EE2703: Assignment 6

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EE19B130

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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]:
```python
import numpy as np
import pandas as pd
from pylab import *
import sys
```

[18]:
```python
"""
    Taking arguments from the user through commandline
    and if the arguments are not provided then the code
    will run on the default values
    where,
    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
"""
#command line input
if(len(sys.argv)==7):
    n,M,nk,u0,p,Msig = [int(x) for x in sys.argv[1:7] ]

#default arguments
else:
    n= 100
    M=5
    nk=500
    u0=7
```

```
    p=0.5
    Msig=1
```

2 Simulation Function

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

[45]:
```
"""
    Simulate a tubelight and return the electron positions
    and velocities, and positions of photon emissions.
"""
def simulateTubelight(n,M,nk,u0,p,Msig):

    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)
        u[kl]=0

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

    return X,V,I
```

3 Plots Function

A function to plot the required graphs is written below:

[50]:
```
"""
    Plot histograms for X and I, and a phase space using X and V.
    Returns the emission intensities and locations of histogram bins.
"""
def plotGraphs(X,V,I):

    # 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()
```

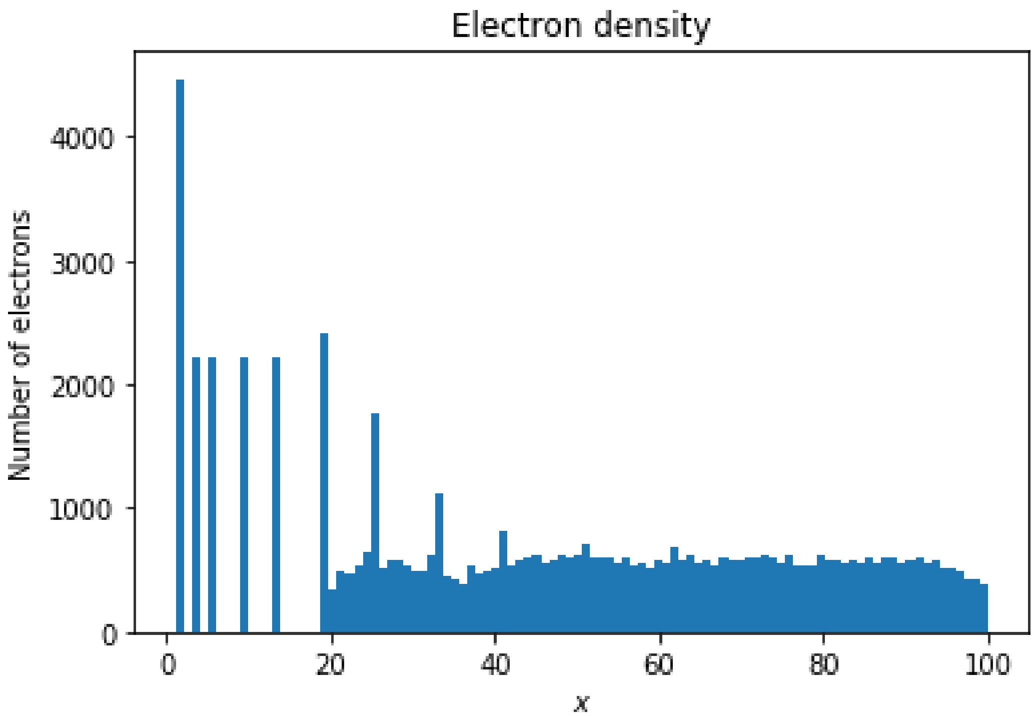
```
    return ints,bins
```

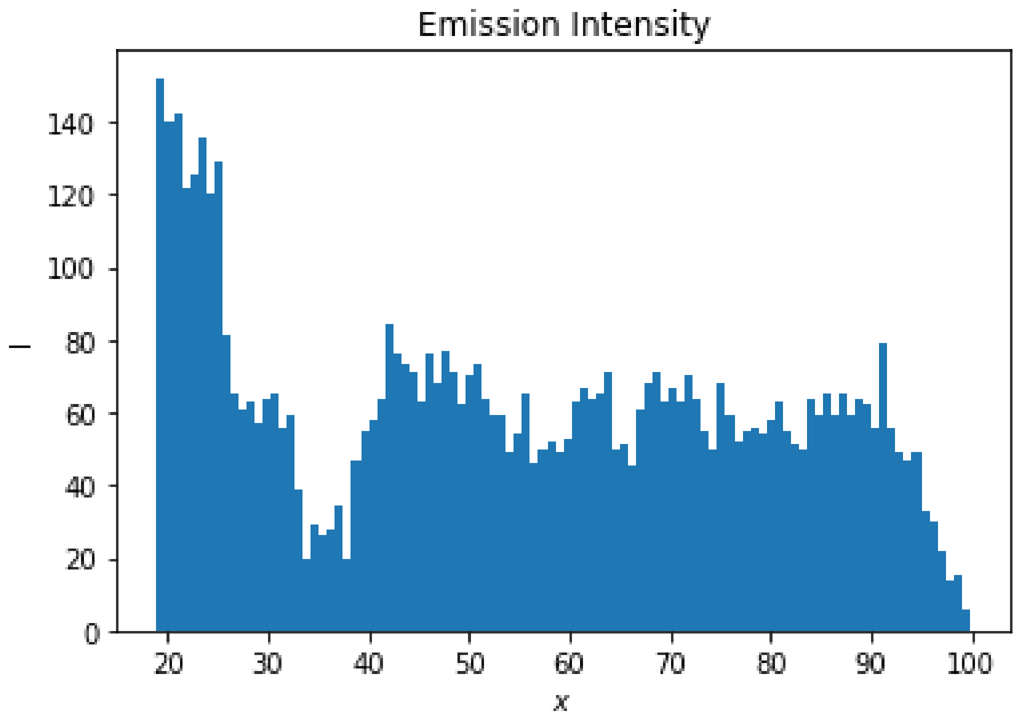
4 Running the simulation

The tubelight is simulated with the default parameters of n=100; M = 5; nk =500; u0=7; p=0.5; Msig=0.1

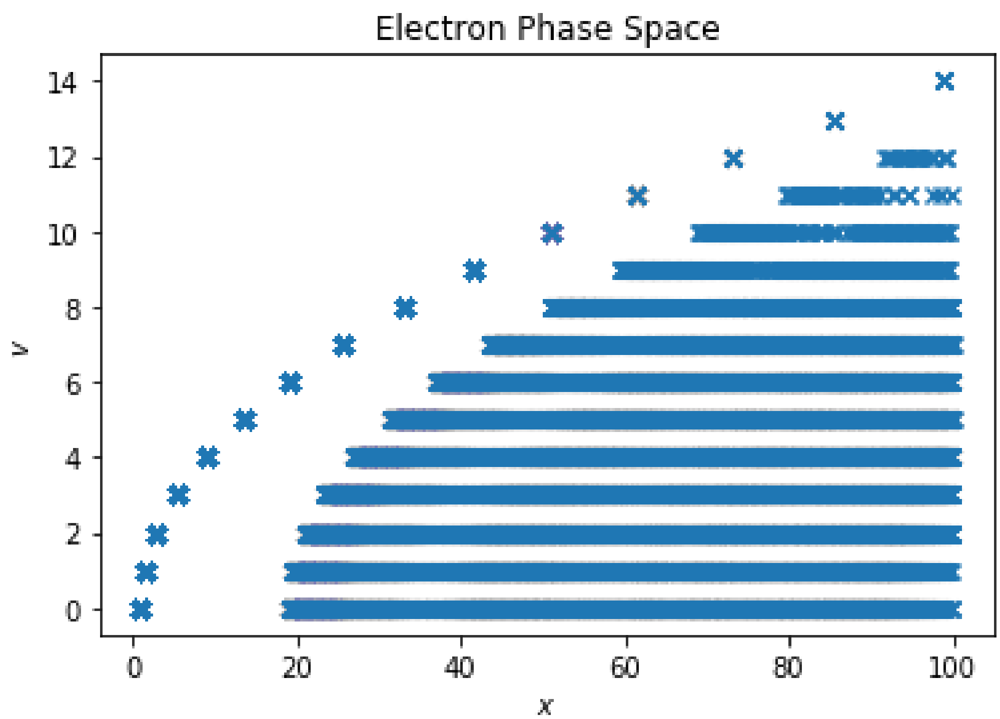
[61]:
```
n=100; M = 5; nk =500; u0=7; p=0.5; Msig=0.1
```

[62]:
```
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)
ints, bins = plotGraphs(X,V,I)
```





