# EE2703 Applied Programming Lab - Assignment 6

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## 1 Introduction

In this assignment, we model a tubelight as a one dimensional space of gas in which electrons are continually injected at the cathode and accelerated towards the anode by a constant electric field. The electrons can ionize material atoms if they achieve a velocity greater than some threshold, leading to an emission of a photon. This ionization is modeled as a random process. The tubelight is simulated for a certain number of timesteps from an initial state of having no electrons. The results obtained are plotted and studied.

## 2 The simulation

A function to simulate the tubelight given certain parameters is written below:

```
def simulateTubelight(n,M,nk,u0,p,Msig):
    """
    Simulate a tubelight and return the electron positions and velocities,
    and positions of photon emissions.

    n: integer length of tubelight
    M: average number of electrons generated per timestep
    nk: total number of timesteps to simulate
    u0: threshold voltage for ionization
    p: probability of ionization given an electron is faster than the threshold
    Msig: stddev of number of electrons generated per timestep

    """

    xx = zeros(n*M)
    u = zeros(n*M)
    dx = zeros(n*M)

    I = []
    X = []
    V = []
```

```
    for k in range(nk):

        # add new electrons
        m=int(randn()*Msig+M)
        jj = where(xx==0)
        xx[jj[0][:m]]=1

        # find electron indices
        ii = where(xx>0)

        # add to history lists
        X.extend(xx[ii].tolist())
        V.extend(u[ii].tolist())

        # update positions and speed
        dx[ii] = u[ii]+0.5
        xx[ii]+=dx[ii]
        u[ii]+=1

        # anode check
        kk = where(xx>=n)
        xx[kk]=0
        u[kk]=0

        # ionization check
        kk = where(u>u0)[0]
        ll=where(rand(len(kk))<=p);
        kl=kk[ll];

        # ionize
        dt = rand(len(kl))
        #xx[kl]=xx[kl]-dx[kl]+((u[kl]-1)*dt+0.5*dt*dt)
        xx[kl]=xx[kl]-dx[kl]*dt

        u[kl]=0

        # add emissions
        I.extend(xx[kl].tolist())

    return X,V,I
```

## 3 Plots

A function to plot the required graphs is written below:

