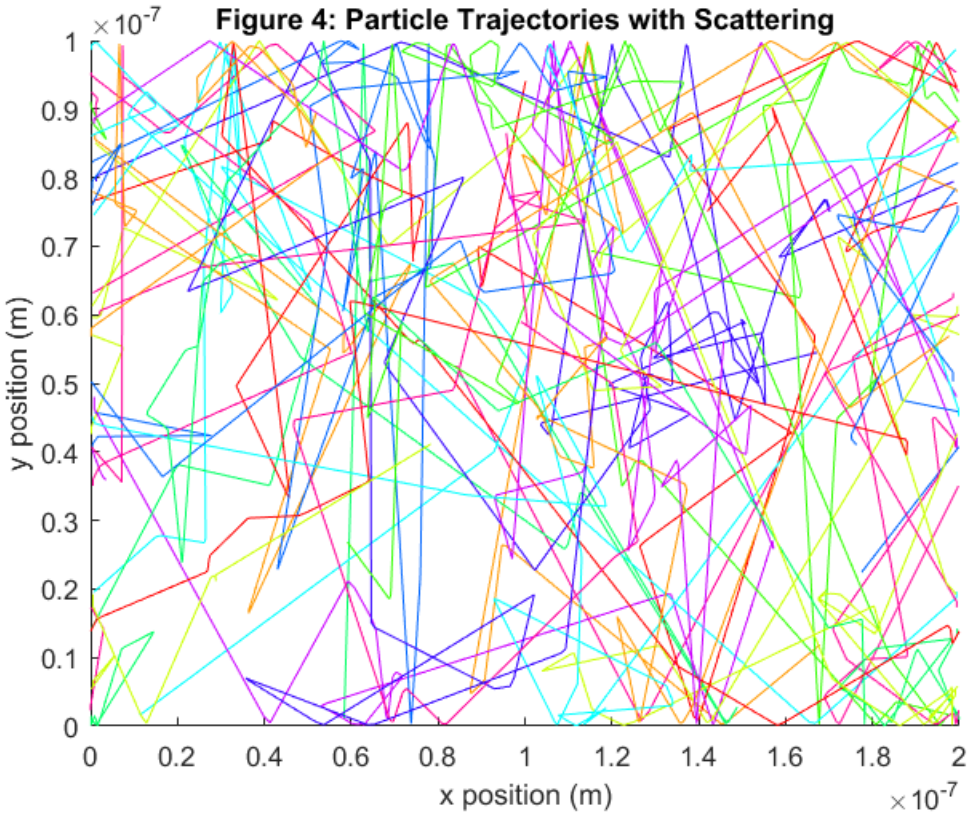


Figure 4: Particle Trajectories with Scattering
×10^-7
y position (m)
x position (m)
×10^-7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8
2

