Assignment 6

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1 Introduction

In this assignment a tubelight is simulated. Whenever a tubelight is used the electrons move from the cathode with zero energy at the cathode to the anode.The electric field in between accelerates the electrons and thus energizes it.Therefore if some electron crosses a threshold energy, then it can excite the atom which it hits and thus it can emit light. But there is some probability with which the electron hits an atom.

1.1 Assumptions in the simulation:

1:The electron comes to rest (i.e. it loses all of it's energy) after collision and is made to accelerate again starting with zero velocity.
2:The electron acceleration due to the electron field is equal to $1 m/s^2$.
3:The time between each update of displacement,velocity and acceleration is 1 sec.
4:Five new electrons with standard deviation of 2 are added into the tubelight after every turn of the simulation.

2 Import Libraries

```
In [1]: from pylab import *
        import sys
```

3 Take input from user or use a set of predefined parameters

```
In [2]: if len(sys.argv)==6:
            n=sys.argv[0]  # spatial grid size.
            M=sys.argv[1]    # number of electrons injected per turn.
            nk=sys.argv[2] # number of turns to simulate.
            u0=sys.argv[3]  # threshold velocity.
            p=sys.argv[4] # probability that ionization will occur
            Msig=sys.argv[5] #deviation of elctrons injected per turn
            params=[n,M,nk,u0,p,Msig]
        else:
            params=[[100,5,500,5,0.25,2],[100,5,500,5,0.50,2],
```

```
[100,5,500,5,1,2],[100,5,500,10,0.25,2],
[100,5,500,10,0.50,2],[100,5,500,10,1,2]]
```

4 The loop of the simulation

Here a function is defined which runs through the main loop of the simulation.
Here the algorithm used is as defined in the problem.
* Note: The algorithm is explained in the comments

```
In [3]: def loop(params,quadratic):
            n=params[0]
            M=params[1]
            nk=params[2]
            u0=params[3]
            p=params[4]
            Msig=params[5]
            xx=np.zeros((n*M))  # electron position
            u=np.zeros((n*M))   #electron velocity
            dx=np.zeros((n*M))  #displacement in current turn

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

            for i in range(1,nk):
                ii=where(xx>0) #get the indices of positions greater than zero
                dx[ii]=u[ii]+0.5 #increase the displacement
                xx[ii]+=dx[ii] #increase the position
                u[ii]+=1 #increase the velocity
                reached=where(xx[ii]>n)#contains the indices
                #set position,velocities,displacements to zero
                xx[ii[0][reached]]=u[ii[0][reached]]=dx[ii[0][reached]]=0
                kk=where(u>=u0)
                ll=where(rand(len(kk[0]))<=p)
                kl=kk[0][ll]#contains the indices
                #of energetic electrons that suffer collision
                u[kl]=0 # reset the velocity after collision
                if quadratic==False:
                    rho=rand(len(kl)) #get random number
                if quadratic==True:
                    rho=power(0.5,len(kl)) # a quadratic probability distribution
                xx[kl]=xx[kl]-dx[kl]*rho #get the actual value of x where it collides
                I.extend(xx[kl].tolist())
                m=int(rand()*Msig+M) #get the (random)number of new electrons to be added
                empty=where(xx==0) #get empty spaces where electrons can be injected
                nv=(min(n*M-len(empty),m)) #if no empty spaces are left
                xx[empty[:nv]]=1 #inject the new electrons
```

```
            u[empty[0][:nv]]=0 #with velocity zero
            dx[empty[0][:nv]]=0 #and displacement zero
            X.extend(xx.tolist())
            V.extend(u.tolist())

        return X,V,I
```

5 The functions to plot the graphs

`plot_no_of_elec` plots the number of electrons vs x.
`plot_intensity` plots the intensity vs x.
`plot_intensity_map` plots the relative brightness of the tubelight in grayscale.
`plot_phase` plots the phase space of the electrons.

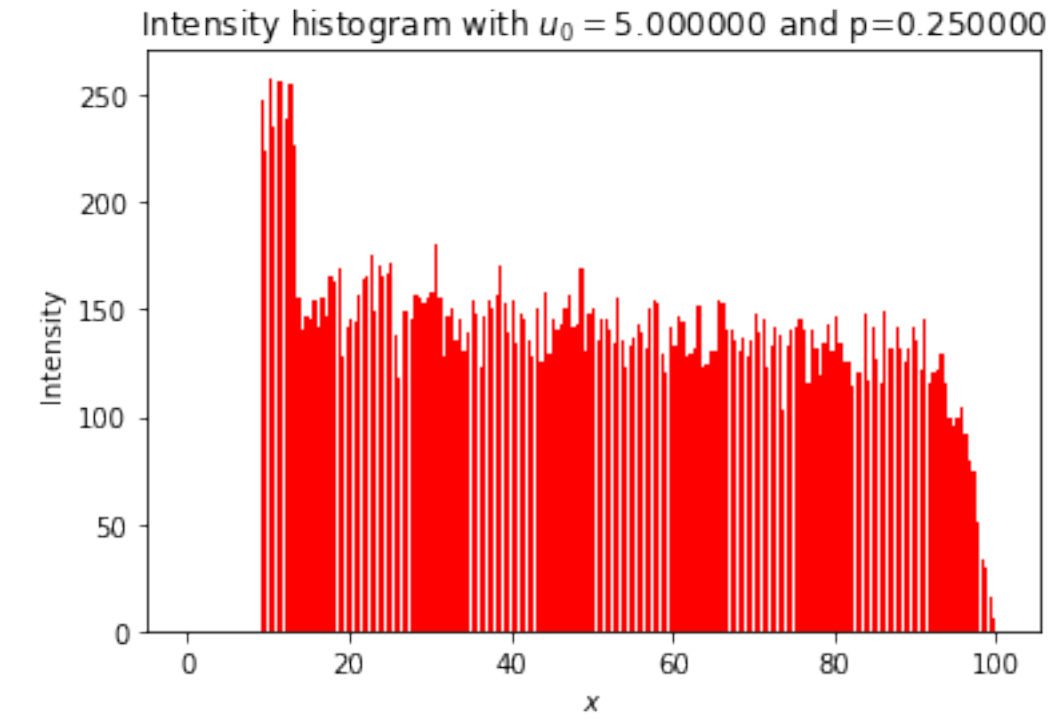
```
In [6]: def plot_no_of_elec(X,u0,p):
        #plot the number of electrons vs x
            figure(1)
            hist(X,bins=np.arange(0,101,0.5),rwidth=0.8,color='g')
            title('Number of Electrons vs $x$ with $u_0=$%f and p=%f'%(u0,p))
            xlabel('$x$')
            ylabel('Number of electrons')
            show()

        def plot_intensity_map(I,u0,p):
        #plot the intensity map
            histogram_=hist(I,bins=np.arange(0,101,1),rwidth=0.8,color='r')
            x=histogram_[1][1:]
            y=histogram_[0]
            fig, (ax) = plt.subplots(nrows=1, sharex=True)
            extent = [x[0]-(x[1]-x[0])/2., x[-1]+(x[1]-x[0])/2.,0,1]
            intensity=ax.imshow(y[np.newaxis,:], cmap="gray", aspect="auto", extent=extent)
            ax.set_yticks([])
            ax.set_xlim(extent[0], extent[1])
            plt.title('Intensity map with $u_0=$%f and p=%f'%(u0,p))
            plt.xlabel('$x$')
            plt.colorbar(intensity)
            plt.tight_layout()
            show()

        def plot_intensity(X,V,u0,p):
            #plot the histogram of intensity
            figure(0)
            histogram=hist(I,bins=np.arange(0,101,0.5),rwidth=0.8,color='r')
            title('Intensity histogram with $u_0=$%f and p=%f'%(u0,p))
            xlabel('$x$')
            ylabel('Intensity')
            show()
```

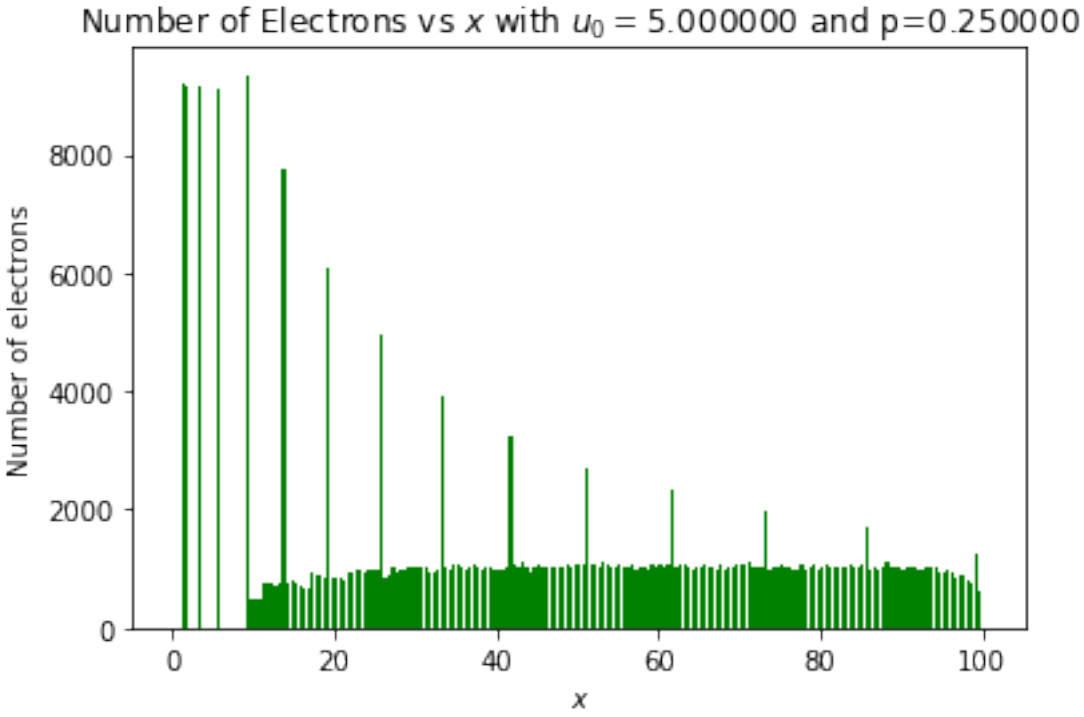
```
    return histogram

def plot_phase(X,V,u0,p):
#plot the phase space
    figure(2)
    plt.plot(X,V,'bo')
    title('Electron Phase Space with $u_0=$%f and p=%f'%(u0,p))
    xlabel('$x$')
    ylabel('Velocity-$v$')
    show()
```

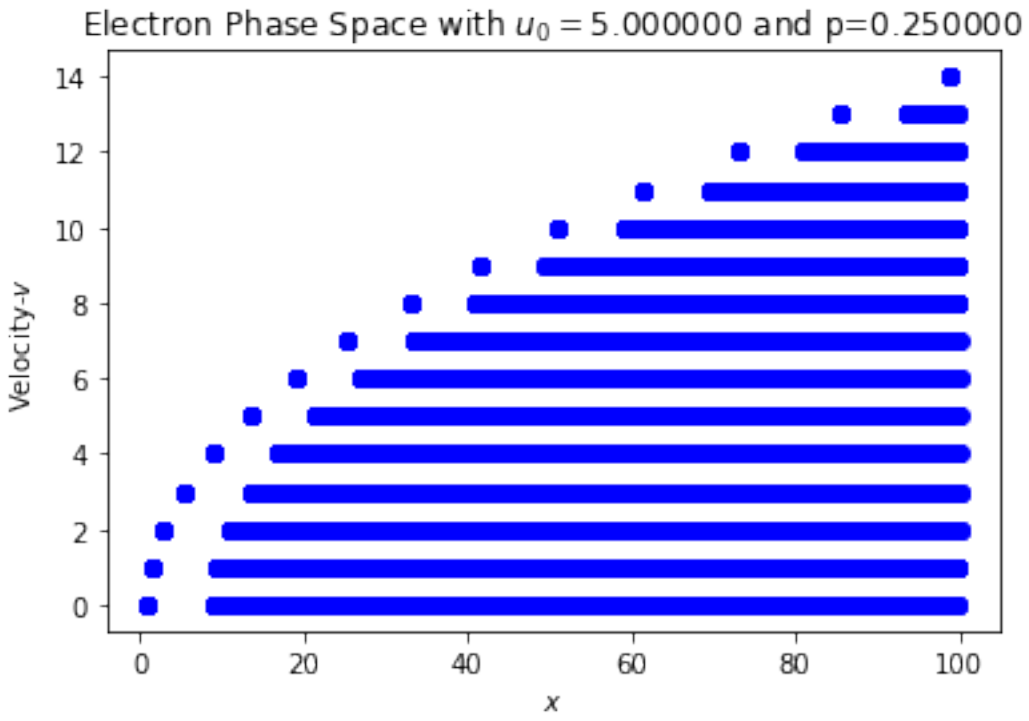
6 Plot of the graphs with uniform probability of electron.