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



Electron Phase Space
v
0
2
4
6
8
10
12
14
0
20
40
60
80
100
x

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

[49]:
```
xpos=0.5*(bins[0:-1]+bins[1:])
M = np.c_[xpos,ints]
df = pd.DataFrame(M,columns=['xpos','count'])
print("Intensity Data:")
print(df.to_string(index=False))
```

```
Intensity Data:
      xpos  count
 19.405146  154.0
 20.209847  159.0
 21.014547  155.0
 21.819247  155.0
 22.623948  124.0
 23.428648  126.0
 24.233349  126.0
 25.038049  123.0
 25.842749   57.0
 26.647450   68.0
 27.452150   72.0
 28.256850   68.0
 29.061551   62.0
 29.866251   64.0
 30.670951   72.0
 31.475652   59.0
 32.280352   55.0
 33.085053   43.0
 33.889753   30.0
 34.694453   21.0
 35.499154   26.0
 36.303854   30.0
 37.108554   27.0
 37.913255   48.0
 38.717955   49.0
 39.522656   61.0
 40.327356   65.0
 41.132056   58.0
 41.936757   71.0
 42.741457   62.0
 43.546157   82.0
 44.350858   81.0
 45.155558   62.0
 45.960258   77.0
 46.764959   79.0
 47.569659   71.0
 48.374360   81.0
 49.179060   70.0
```

49.983760	67.0
50.788461	67.0
51.593161	67.0
52.397861	70.0
53.202562	64.0
54.007262	49.0
54.811963	45.0
55.616663	59.0
56.421363	50.0
57.226064	50.0
58.030764	60.0
58.835464	42.0
59.640165	57.0
60.444865	53.0
61.249566	55.0
62.054266	62.0
62.858966	51.0
63.663667	48.0
64.468367	59.0
65.273067	63.0
66.077768	71.0
66.882468	66.0
67.687168	65.0
68.491869	63.0
69.296569	70.0
70.101270	65.0
70.905970	69.0
71.710670	66.0
72.515371	66.0
73.320071	61.0
74.124771	49.0
74.929472	47.0
75.734172	63.0
76.538873	57.0
77.343573	54.0
78.148273	67.0
78.952974	64.0
79.757674	52.0
80.562374	54.0
81.367075	64.0
82.171775	62.0
82.976475	62.0
83.781176	70.0
84.585876	52.0
85.390577	69.0
86.195277	49.0
86.999977	60.0
87.804678	64.0

```
88.609378   51.0
89.414078   68.0
90.218779   66.0
91.023479   61.0
91.828180   64.0
92.632880   50.0
93.437580   59.0
94.242281   44.0
95.046981   39.0
95.851681   43.0
96.656382   27.0
97.461082   18.0
98.265783    4.0
99.070483    5.0
```