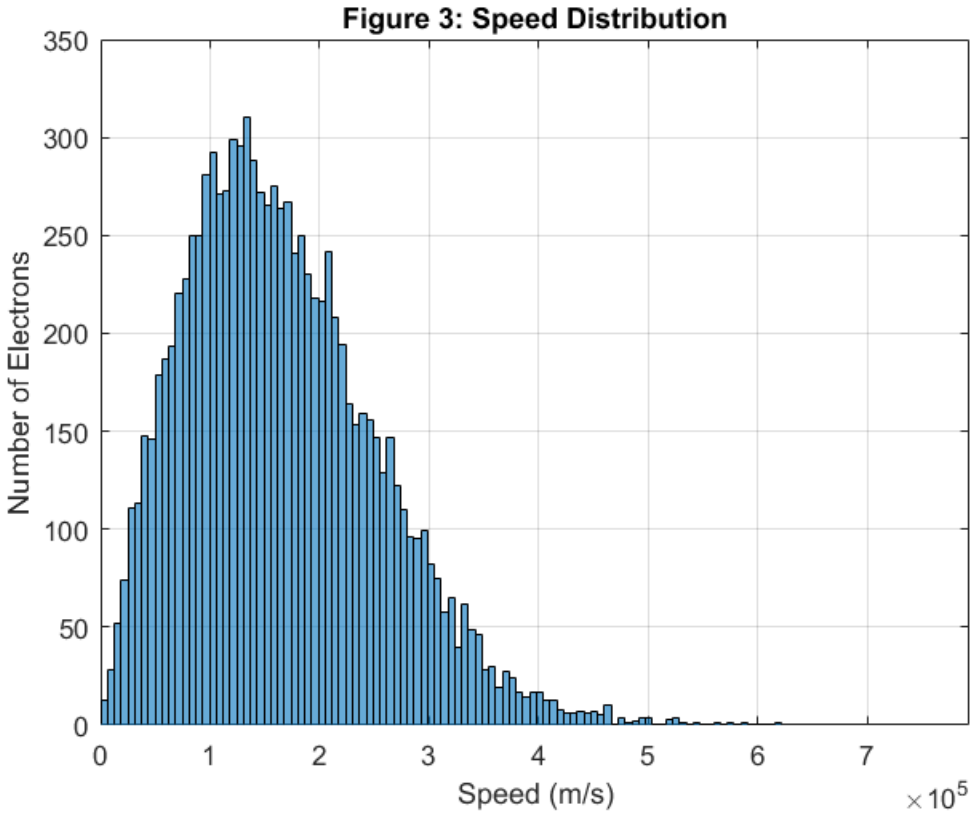
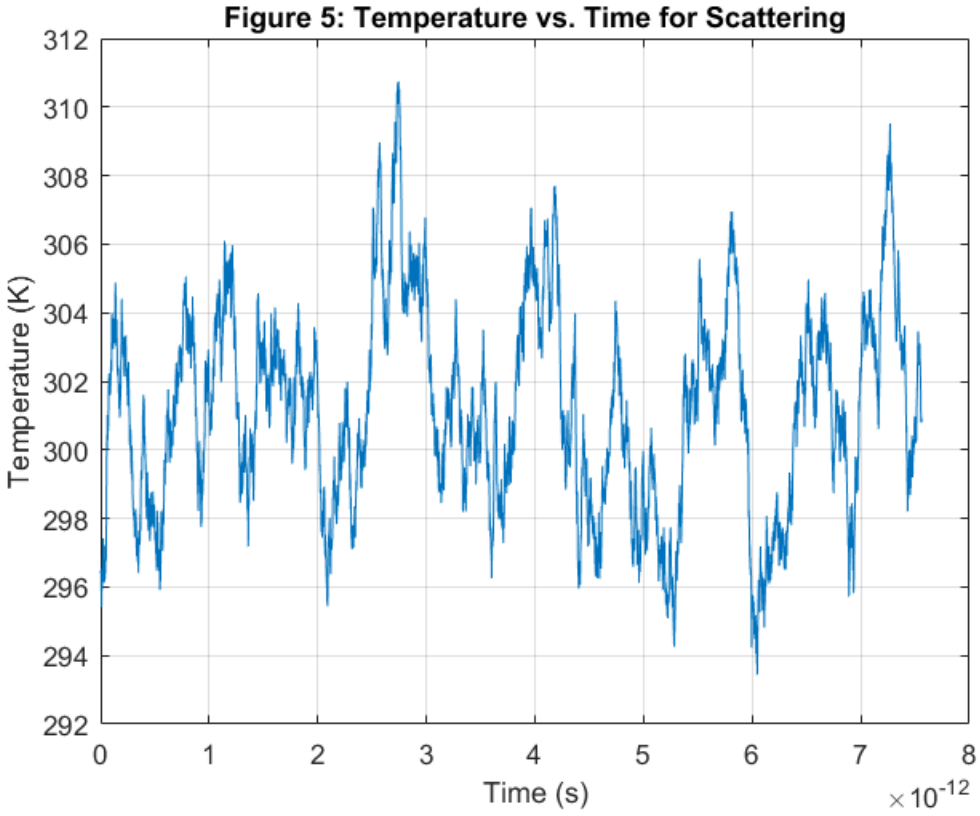


Figure 3: Speed Distribution
Number of Electrons
Speed (m/s)
×10^5
0
50
100
150
200
250
300
350
1
2
3
4
5
6
7




a) Figure 3 shows a histogram of the different speeds. This histogram is a Maxwell-Boltzman distribution.

b) Figure 4 shows some particle trajectories with the scattering functionality. The particles scatter after different distances traveled.

c) Figure 5 shows the temperature of the system over time when the scattering functionality is present. The temperature fluctates slightly over time. It tends to be close to the set temperature of 300K. The flucuation occurs due to the random scattering which does not account for conservation of energy.

d) The measured value for the time between collisions (above) is quite closed to the set value of $2 \times 10^{-13}$ s. The measured MFP (above) is somewhat off from the actual value of $3.740 \times 10^{-8}$ m (see question 1). This discrepancy may be due to approximations and random changes of the simulation.

# Question 3 - Enhancements

Futher changes where made to the simulation. A 'bottle neck' was added. The bottom boundary is diffusive and the top one is specular.