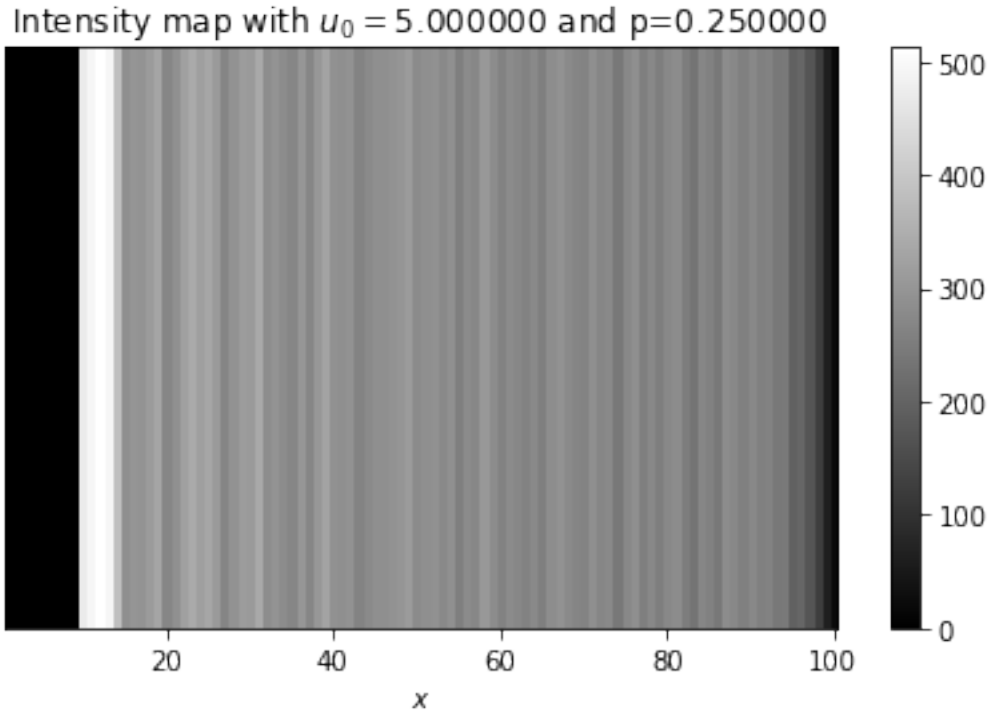
In the intensity vs x graph the intensity reaches a maximum at around x=15 and stays like that for around 4-5 bins and then it decreases.This is because of the fact that the electron comes to rest after collision.So it has to gain energy again from zero to be able to excite the atom for emitting light.
In the electron phase space the graph shows the allowed velocities at a particular value of x thus we can say that the velocities are quantized.
The number of electrons vs x graph shows the number of electrons which got excited at that value of x.

```
In [7]: param=[100,5,500,5,0.25,2]
        X,V,I=loop(param,False)
        histo=plot_intensity(X,V,param[3],param[4])
        plot_no_of_elec(X,param[3],param[4])
        plot_phase(X,V,param[3],param[4])
        plot_intensity_map(I,param[3],param[4])
```


Intensity histogram with $u_0 = 5.000000$ and p=0.250000
Intensity
x
0
50
100
150
200
250
0
20
40
60
80
100


Number of Electrons vs x with $u_0 = 5.000000$ and p=0.250000
Number of electrons
x
0
2000
4000
6000
8000
0
20
40
60
80
100


Electron Phase Space with $u_0 = 5.000000$ and p=0.250000
Velocity-v
x
0
2
4
6
8
10
12
14
0
20
40
60
80
100


Intensity map with $u_0 = 5.000000$ and p=0.250000
x
20
40
60
80
100
0
100
200
300
400
500

7 Table of Population vs xpos

Sr.No.	xpos	Population
0	0.0	0.0
2	1.0	0.0
4	2.0	0.0
6	3.0	0.0
8	4.0	0.0
10	5.0	0.0
12	6.0	0.0
14	7.0	0.0
16	8.0	0.0
18	9.0	248.0
20	10.0	258.0
22	11.0	256.0
24	12.0	239.0
26	13.0	227.0
28	14.0	141.0
30	15.0	146.0
32	16.0	142.0
34	17.0	147.0
36	18.0	163.0
38	19.0	128.0
40	20.0	145.0
42	21.0	157.0
44	22.0	165.0
46	23.0	149.0
48	24.0	166.0
50	25.0	172.0
52	26.0	118.0
54	27.0	149.0
56	28.0	157.0
58	29.0	153.0
..	...	...
142	71.0	146.0
144	72.0	133.0
146	73.0	138.0
148	74.0	133.0
150	75.0	142.0
152	76.0	140.0
154	77.0	141.0
156	78.0	119.0
158	79.0	143.0
160	80.0	147.0
162	81.0	126.0
164	82.0	114.0
166	83.0	121.0
168	84.0	117.0

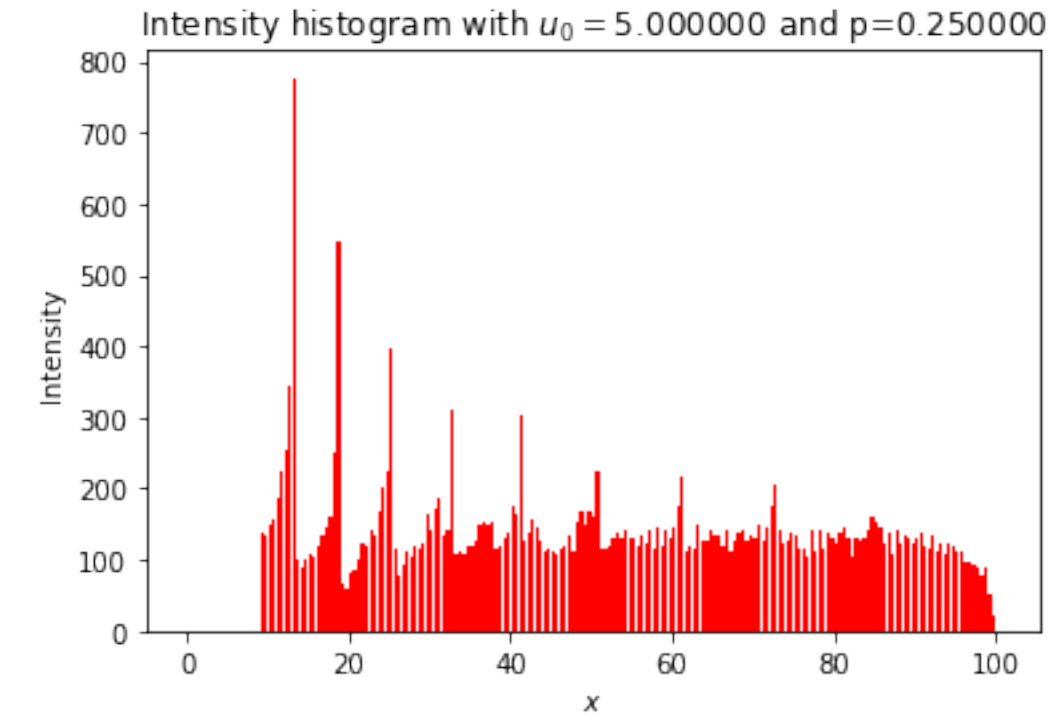
```
170   85.0       127.0
172   86.0       149.0
174   87.0       132.0
176   88.0       132.0
178   89.0       132.0
180   90.0       135.0
182   91.0       146.0
184   92.0       120.0
186   93.0       129.0
188   94.0        99.0
190   95.0       100.0
192   96.0        92.0
194   97.0        74.0
196   98.0        34.0
198   99.0        16.0
200  100.0         0.0
```

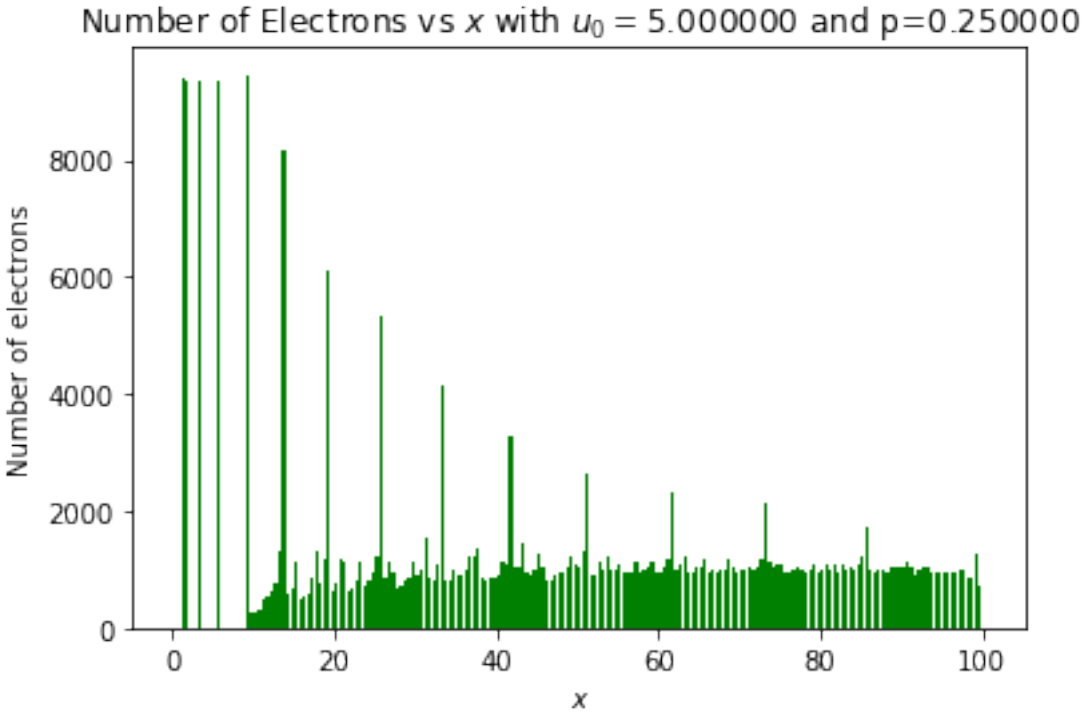
Note:For the purpose of showing the table every alternate element is shown in the table.

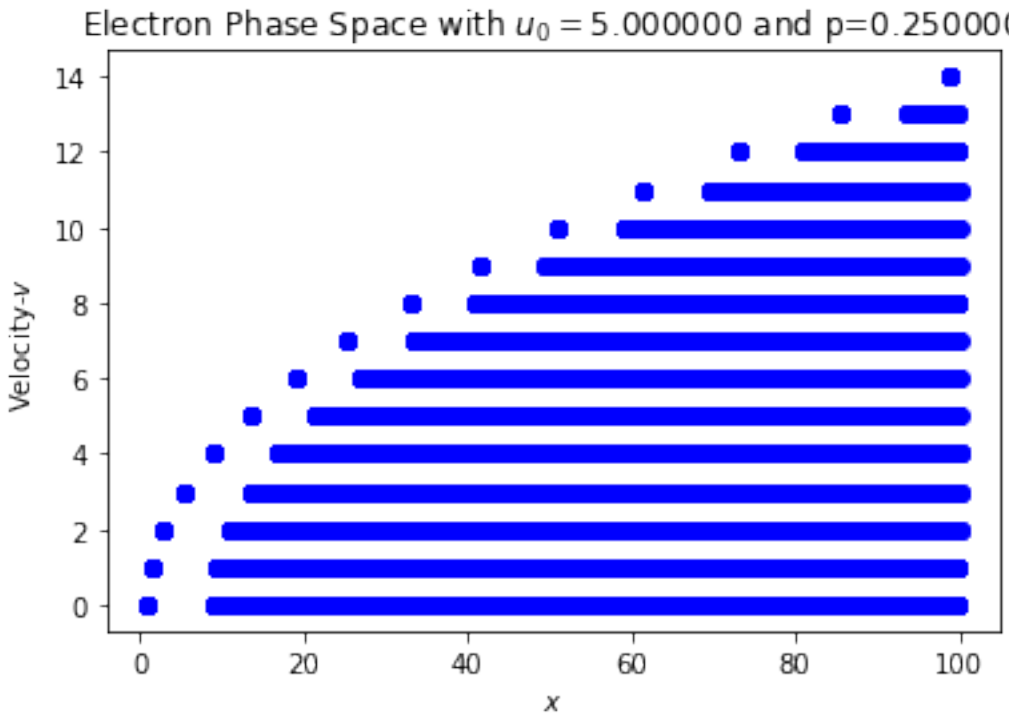
8 Plot of the graphs with quadratic probability of electron.