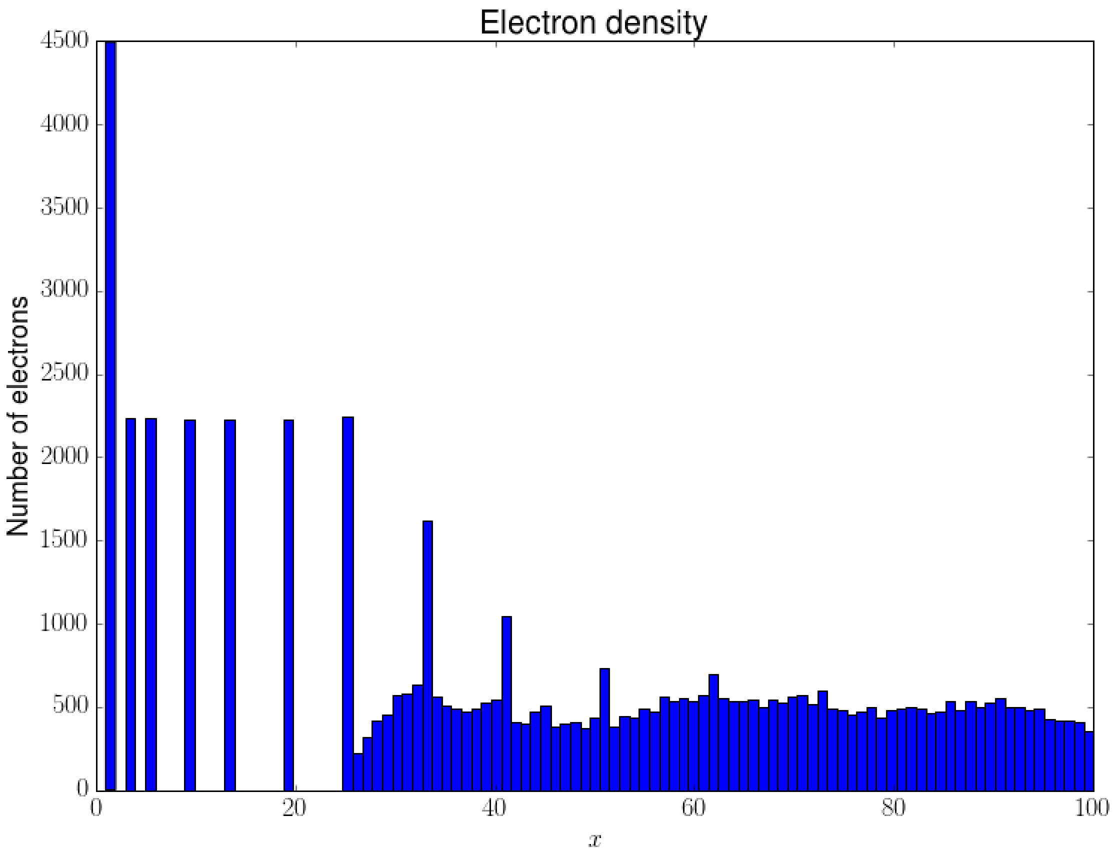
```
def plotGraphs(X,V,I):
    """
```

```python
    Plot histograms for X and I, and a phase space using X and V.
    Returns the emission intensities and locations of histogram bins.
    """

    # electron density
    figure()
    hist(X,bins=n,cumulative=False)
    title("Electron density")
    xlabel("$x$")
    ylabel("Number of electrons")
    show()

    # emission instensity
    figure()
    ints,bins,trash = hist(I,bins=n)
    title("Emission Intensity")
    xlabel("$x$")
    ylabel("I")
    show()

    # electron phase space
    figure()
    scatter(X,V,marker='x')
    title("Electron Phase Space")
    xlabel("$x$")
    ylabel("$v$")
    show()

    return ints,bins
```