The simulation was run:

```
electron_box_3modes(3)
```

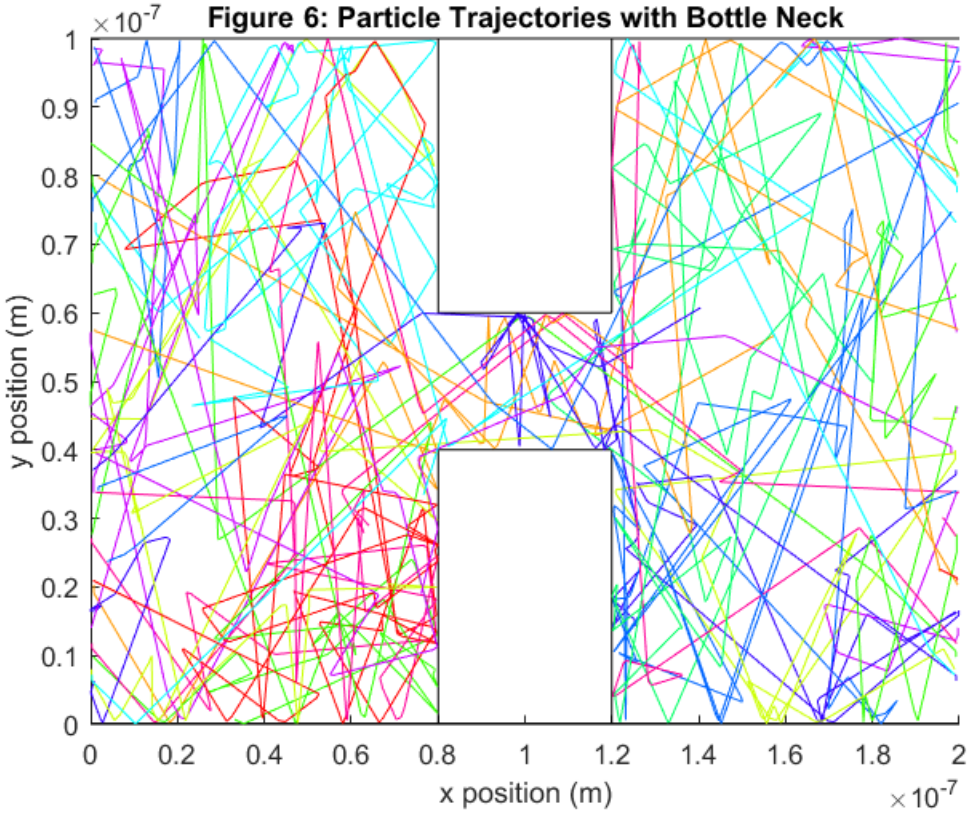


Figure 6: Particle Trajectories with Bottle Neck
×10^-7
y position (m)
x position (m)
×10^-7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8
2