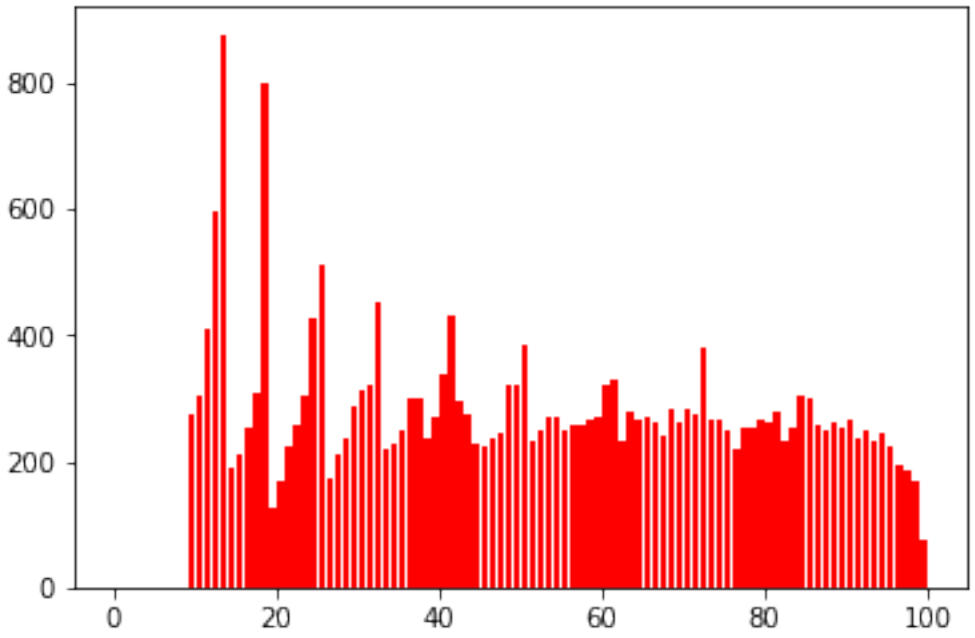
In the intensity vs x graph the intensity increases and then suddenly drops.This is different than the previous model as the electron getting excited is more towards the right side as it's velocity increases.

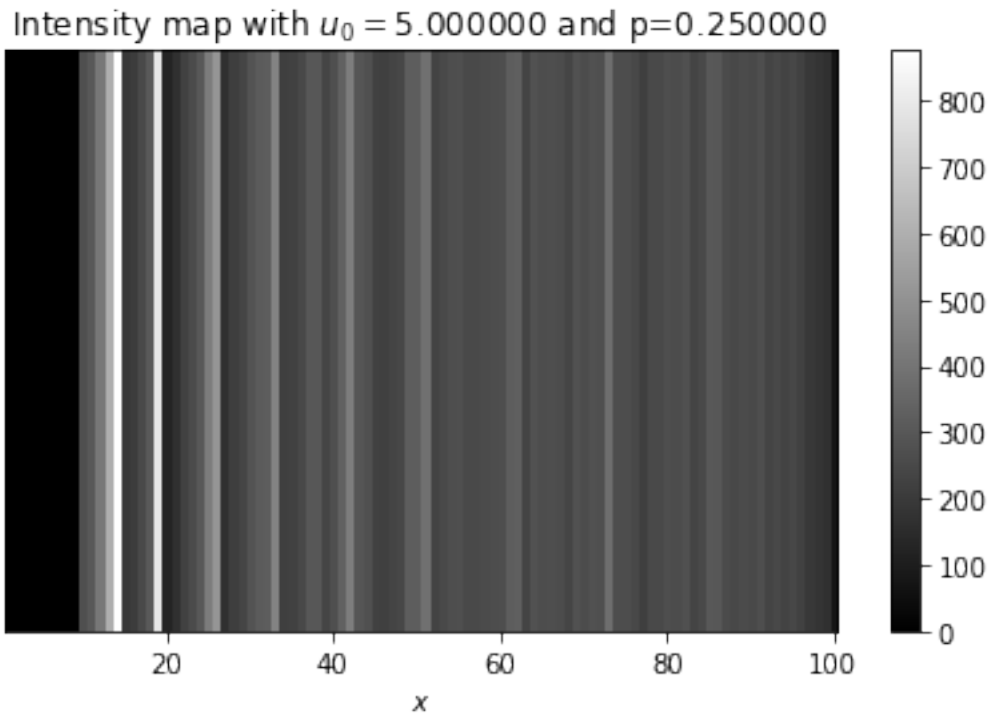
```
In [15]: param=[100,5,500,5,0.25,2]
         X,V,I=loop(param,True)
         plot_intensity(X,V,param[3],param[4])
         plot_no_of_elec(X,param[3],param[4])
         plot_phase(X,V,param[3],param[4])
         plot_intensity_map(I,param[3],param[4])
```


Intensity histogram with $u_0 = 5.000000$ and p=0.250000
Intensity
x
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100


Number of Electrons vs x with $u_0 = 5.000000$ and p=0.250000
Number of electrons
x
0
2000
4000
6000
8000
0
20
40
60
80
100


Electron Phase Space with $u_0 = 5.000000$ and p=0.250000
Velocity-v
x
0
2
4
6
8
10
12
14
0
20
40
60
80
100

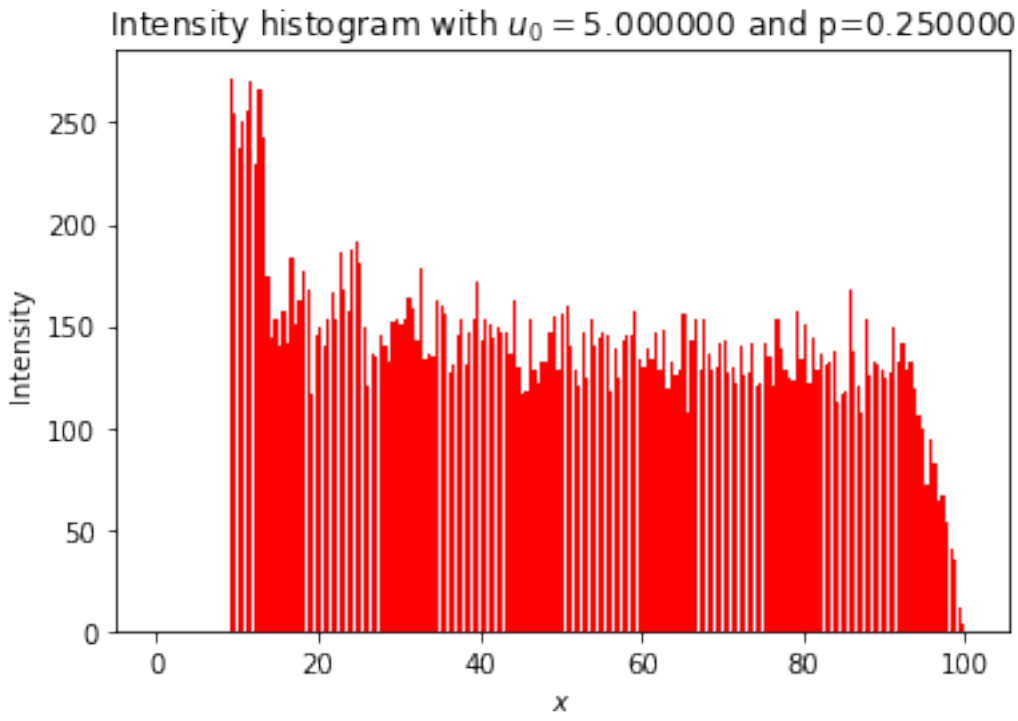

0
200
400
600
800
0
20
40
60
80
100

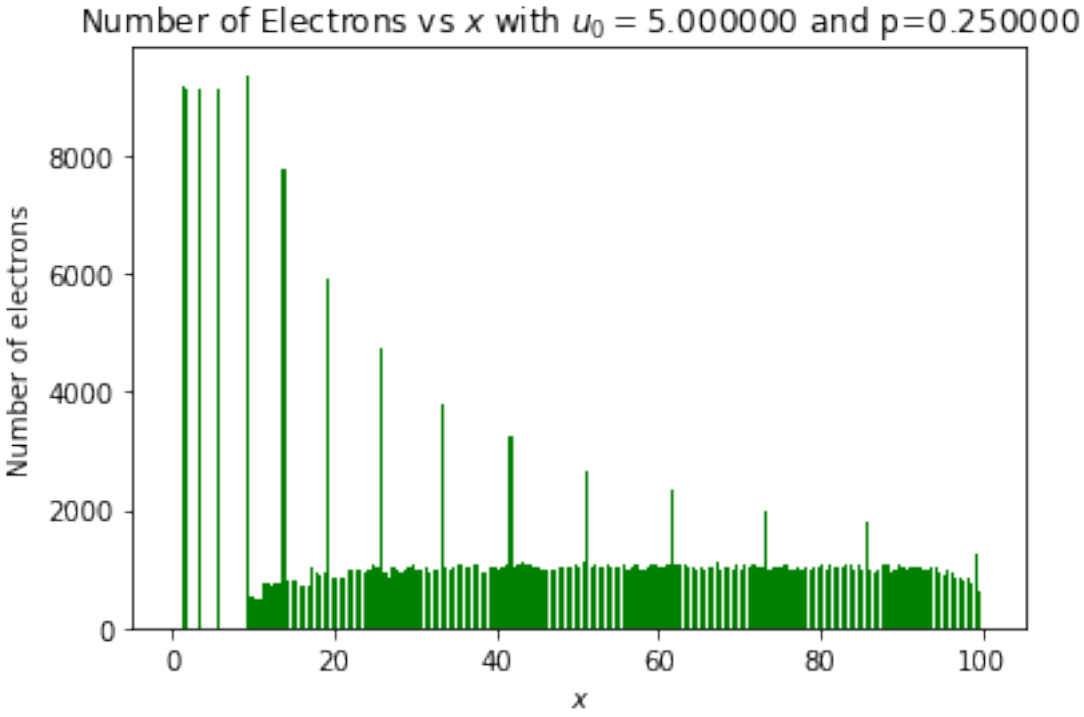


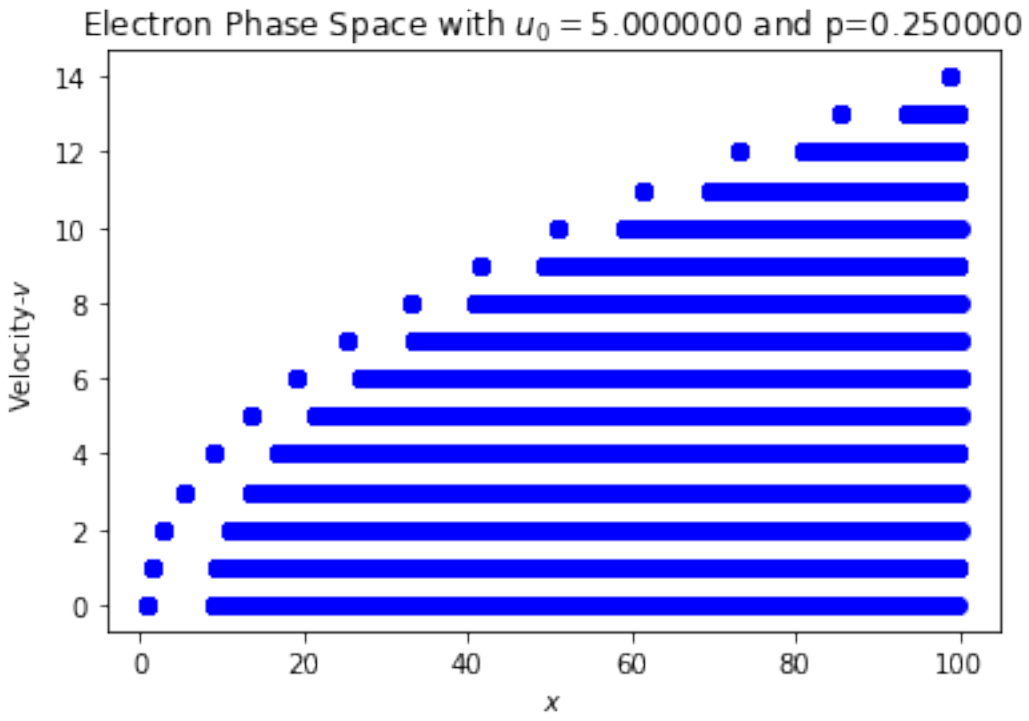
9 Iterating through the different parameters

