Assignment 6

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April 2021

1 Introduction

In this assignment, we will simulate a 1D model of a tubelight under the presence of a uniform applied electric field. We will make approximations to simplify the analysis and implementation.

2 Simulation

We perform the required simulation for a fixed number of turns, as specified by the user. Initially, the tubelight is discretized into n number of bins. A particular number m, governed by a Gaussian Probability Distribution, electrons are injected into the tubelight from the cathode in each turn.

The following are the default parameters used for the simulation:

```
n=100 # spatial grid size.
M=5 # number of electrons injected per turn.
nk=500 # number of turns to simulate.
u0=5 # threshold velocity.
p=0.25 # probability that ionization will occur
```

We keep track of the following parameters of the electrons:

```
Electron position xx
Electron velocity u
Displacement in current turn dx
```

We update the displacement as follows:

$$dx_i = u_i\Delta t + \frac{1}{2}a(\Delta t)^2 = u_i + 0.5$$

When a particle reaches the anode, its velocity and position is reset to zero.Then, we find which electrons have crossed the threshold velocity and which ones emit photons, determined by a Gaussian Distribution. We then inject a number of electrons into the tubelight using a probability distribution.

The above is done as follows:

```
# Initializing Vectors
xx = np.zeros(n*M)
u = np.zeros(n*M)
dx = np.zeros(n*M)
I = []
X = []
V = []

for i in range(nk):
    # Updating the vectors
    ii = np.where(xx>0)[0]
    dx[ii] = u[ii] + 0.5
    xx[ii] = xx[ii] + dx[ii]
    u[ii] = u[ii] + 1
    # Checking if electrons reached anode and resetting vectors
    reached_anode = np.where(xx > n)[0]
    xx[reached_anode] = 0
    u[reached_anode] = 0
    dx[reached_anode] = 0
    # Checking if velocity more than theshold
    kk = np.where(u>u0)[0]
    ll = np.where(np.random.randn(len(kk))<=p)[0]
    kl = kk[ll]

    u[kl] = 0
    xx[kl] = xx[kl] - dx[kl]*np.random.rand()

    I.extend(xx[kl].tolist())

    m = int(np.random.randn()*Msig+M)
    # Injecting electrons in each turn
    free_slots = np.where(xx==0)[0]
    # Checking if number of free bins are greater than m
    if len(free_slots)>=m:
        xx[free_slots[np.random.randint(len(free_slots)):
        np.random.randint(len(free_slots))+m]] = 1
        u[free_slots[np.random.randint(len(free_slots)):
        np.random.randint(len(free_slots))+m]] = 0
    else:
        xx[free_slots] = 1
        u[free_slots] = 0

    remaining_electrons = np.where(xx>0)[0]
    X.extend(xx[remaining_electrons].tolist())
    V.extend(u[remaining_electrons].tolist())
```

3 Plotting

We plot the following plots for various values of the simulation parameters:

- Light Intensity Histogram
- Electron Density Histogram
- Electron Phase Space Plot

The above can be done as follows:

```
fig, axes = plt.subplots(1,2, figsize = (15,5))
axes[0].hist(X,bins=np.arange(1,100), ec = 'black')
axes[0].title.set_text('Electron Density Histogram')
axes[0].set_xlabel('Bin Number')

axes[1].hist(I,bins=np.arange(1,100), ec = 'black')
axes[1].title.set_text('Light Intensity Histogram')
axes[1].set_xlabel('Bin Number')

plt.show()

plt.plot(xx, u, '*')
plt.xlabel('Position')
plt.ylabel('Velocity')
plt.title('Electron Phase Space Plot')
plt.show()
```

The following are the plots for the parameters

```
n=100
M=5
nk=500
u0=5
p=0.25
Msig = 0.2
```