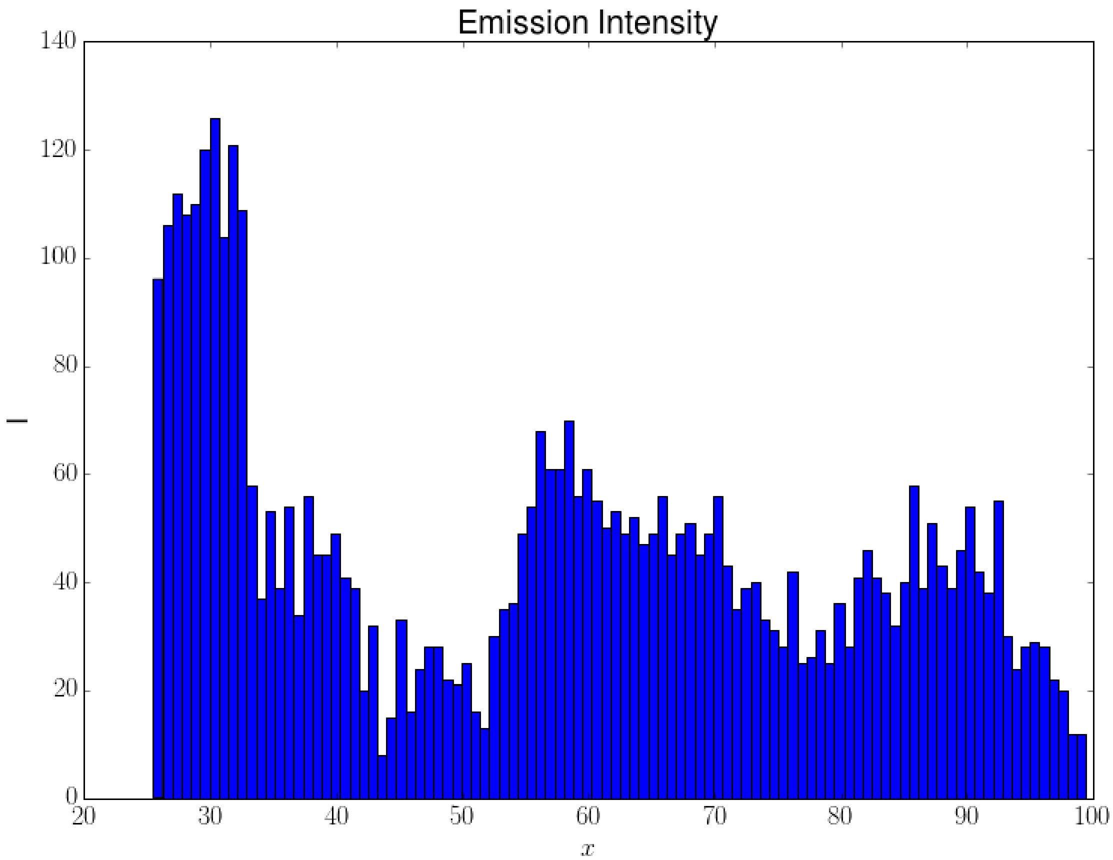
## 4 Running the simulation

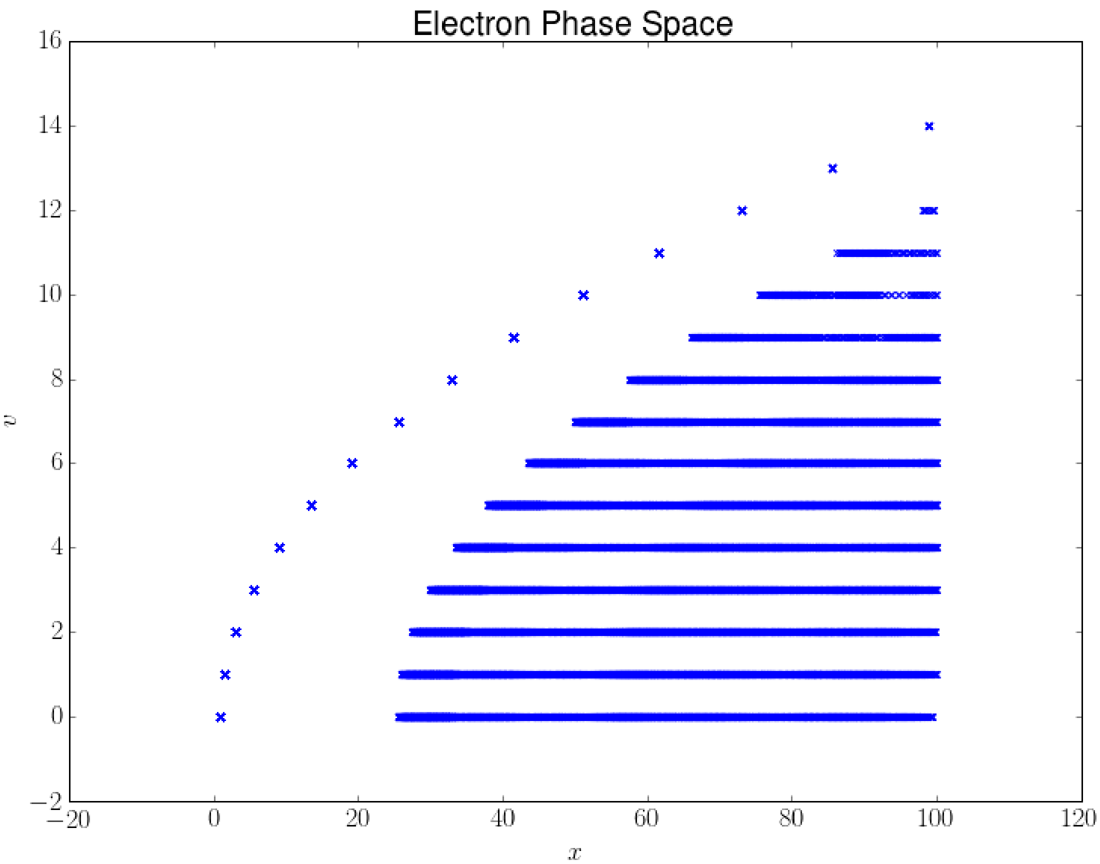
The tubelight is simulated with the default parameters of $n = 100$, $M = 5$, $nk = 500$ and $Msig = 1$. A threshold speed of $u0 = 7$, and an ionization probability of $p = 0.5$ are chosen.

```python
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)

ints, bins = plotGraphs(X,V,I)
```