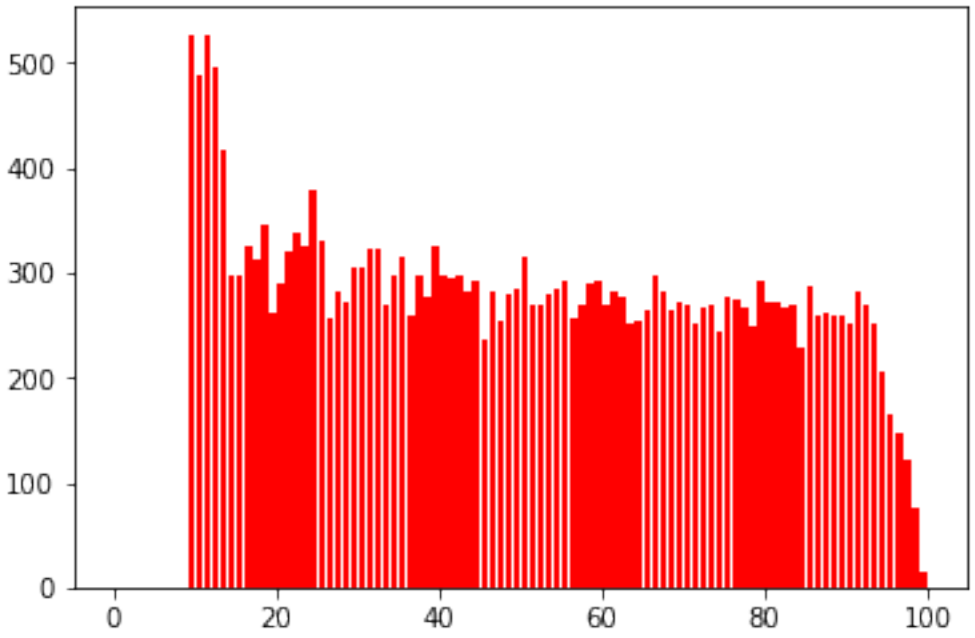
The variation in the graphs when the cutoff velocity and probability are captured here.
One specific observation is that as the probability increases the graphs become more variate i.e. the superposition of the probability graphs become more seperated.
Also the maximum intensity also increases as the electrons get inonized more often.
Also as the cutoff velocity (i.e. the gas inside the tubelight is changed) is increased they initial excitation happens at a higher value of x.This is because the elctron has to travel longer distances to be able to reach cutoff frequency.

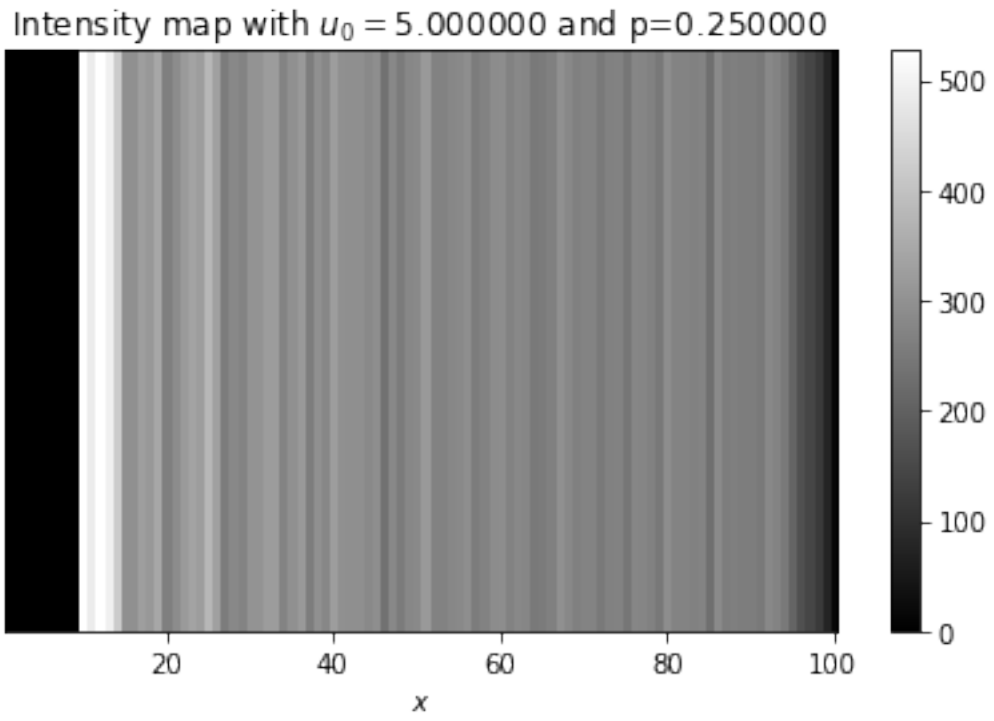
```
In [50]: for param in params:
             X,V,I=loop(param,False)
             plot_intensity(X,V,param[3],param[4])
             plot_no_of_elec(X,param[3],param[4])
             plot_phase(X,V,param[3],param[4])
             plot_intensity_map(I,param[3],param[4])
```

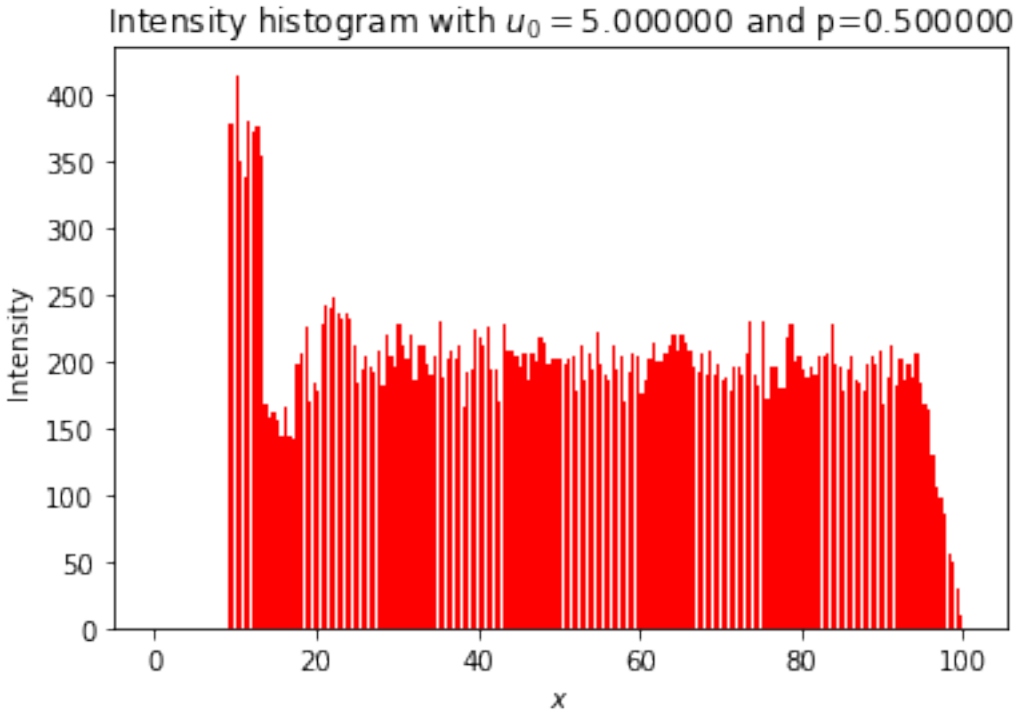

Intensity histogram with $u_0 = 5.000000$ and p=0.250000
Intensity
0
50
100
150
200
250
0
20
40
60
80
100
x

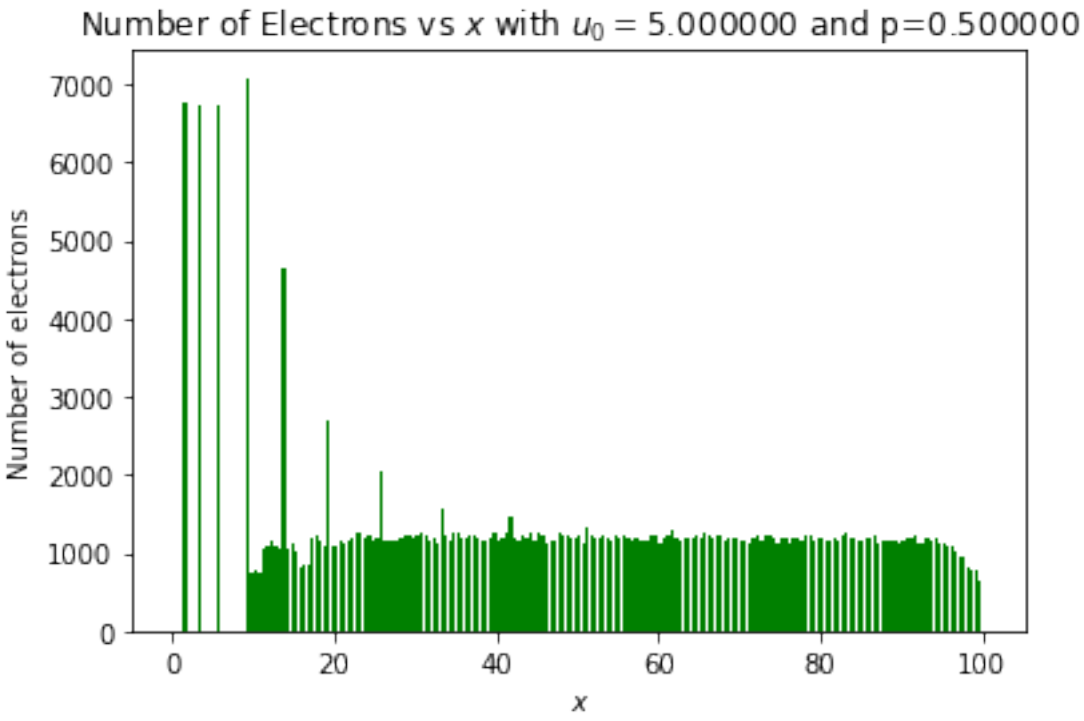

Number of Electrons vs x with $u_0 = 5.000000$ and p=0.250000
Number of electrons
0
2000
4000
6000
8000
0
20
40
60
80
100
x