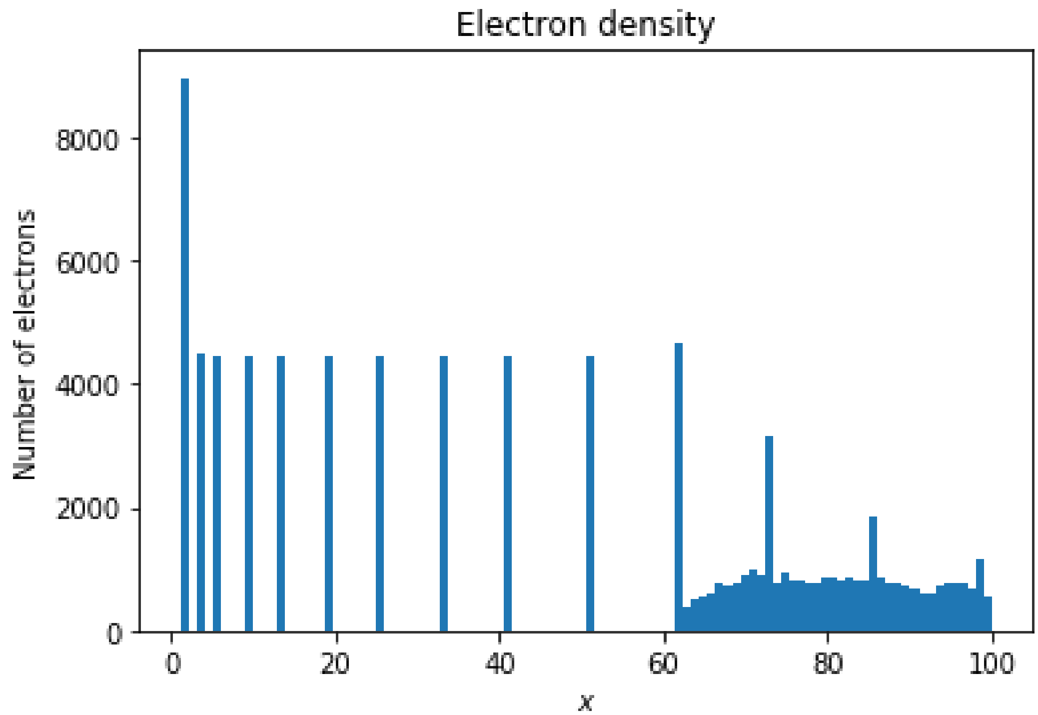
5 Altering Simulation Parameters

We try out the following set of parameters: 1. n=100, M = 5, nk =1000, u0=12, p=0.5,Msig=0.2 (larger threshold velocity). 2. n=100, M = 5, nk =1000, u0=7, p=0.1 ,Msig=0.2 (lower probabiltiy of collision). 3. n=100, M = 5, nk =1000, u0=7, p=0.1 ,Msig=4 (higher variance of randomness(normal variable)).