Electron density
Number of electrons
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
$x$


Emission Intensity
140
120
100
80
60
40
20
0
I
20
30
40
50
60
70
80
90
100
$x$




We can make the following observations from the above plots:

- The electron density is peaked at the initial parts of the tubelight as the electrons are gaining speed here and are not above the threshold. This means that the peaks are the positions of the electrons at the first few timesteps they experience.
- The peaks slowly smoothen out as $x$ increases beyond 25. This is because the electrons achieve a threshold speed of 7 only after traversing a distance of 25 units. This means that they start ionizing the gas atoms and lose their speed due to an inelastic collision.
- The emission intensity also shows peaks which get diffused as $x$ increases. This is due the same reason as above. Most of the electrons reach the threshold at roughly the same positions, leading to peaks in the number of photons emitted there.
- This phenomenon can also be seen in the phase space plot. Firstly, the velocities are restricted to discrete values, as the acceleration is set to 1.
- One trajectory is separated from the rest of plot. This corresponds to those electrons which travel until the anode without suffering any inelastic collisions with gas atoms. This can be seen by noticing that the trajectory is parabolic. This means that $v = k\sqrt{x}$, which is precisely the case for a particle moving with constant acceleration.

- The rest of the plot corresponds to the trajectories of those electrons which have suffered at least one collision with an atom. Since the collisions can occur over a continuous range of positions, the trajectories encompass all possible positions after $x = 25$.

The emission count for each value of $x$ is tabulated below:

```
xpos=0.5*(bins[0:-1]+bins[1:])
from tabulate import *
print("Intensity Data")
print(tabulate(stack((xpos,ints)).T,["xpos","count"]))
```

```
Intensity Data
   xpos    count
-------  -------
25.8737       96
26.6131      106
27.3525      112
28.092       108
28.8314      110
29.5708      120
30.3103      126
31.0497      104
31.7891      121
32.5286      109
33.268        58
34.0074       37
34.7469       53
35.4863       39
36.2257       54
36.9652       34
37.7046       56
38.444        45
39.1835       45
39.9229       49
40.6623       41
41.4018       39
42.1412       20
42.8806       32
43.6201        8
44.3595       15
45.0989       33
45.8384       16
46.5778       24
47.3172       28
48.0567       28
48.7961       22
49.5355       21
50.275        25
```