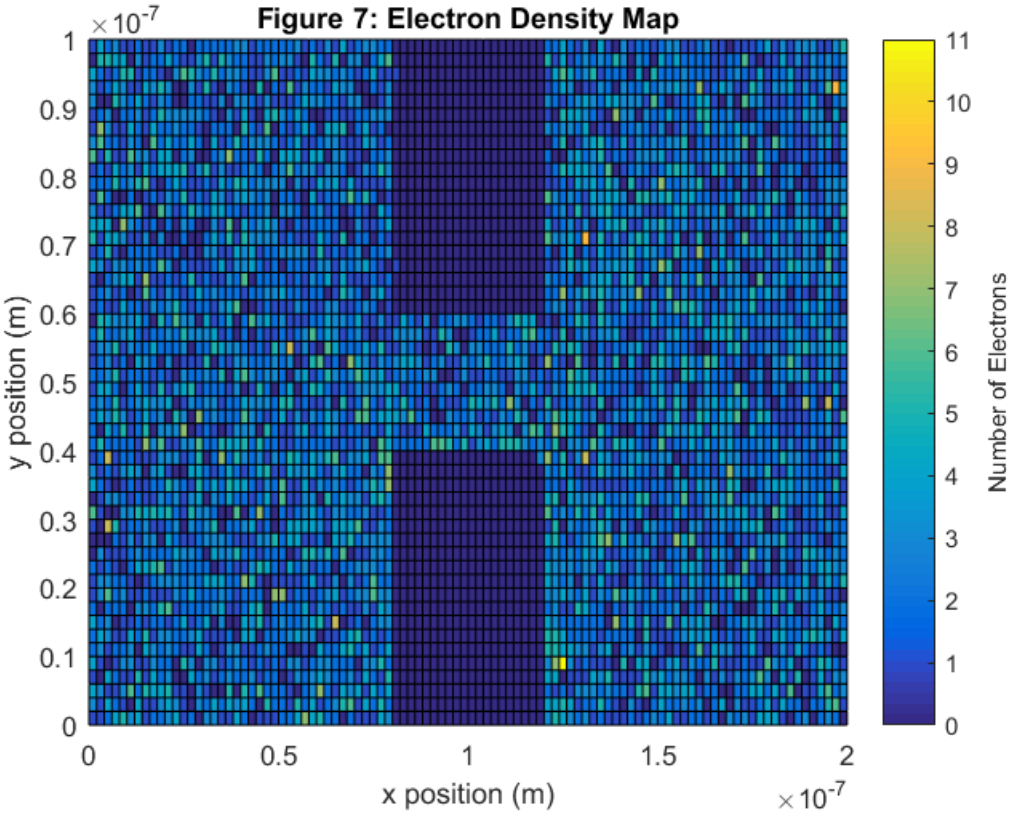
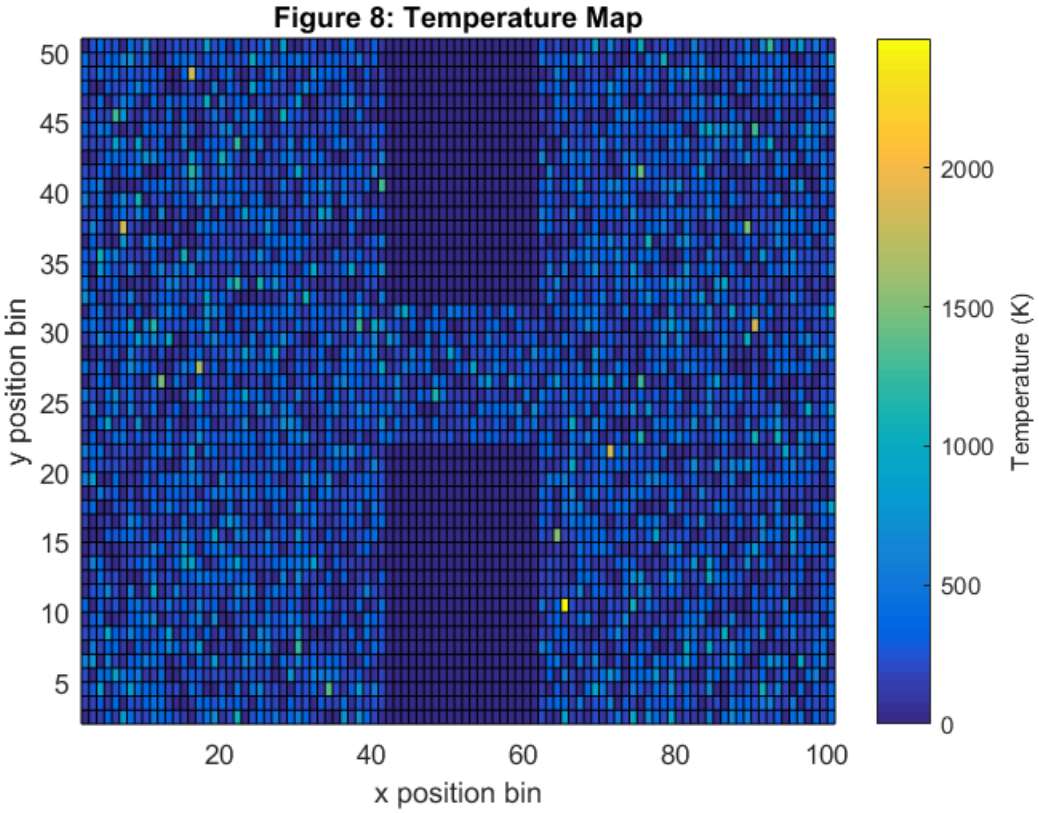


Figure 7: Electron Density Map
×10^-7
y position (m)
x position (m)
×10^-7
Number of Electrons
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.5
1
1.5
2
0
1
2
3
4
5
6
7
8
9
10
11




a) Figure 6 shows some particle trajectories with the added 'bottle neck'. The particles bounce with the same angle for the top boundary (specular). The particles bounce with a different angle off the bottom boundary (diffusive).

c) Figure 7 shows a electron density map. The electrons appear to spread out in the area outside the boundaries.

d) Figure 8 shows a temperature map. Due to the size of the bins, the local temperatures vary greatly. Some electrons happen to be travelling quite fast resulting in a much higher local temperature. For bins without any electrons, the temperature was set to be zero although there is not really any local temperature.

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