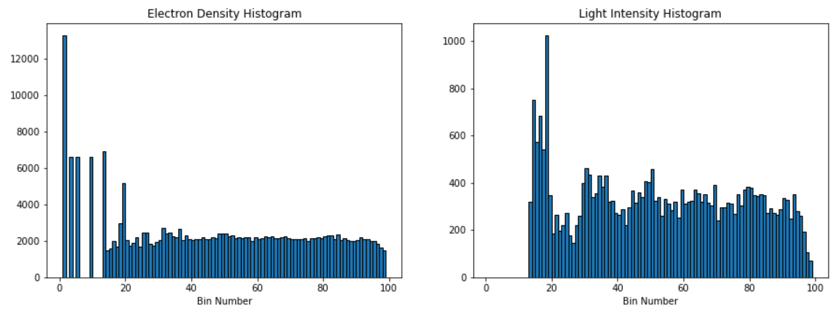

Figure 1: Histograms of Electron Density and Light Intensity

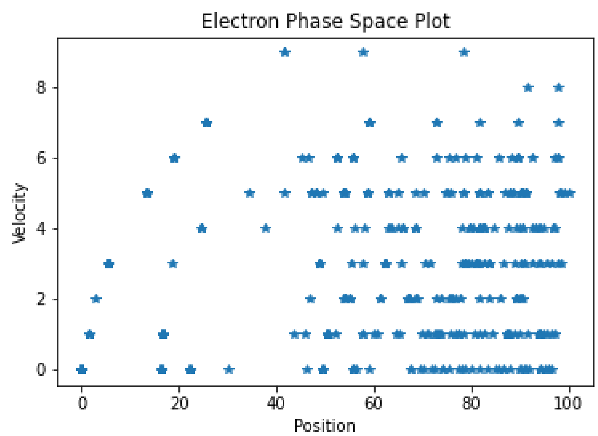

Figure 2: Electron Phase Space Plot

Let us now print the intensity values as a table. This can be done as follows,

```
a,bins,_=plt.hist(I,bins=np.arange(1,100),ec='black')
xpos=0.5*(bins[0:-1]+bins[1:])
d={'Position':xpos,'Count':a}
p=pd.DataFrame(d)
print(p)
```

The following are the intensity values displayed as a table.

```
    Position  Count
0        1.5    0.0
1        2.5    0.0
2        3.5    0.0
3        4.5    0.0
```

```
4        5.5    0.0
..       ...    ...
93      94.5  280.0
94      95.5  261.0
95      96.5  194.0
96      97.5  107.0
97      98.5   71.0
```

For the above simulation parameters, it can be noticed that in the intensity plot, the intensity is zero for positions less than around 15. This is because the electrons are building up their energy till that point and hence there is a peak in the beginning. After the first peak, the intensity decays but there are other peaks which are less prominent.

4 Changing Simulation Parameters

Let us plot the above plots for different values of the initial simulation parameters to derive more insights. Let us simulate using the following parameters,

```
n = 100
M = 5
nk = 500
u0 = 10
p = 0.25
Msig = 0.2
```

Notice that we have kept every parameter fixed and only changed the **threshold velocity**.

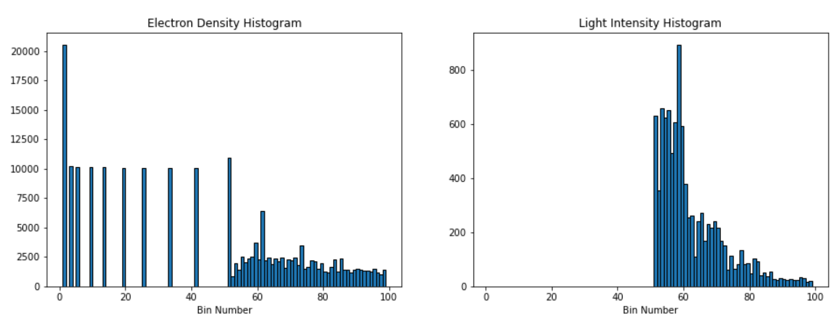

Figure 3: Histograms of Electron Density and Light Intensity

It can be noticed from the above Light Intensity Plot that the distance to the first peak has increased significantly. We can conclude from this that increasing the threshold velocity increases the distance till the first peak.