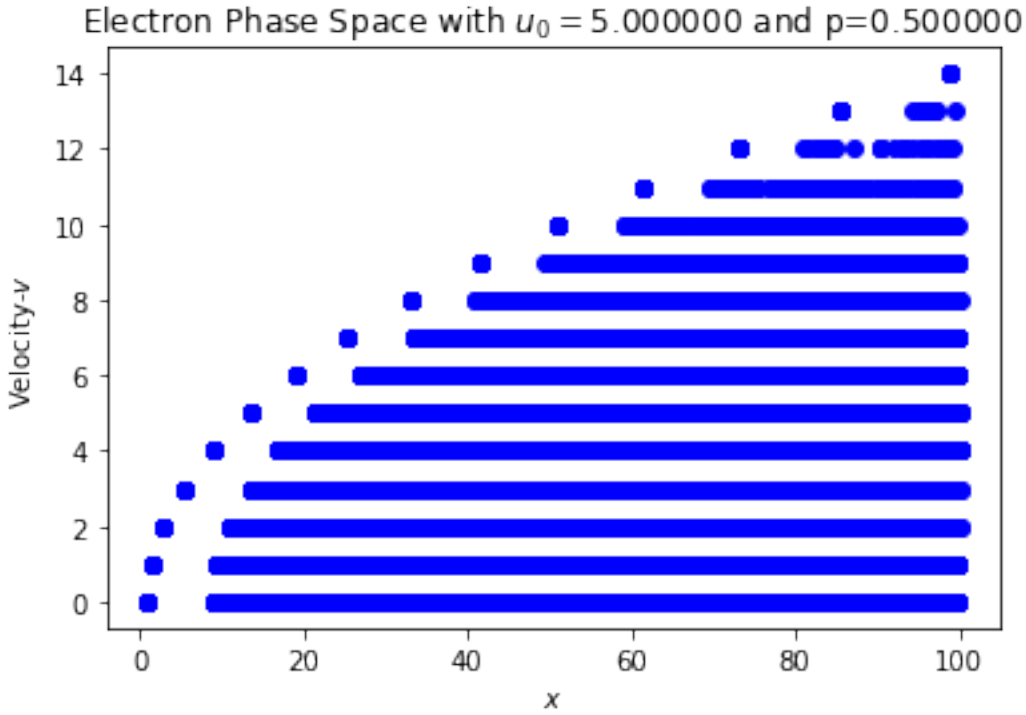

Electron Phase Space with $u_0 = 5.000000$ and p=0.250000
Velocity-v
x
0
2
4
6
8
10
12
14
0
20
40
60
80
100

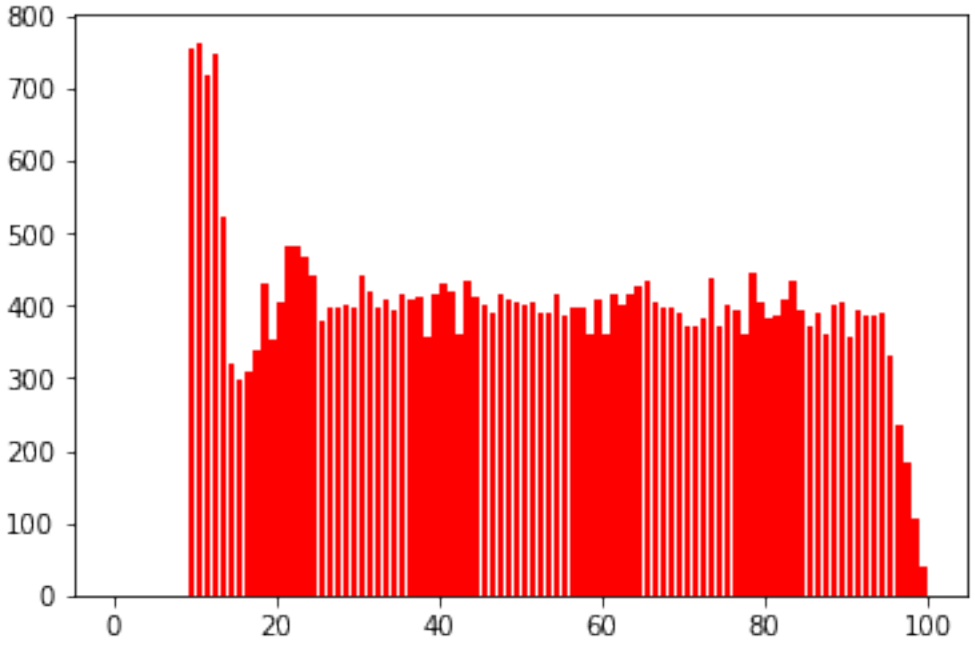

0
100
200
300
400
500
0
20
40
60
80
100

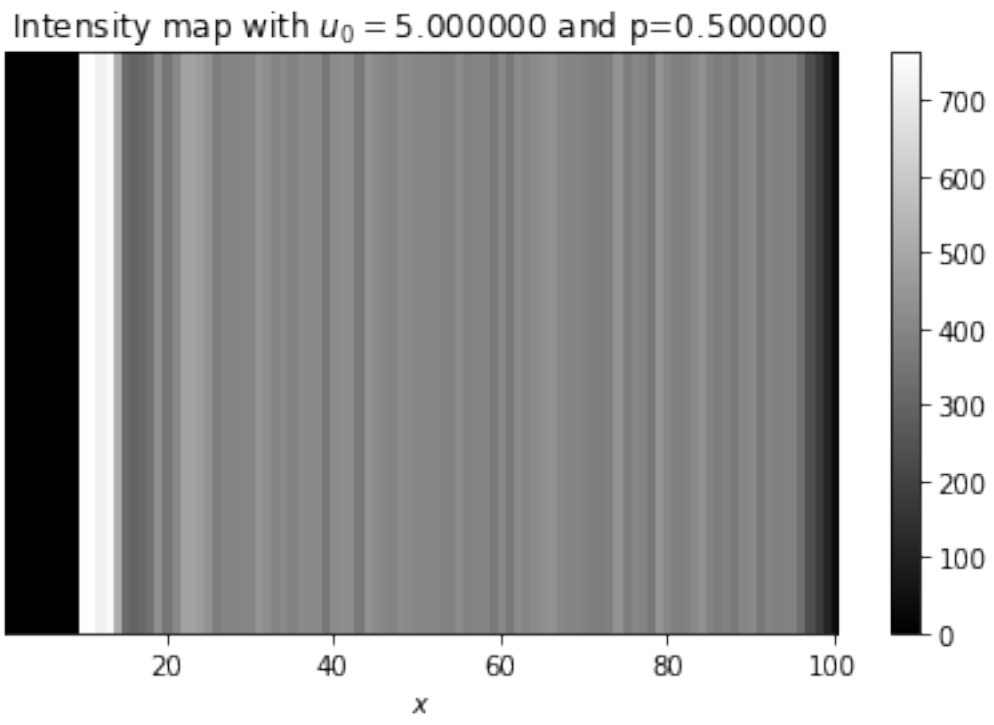

Intensity map with $u_0 = 5.000000$ and p=0.250000
500
400
300
200
100
0
20
40
60
80
100
x

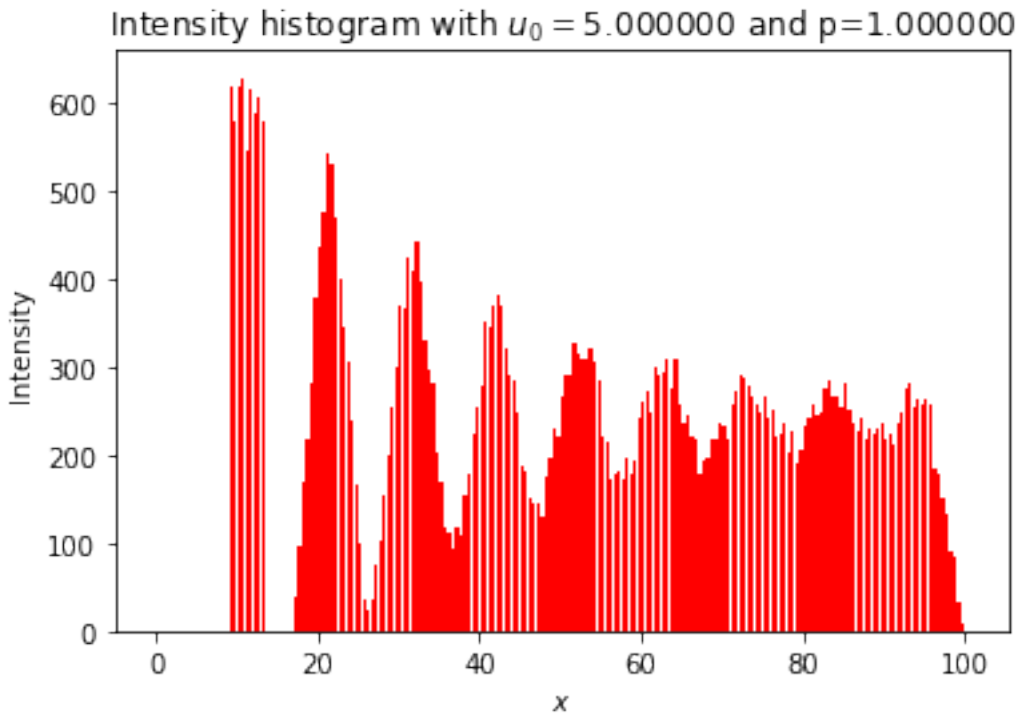

Intensity histogram with $u_0 = 5.000000$ and p=0.500000
Intensity
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
x

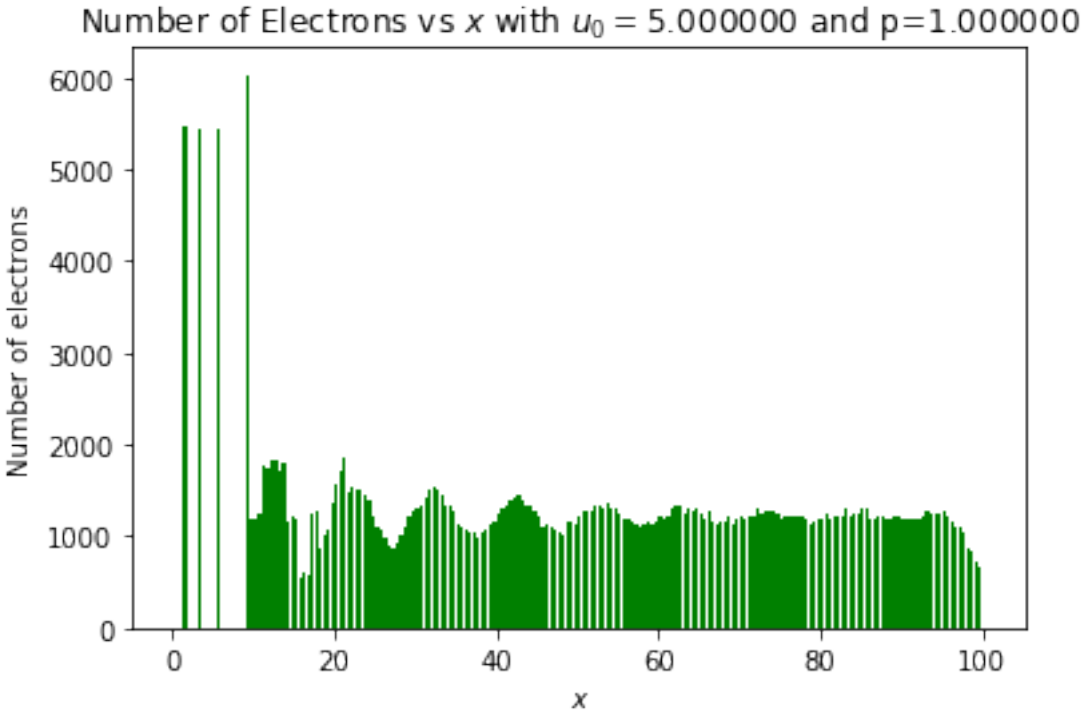

Number of Electrons vs x with $u_0 = 5.000000$ and p=0.500000
Number of electrons
0
1000
2000
3000
4000
5000
6000
7000
0
20
40
60
80
100
x