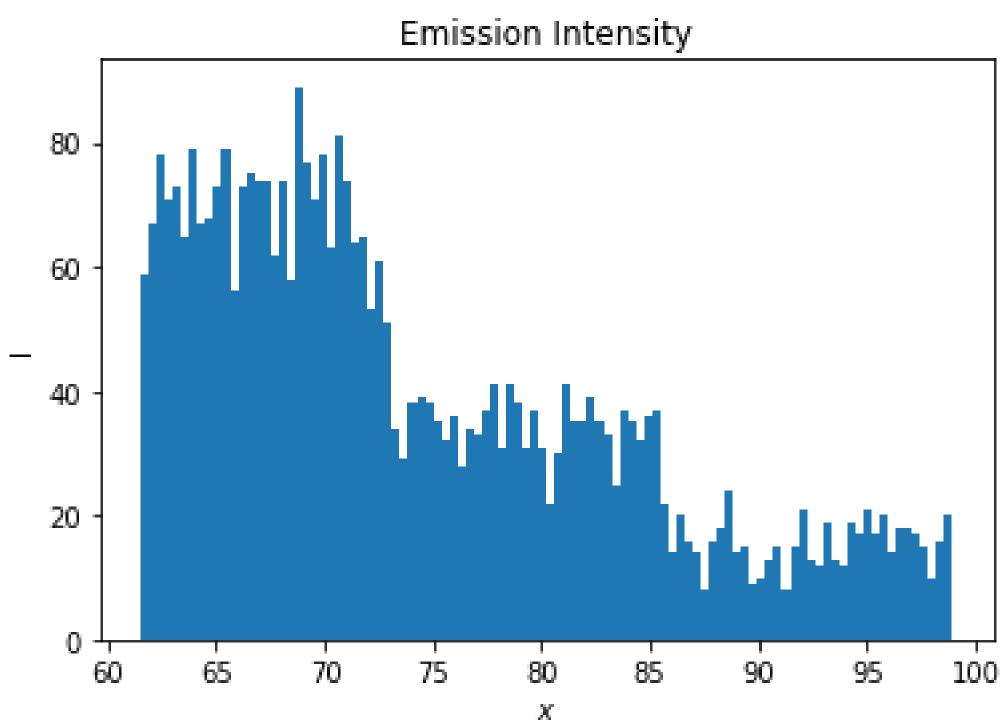
Larger threshold velocity

[59]:
```
n=100; M = 5; nk =1000; u0=12; p=0.5; Msig=0.2
```

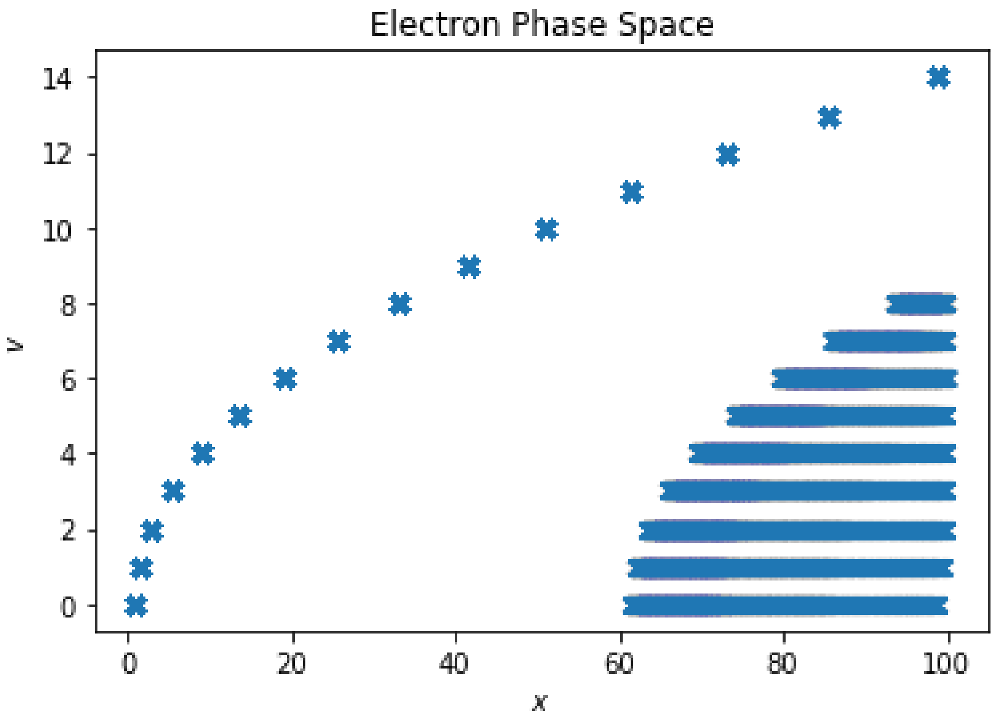
[60]:
```
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)
ints, bins = plotGraphs(X,V,I)
```



Electron density
Number of electrons
8000
6000
4000
2000
0
0
20
40
60
80
100
x



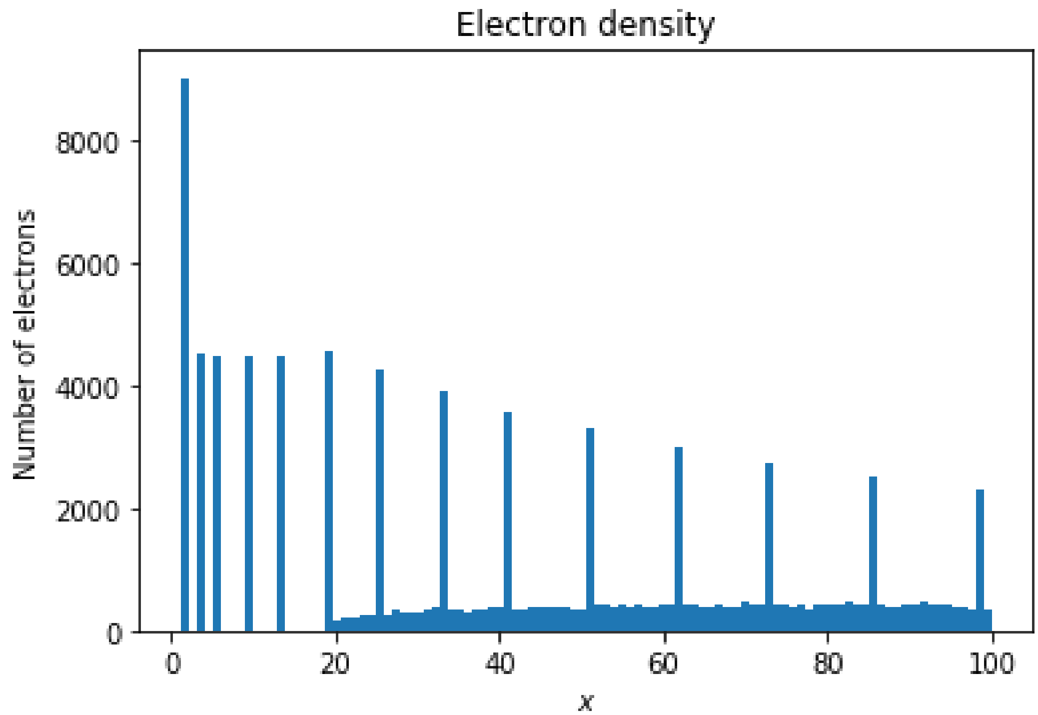
Emission Intensity
I
80
60
40
20
0
60
65
70
75
80
85
90
95
100
x