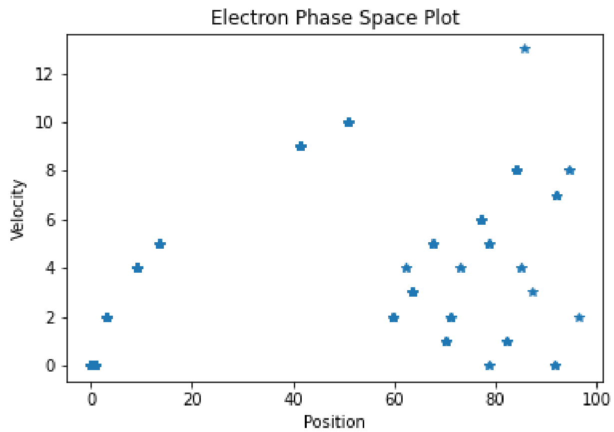

Figure 4: Electron Phase Space Plot

Now, let us keep all parameters constant and only vary the **probability of collision**. We will plot for the following parameters,

```
n = 100
M = 5
nk = 500
u0 = 5
p = 0.05
Msig = 0.2
```

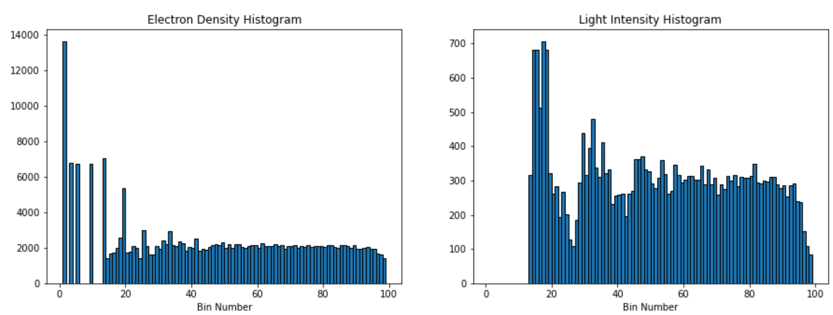

Figure 5: Histograms of Electron Density and Light Intensity

We can notice that by lowering the value of the **probability of collision**, the intensity of the first peak has reduced, while the intensity of the smaller peaks have increased.

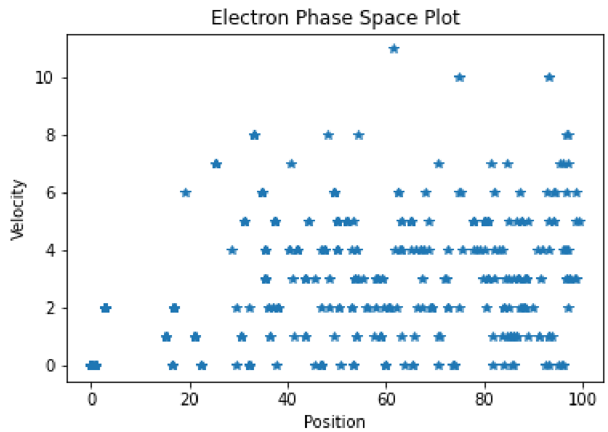

Figure 6: Electron Phase Space Plot

5 Conclusion

In this assignment, we simulated a tubelight and its Light Intensity Histogram, Electron Density Histogram and Electron Phase Space plot. We made several insightful observations, some of which are as follows,

- The Light Intensity Histogram is zero for the first few positions, because the electrons build up energy in this region.
- The Intensity Histogram has a peak in the beginning followed by other smaller peaks and dark spaces.
- The Electron Phase Space Plot shows that the electrons undergo constant acceleration initially, and then undergo random motion due to collisions.
- We then observed the effect of increasing the threshold velocity on the simulation. We concluded from the intensity plot that increasing the threshold velocity increased the distance to the first peak.
- Finally, we observed the effect of decreasing the probability of collision. We concluded that decreasing the probability of collisions decreased the intensity of the first peak and increased the intensities of the other peaks.