| | |
|---|---|
| 51.0144 | 16 |
| 51.7538 | 13 |
| 52.4933 | 30 |
| 53.2327 | 35 |
| 53.9721 | 36 |
| 54.7116 | 49 |
| 55.451 | 54 |
| 56.1904 | 68 |
| 56.9298 | 61 |
| 57.6693 | 61 |
| 58.4087 | 70 |
| 59.1481 | 56 |
| 59.8876 | 61 |
| 60.627 | 55 |
| 61.3664 | 50 |
| 62.1059 | 53 |
| 62.8453 | 49 |
| 63.5847 | 52 |
| 64.3242 | 47 |
| 65.0636 | 49 |
| 65.803 | 56 |
| 66.5425 | 45 |
| 67.2819 | 49 |
| 68.0213 | 51 |
| 68.7608 | 45 |
| 69.5002 | 49 |
| 70.2396 | 56 |
| 70.9791 | 43 |
| 71.7185 | 35 |
| 72.4579 | 39 |
| 73.1974 | 40 |
| 73.9368 | 33 |
| 74.6762 | 31 |
| 75.4157 | 28 |
| 76.1551 | 42 |
| 76.8945 | 25 |
| 77.634 | 26 |
| 78.3734 | 31 |
| 79.1128 | 25 |
| 79.8523 | 36 |
| 80.5917 | 28 |
| 81.3311 | 41 |
| 82.0706 | 46 |
| 82.81 | 41 |
| 83.5494 | 38 |
| 84.2889 | 32 |
| 85.0283 | 40 |
| 85.7677 | 58 |

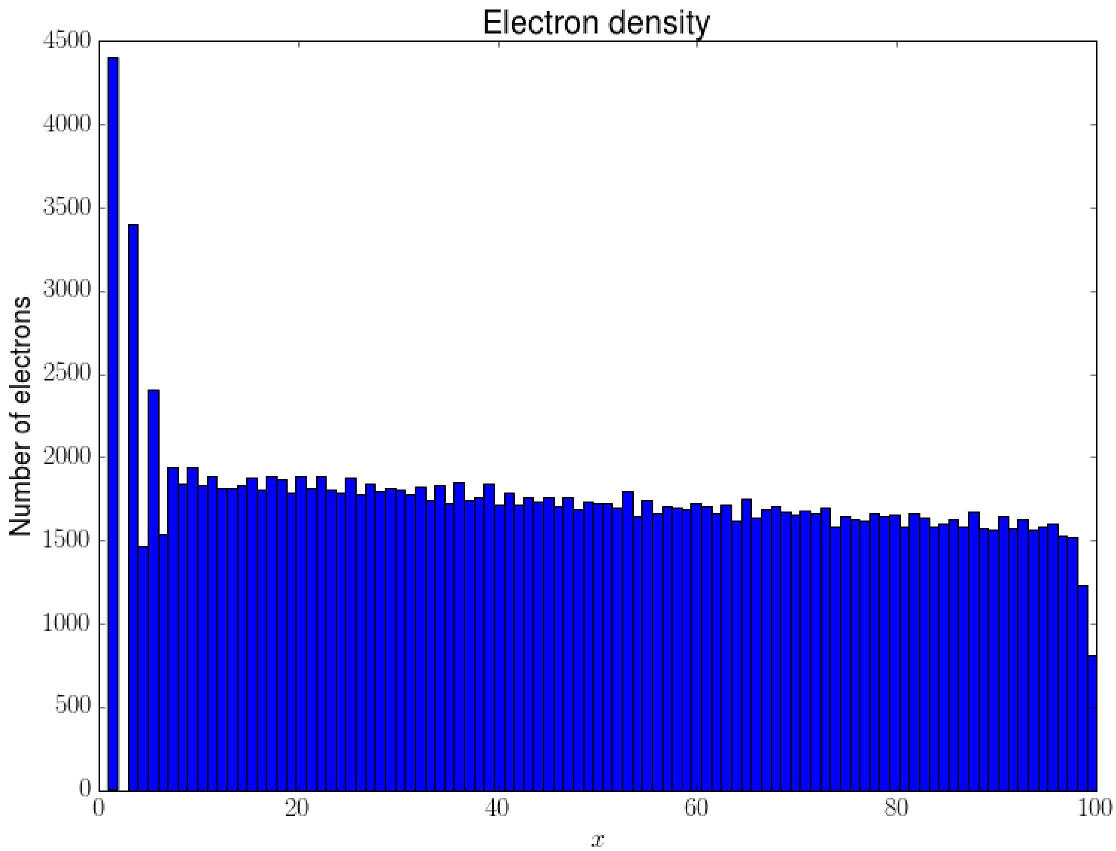
```
86.5072       39
87.2466       51
87.986        43
88.7255       39
89.4649       46
90.2043       54
90.9438       42
91.6832       38
92.4226       55
93.1621       30
93.9015       24
94.6409       28
95.3804       29
96.1198       28
96.8592       22
97.5987       20
98.3381       12
99.0775       12
```