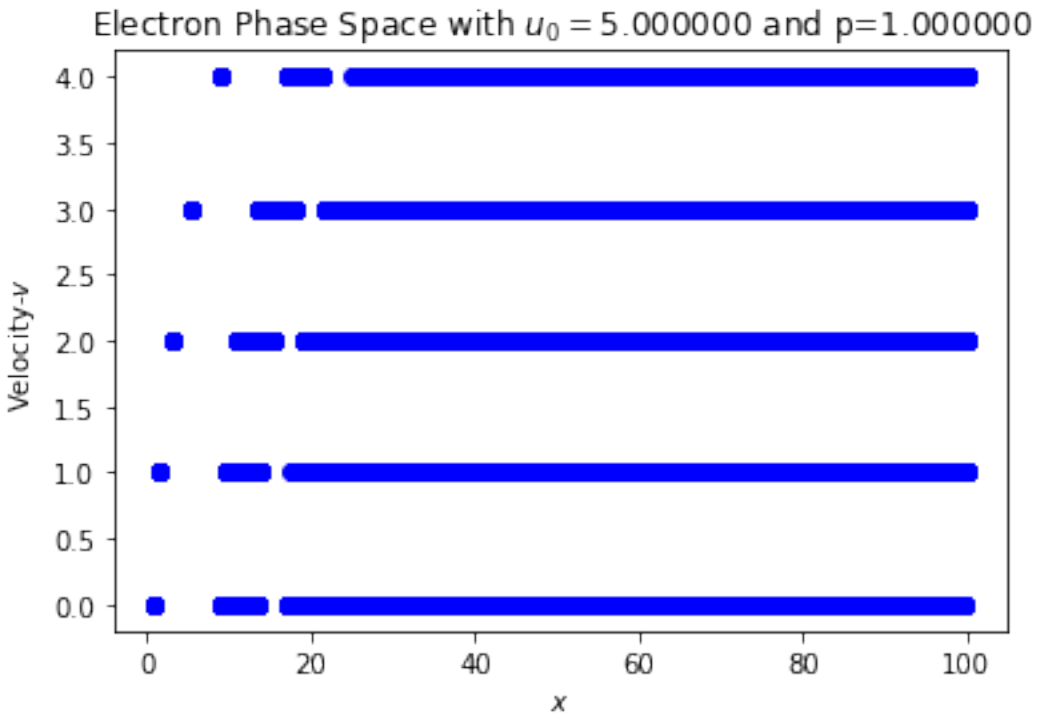

Electron Phase Space with $u_0 = 5.000000$ and p=0.500000
Velocity-v
0
2
4
6
8
10
12
14
0
20
40
60
80
100
x

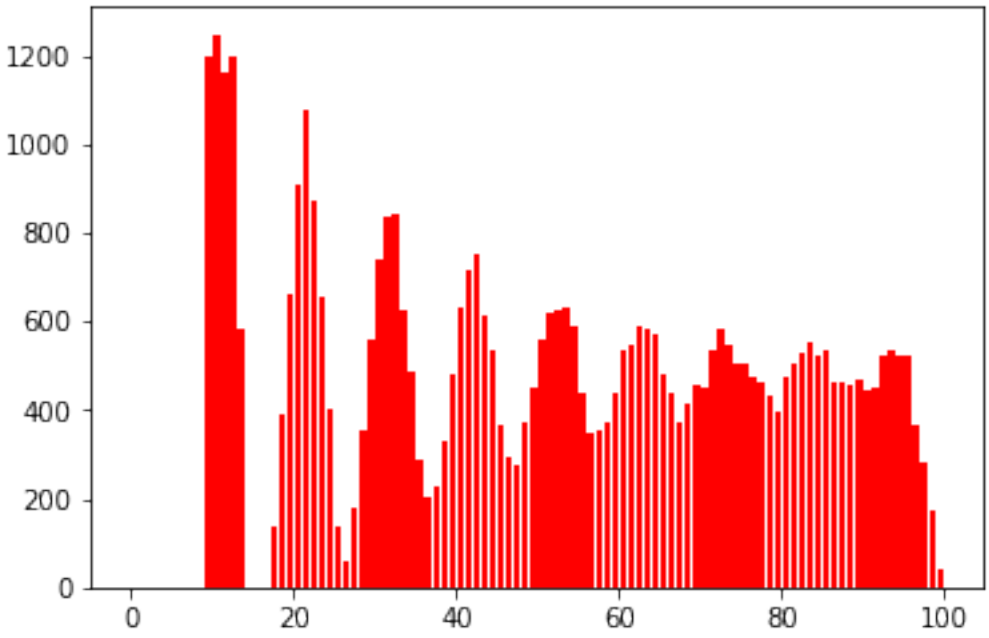

800
700
600
500
400
300
200
100
0
0
20
40
60
80
100

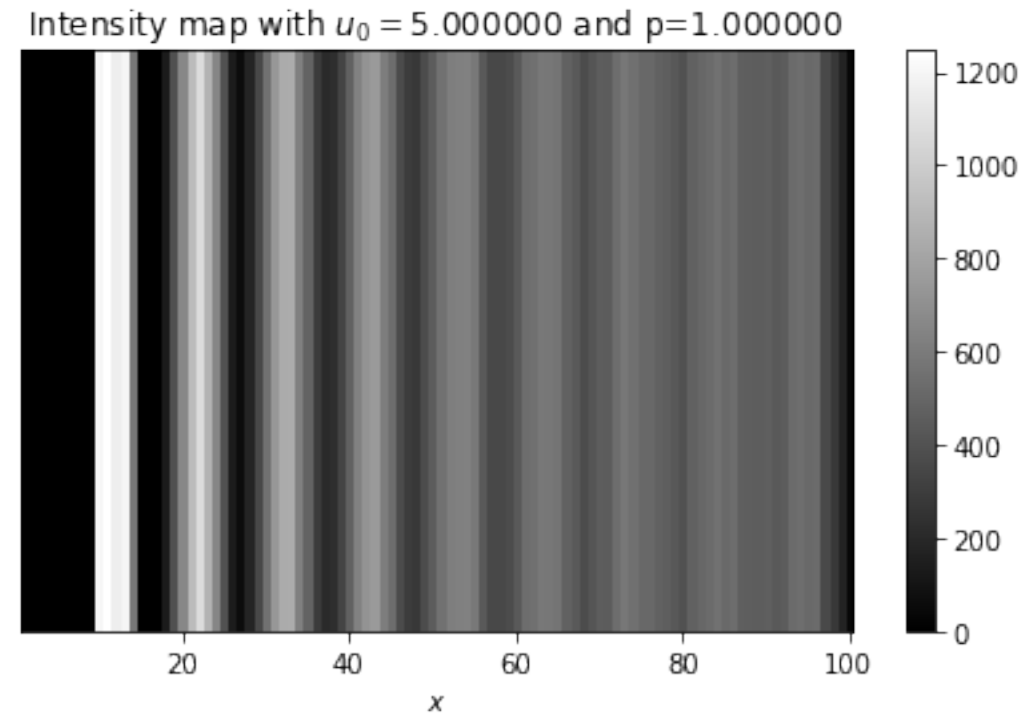

Intensity map with $u_0 = 5.000000$ and p=0.500000
700
600
500
400
300
200
100
0
20
40
60
80
100
x

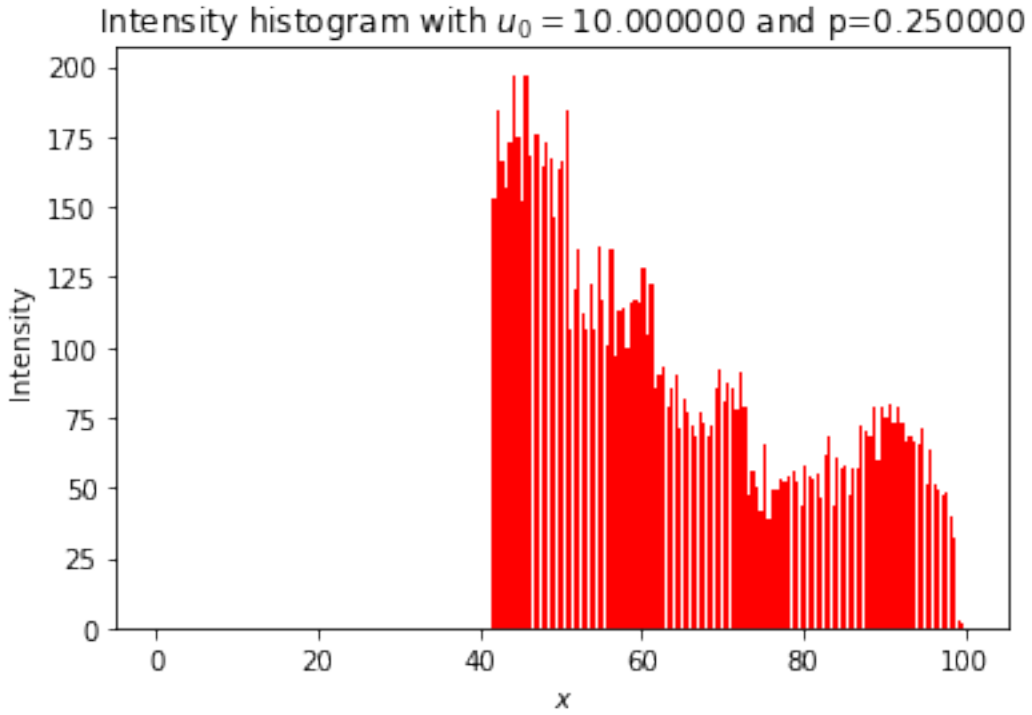

Intensity histogram with $u_0 = 5.000000$ and p=1.000000
Intensity
0
100
200
300
400
500
600
0
20
40
60
80
100
x

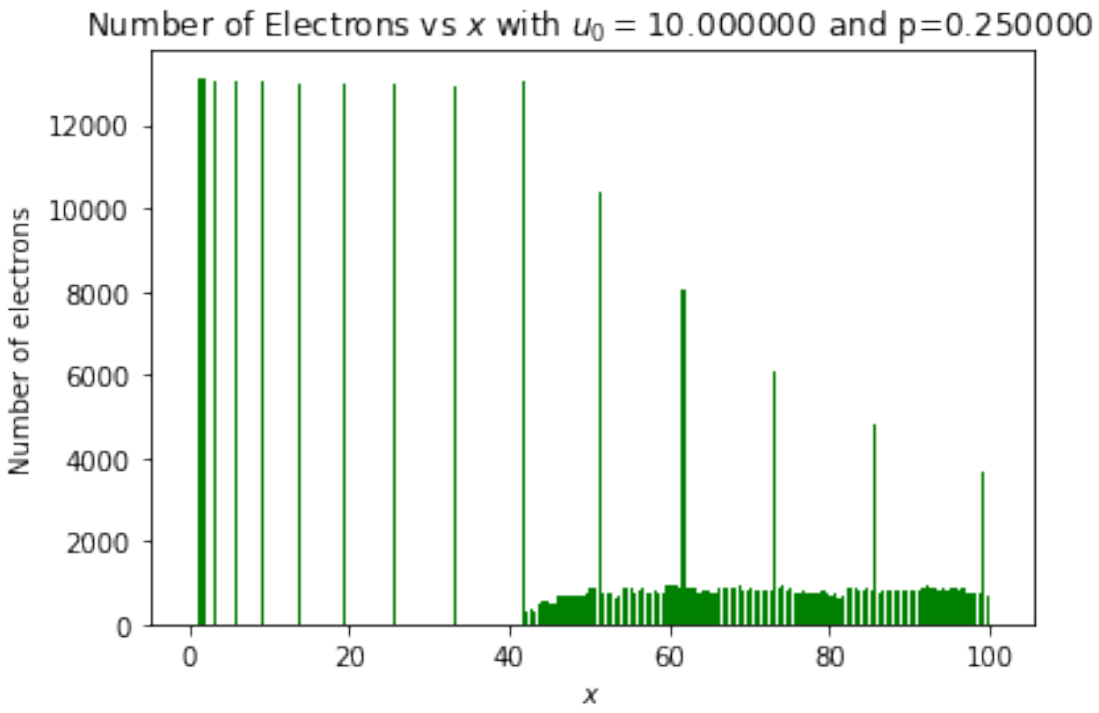

Number of Electrons vs x with $u_0 = 5.000000$ and p=1.000000
Number of electrons
0
1000
2000
3000
4000
5000
6000
0
20
40
60
80
100
x