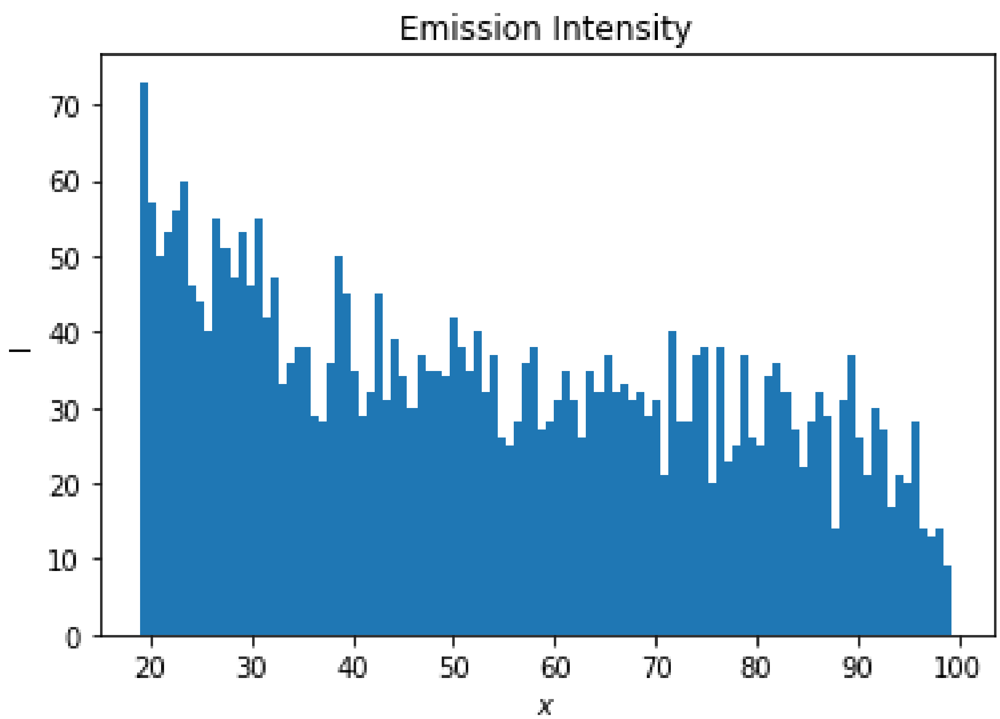


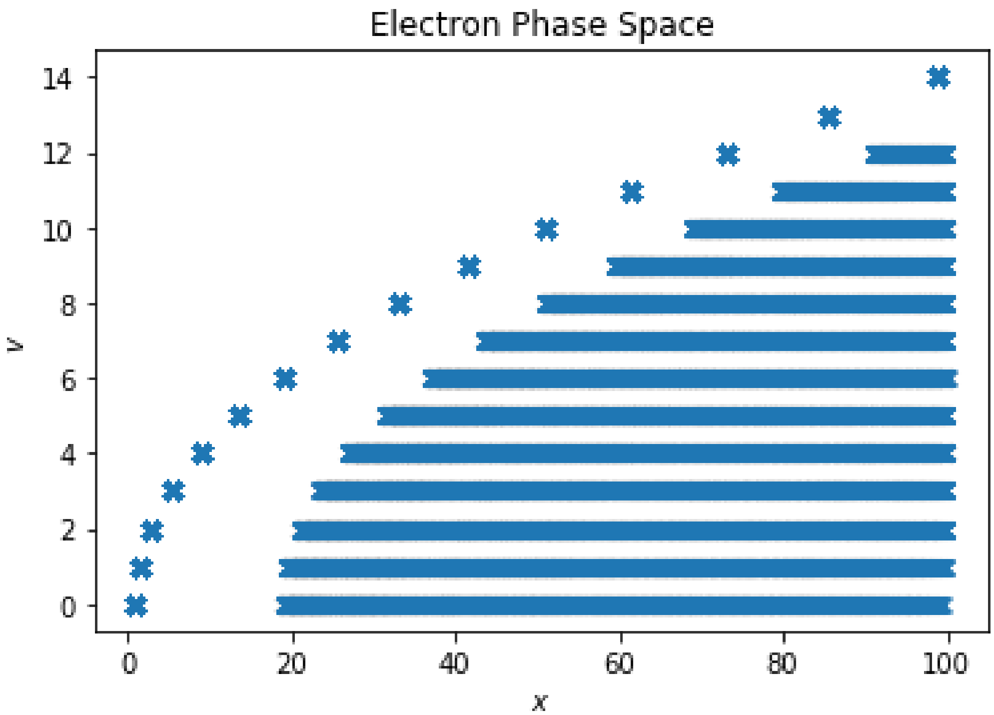
5.0.1 Lower probabiltiy of collision

[64]:
```
n=100; M = 5; nk =1000; u0=7; p=0.1; Msig=0.2
```

[65]:
```
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)
ints, bins = plotGraphs(X,V,I)
```