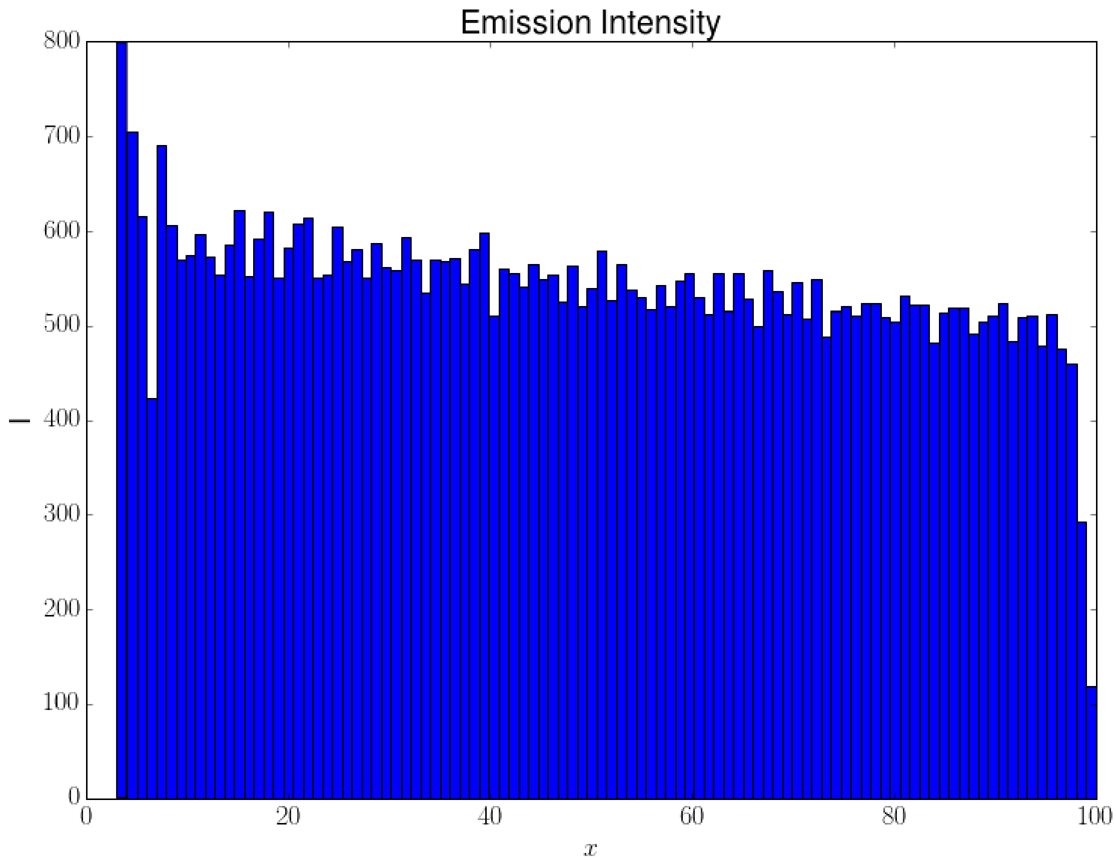
## 5 Different set of parameters

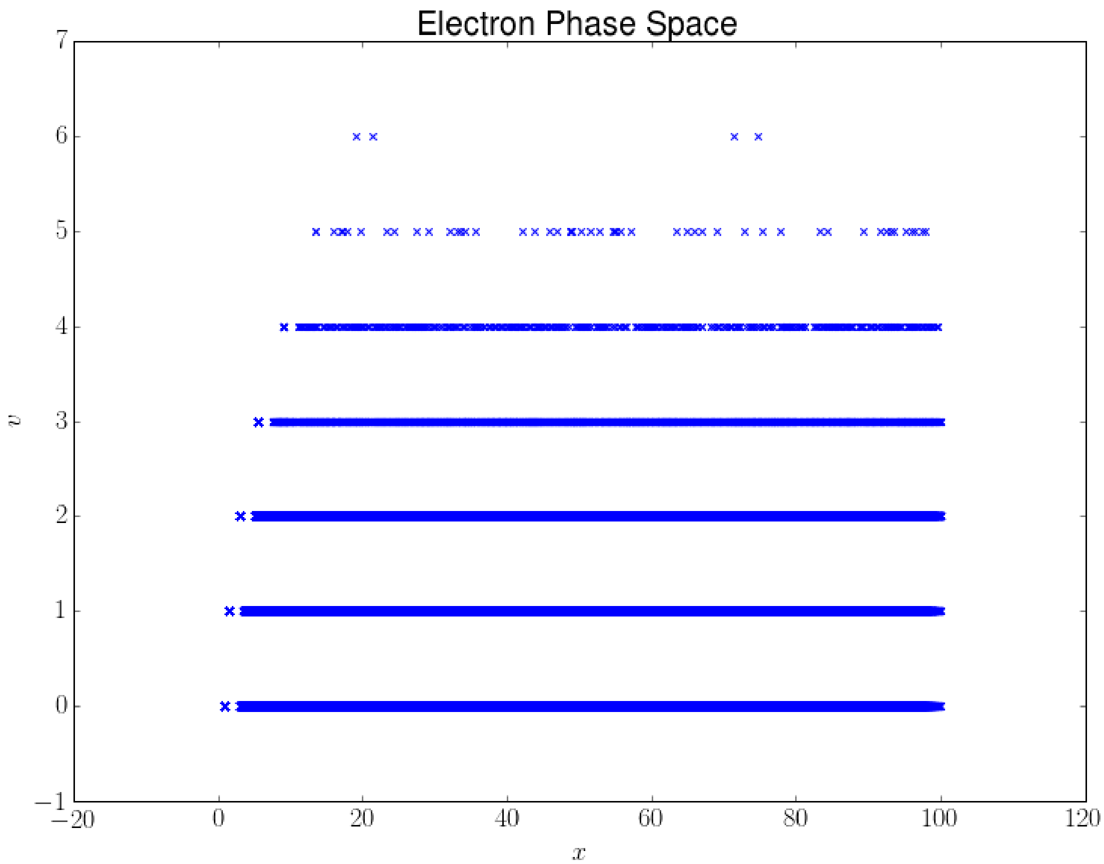
The simulation is repeated using a different set of parameters. Namely, the threshold velocity is greatly reduced to $u0 = 2$, and the ionization probability is increased to 0.9.

```
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)
```

```
ints, bins = plotGraphs(X,V,I)
```


Electron density
Number of electrons
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
x


Emission Intensity
0
100
200
300
400
500
600
700
800
I
0
20
40
60
80
100
x




## 6 Conclusion

We can make the following conclusions from the above plots:

- Since the threshold speed is much lower, photon emission starts occuring from a much lower value of x. This means that the electron density is more evenly spread out. It also means that the emission intensity is very smooth, and the emission peaks are very diffused.
- Since the probability of ionization is very high, total emission intensity is also relatively higher compared to the first case.
- We can conclude from the above observations that a gas which has a lower threshold velocity and a higher ionization probability is better suited for use in a tubelight, as it provides more uniform and a higher amount of photon emission intensity.