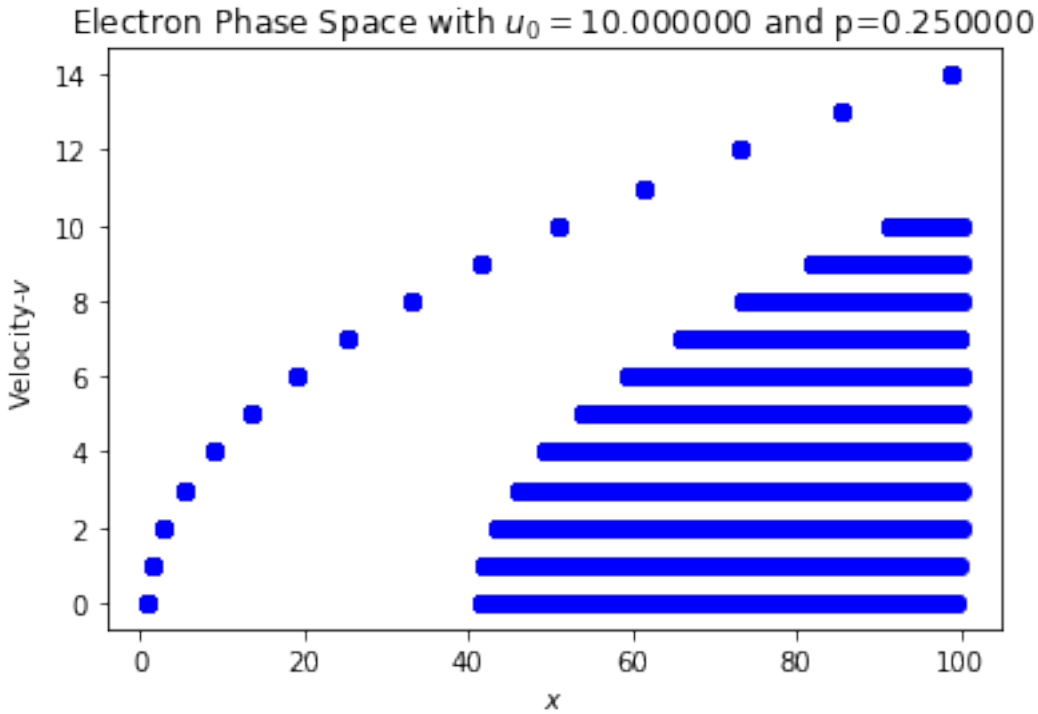

Electron Phase Space with $u_0 = 5.000000$ and p=1.000000
Velocity-v
x
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
20
40
60
80
100

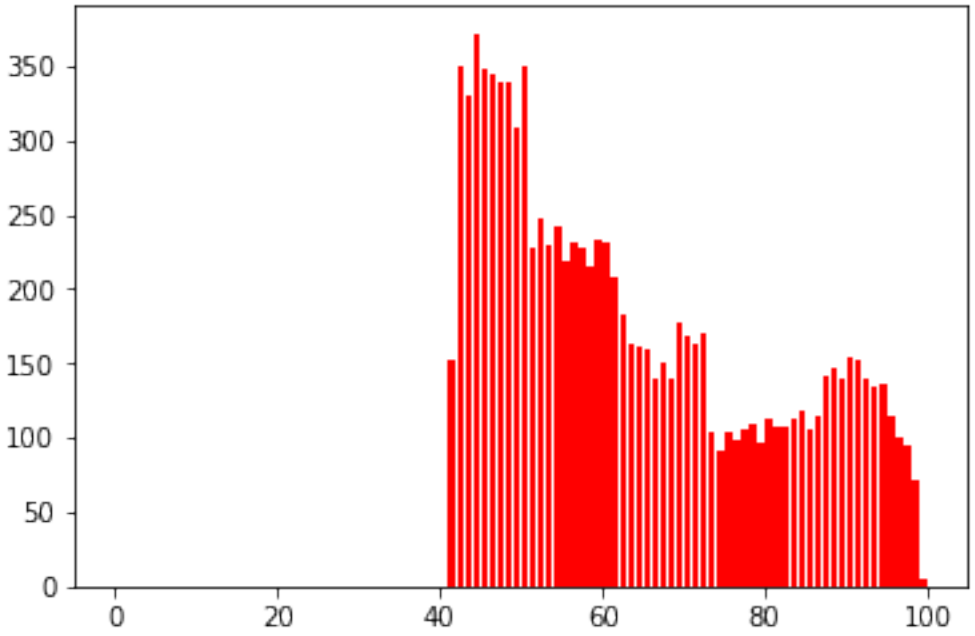

0
200
400
600
800
1000
1200
0
20
40
60
80
100

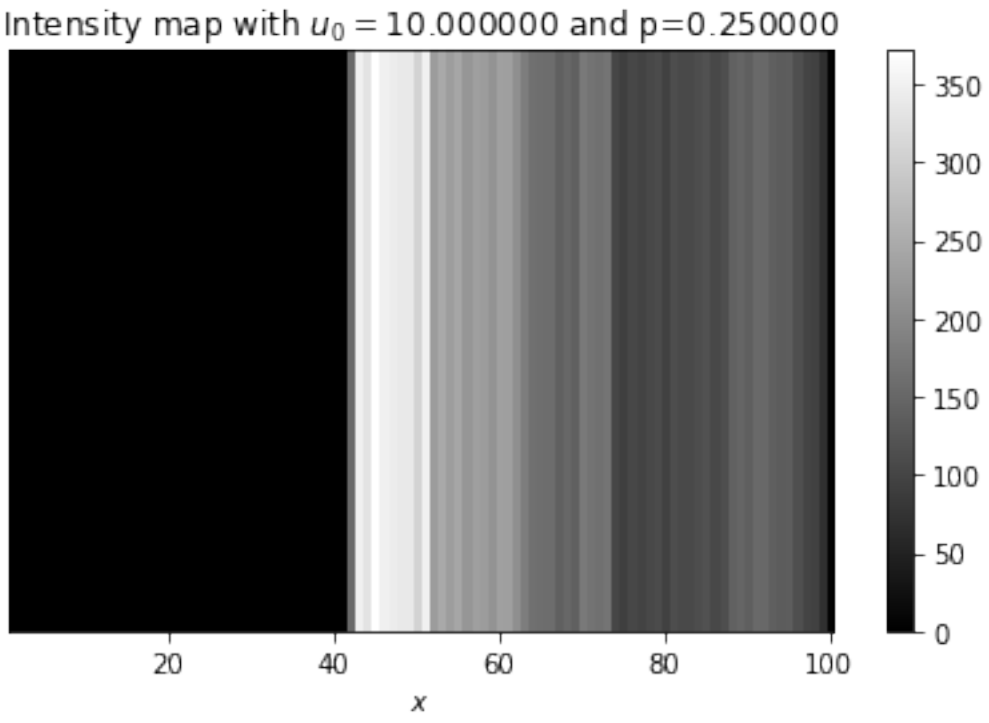

Intensity map with $u_0 = 5.000000$ and p=1.000000
1200
1000
800
600
400
200
0
20
40
60
80
100
x

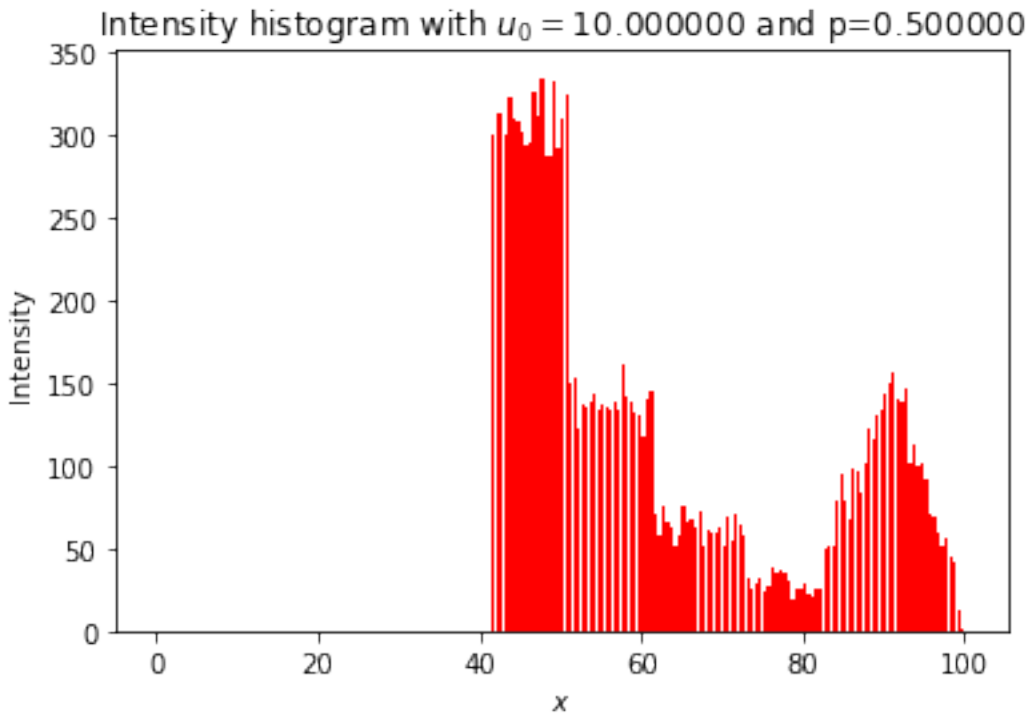

Intensity histogram with $u_0 = 10.000000$ and p=0.250000
Intensity
200
175
150
125
100
75
50
25
0
0
20
40
60
80
100
x

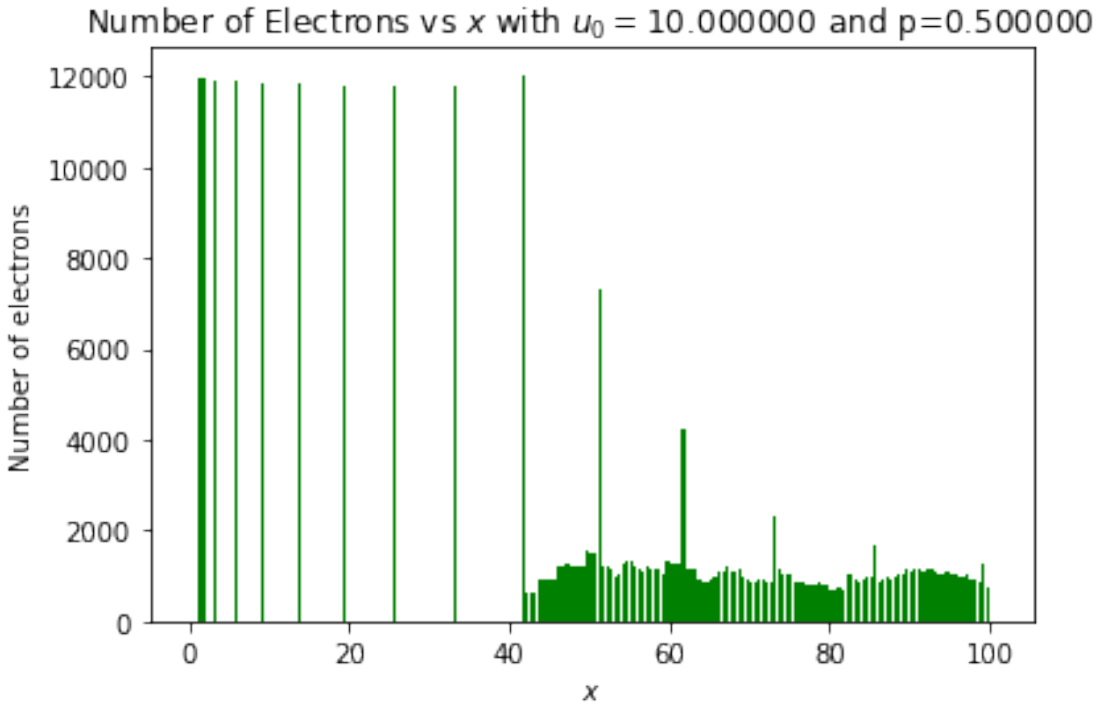

Number of Electrons vs x with $u_0 = 10.000000$ and p=0.250000
Number of electrons
0
2000
4000
6000
8000
10000
12000
0
20
40
60
80
100
x