Electron density
Number of electrons
0
2000
4000
6000
8000
0
20
40
60
80
100
x

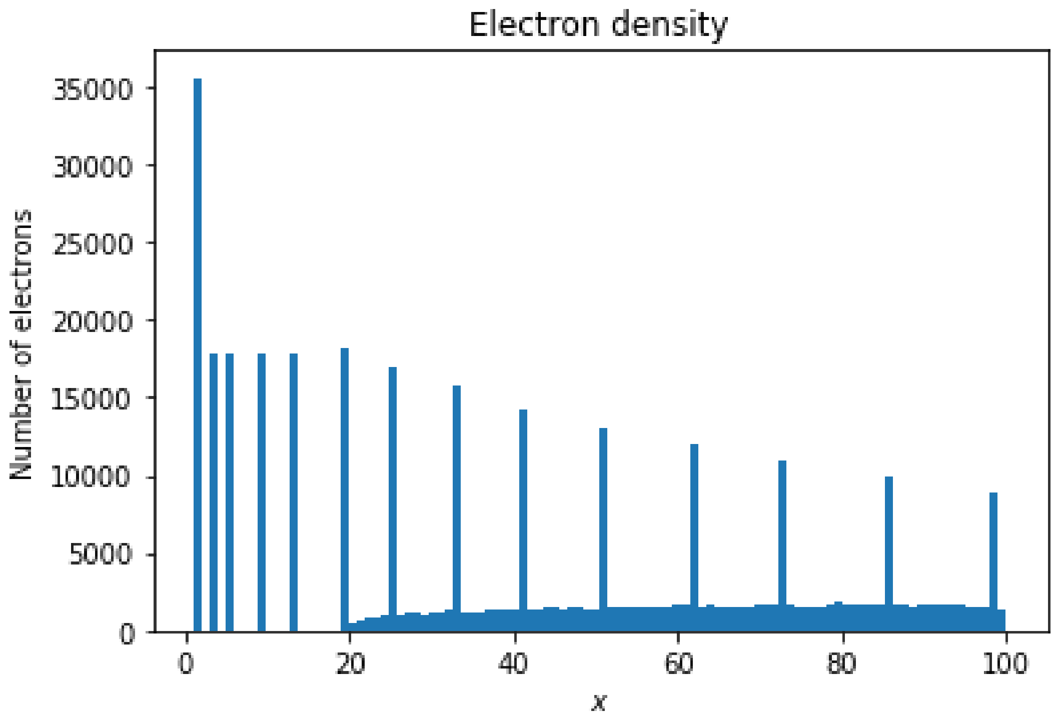

Emission Intensity
I
0
10
20
30
40
50
60
70
20
30
40
50
60
70
80
90
100
x

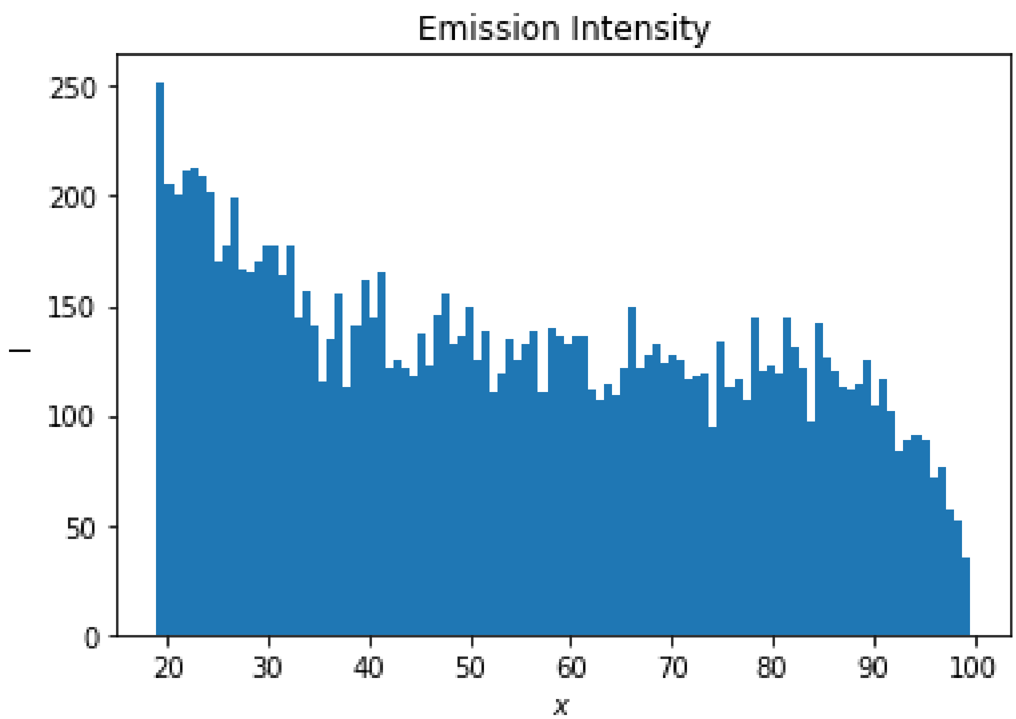


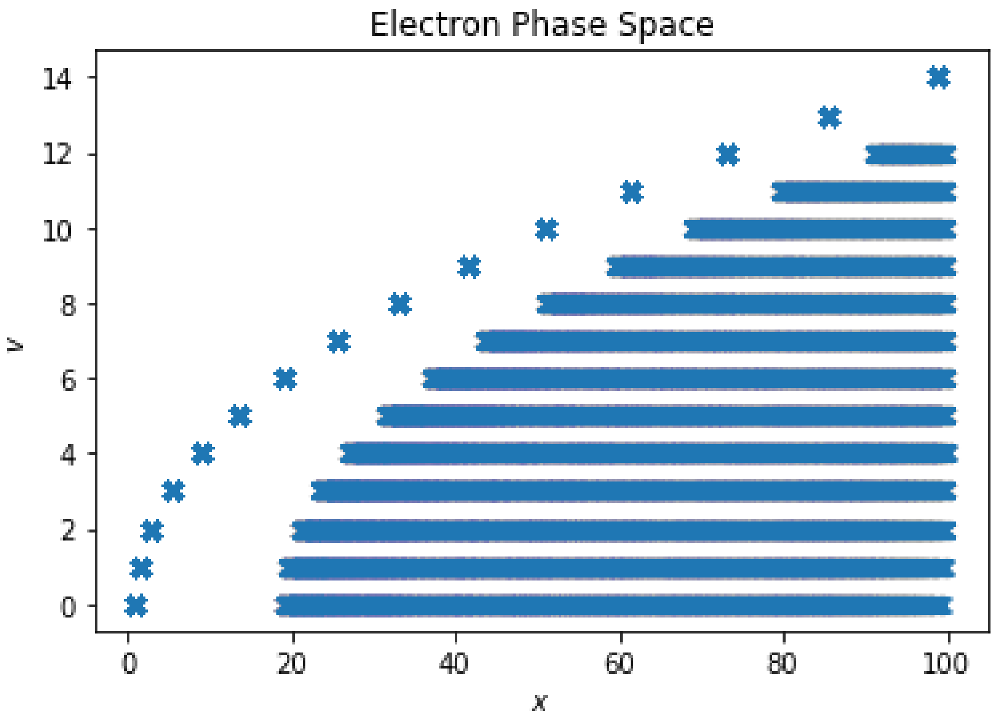
5.0.2 Higher variance of randomness(normal variable)

[68]:
```
n=100; M = 5; nk =1000; u0=7; p=0.1; Msig=4
```

[70]:
```
X,V,I = simulateTubelight(n,M,nk,u0,p,Msig)
ints, bins = plotGraphs(X,V,I)
```


Electron density
Number of electrons
0
5000
10000
15000
20000
25000
30000
35000
0
20
40
60
80
100
x


Emission Intensity
I
0
50
100
150
200
250
20
30
40
50
60
70
80
90
100
x



6 Conclusion

This week's assignment covers using python to simulate models for various requirements. In this case,we utilsise it for simualting electron motion in a tubelight, and hence find out the illumination at different points. The existence of an initial peak, and those of dark patches. In the subsequent sections, we also went over the effect of changing various parameters including probability of collision, threshold velocities and standard deviation.

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 19. This is because the electrons achieve a threshold speed of 7 only after traversing a distance of 19 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, and we are not yet performing accurate velocity updates after collisions.
- 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 $x = 19$.
- 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.
- The intensity histogram reveals that the electrons do not cause excitation of atoms till they cross a particular threshold velocity, as dictated by the nature of the gas used. Secondly, this gives rise to a peak in intensity just after the first mean length. This is beaucse a majority of electrons collide with atoms at this distance. Further this, subsequent peaks do exist, but have larger spread and are less prominent. We observer around 2 dark bands in this intensity profile.
- The electron phase plots show the constant acceleration all electrons initially undergo, and the subsequent random motion post collision. The phase plots are nearly uniformly distributed in the middle portion of the tubelight.