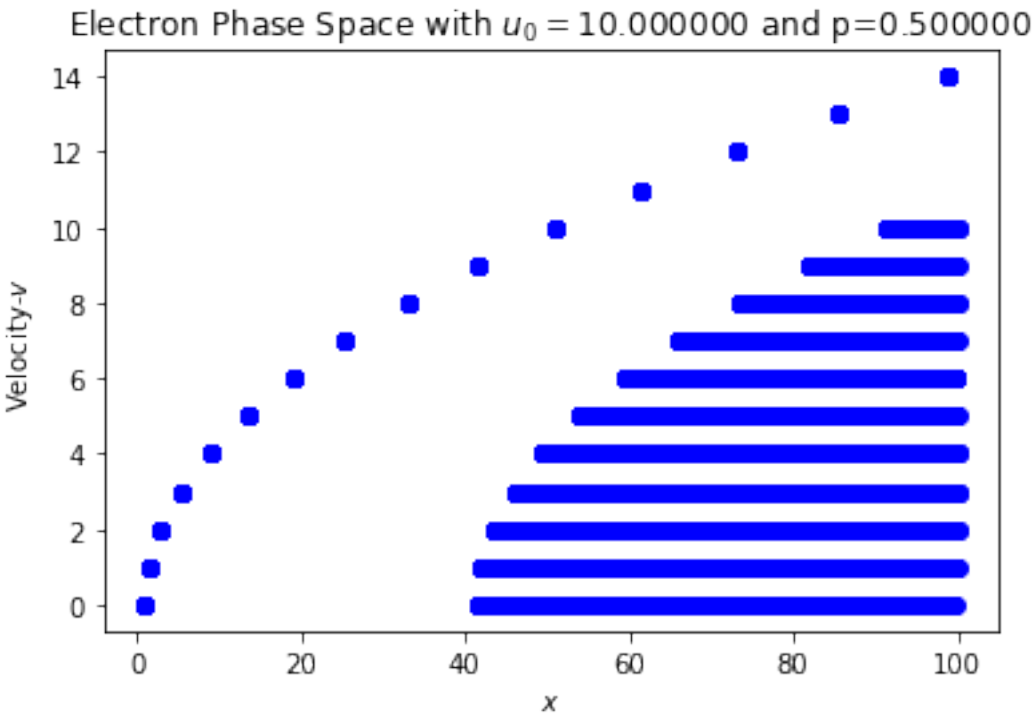

Electron Phase Space with $u_0 = 10.000000$ and p=0.250000
Velocity-v
0
2
4
6
8
10
12
14
0
20
40
60
80
100
x

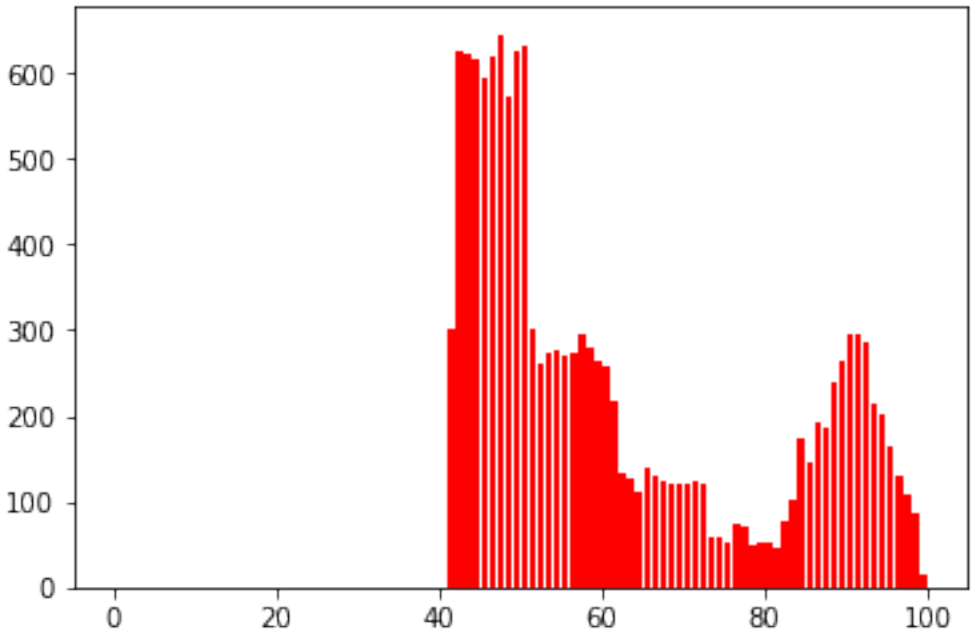

350
300
250
200
150
100
50
0
0
20
40
60
80
100

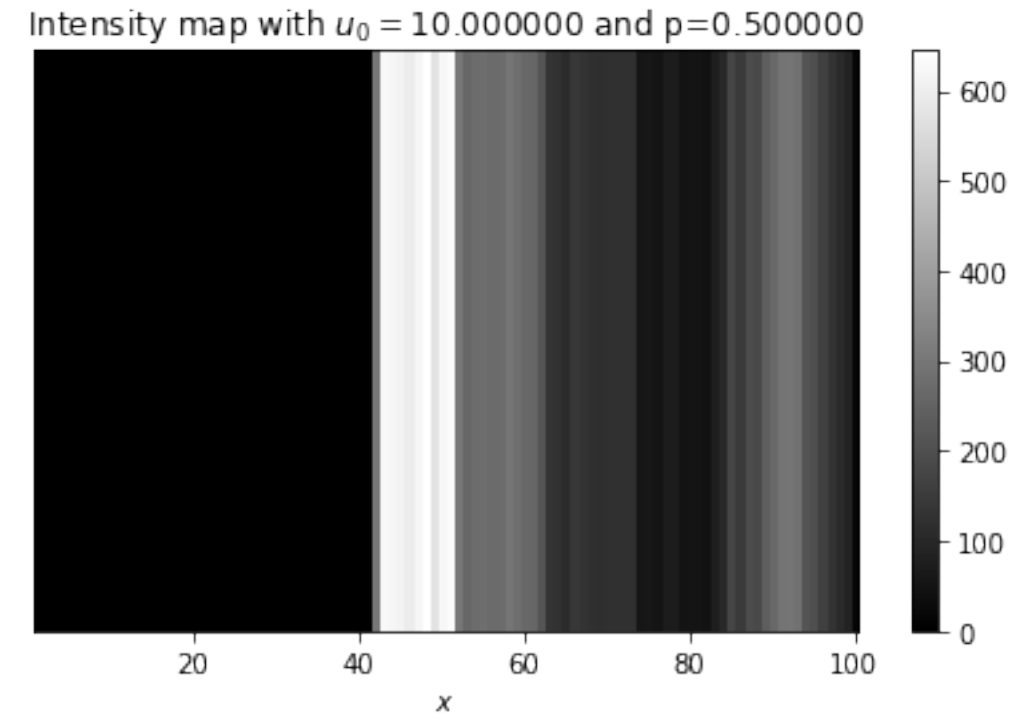

Intensity map with $u_0 = 10.000000$ and p=0.250000
350
300
250
200
150
100
50
0
20
40
60
80
100
x

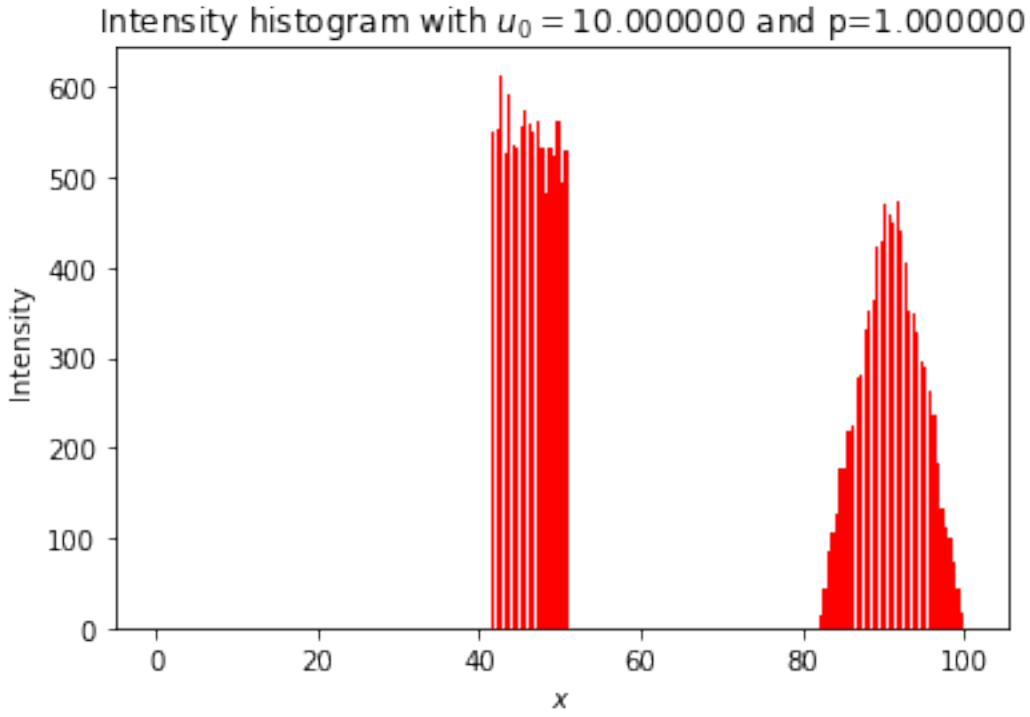

Intensity histogram with $u_0 = 10.000000$ and p=0.500000
Intensity
x
0
50
100
150
200
250
300
350
0
20
40
60
80
100

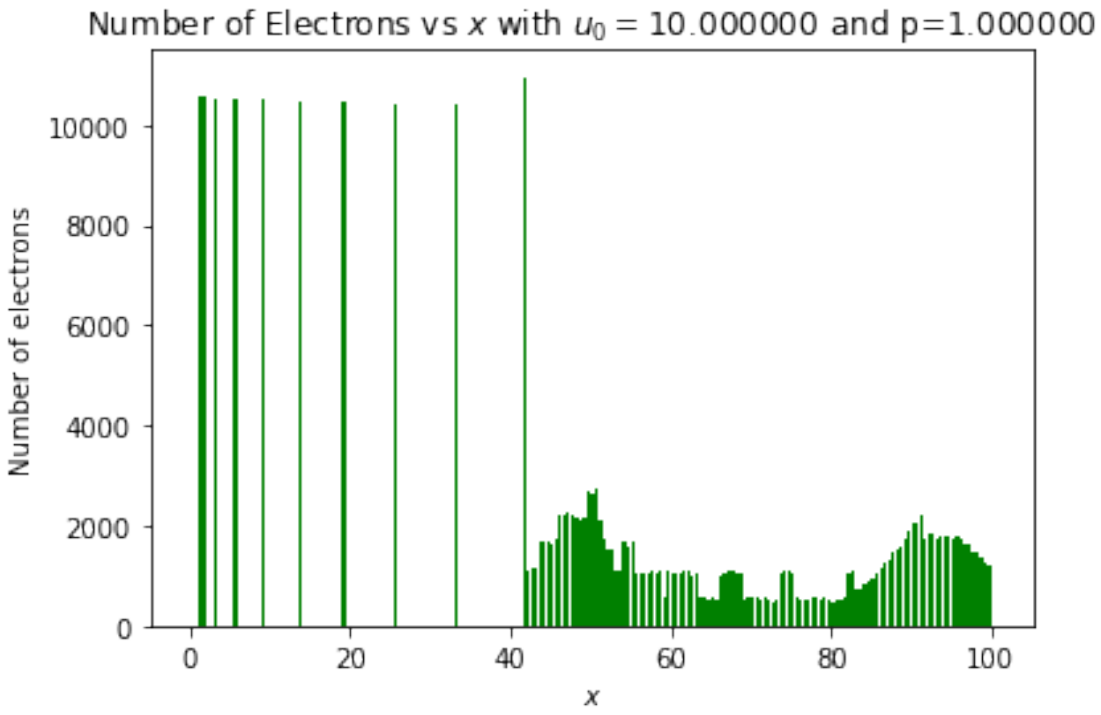

Number of Electrons vs x with $u_0 = 10.000000$ and p=0.500000
Number of electrons
x
0
2000
4000
6000
8000
10000
12000
0
20
40
60
80
100

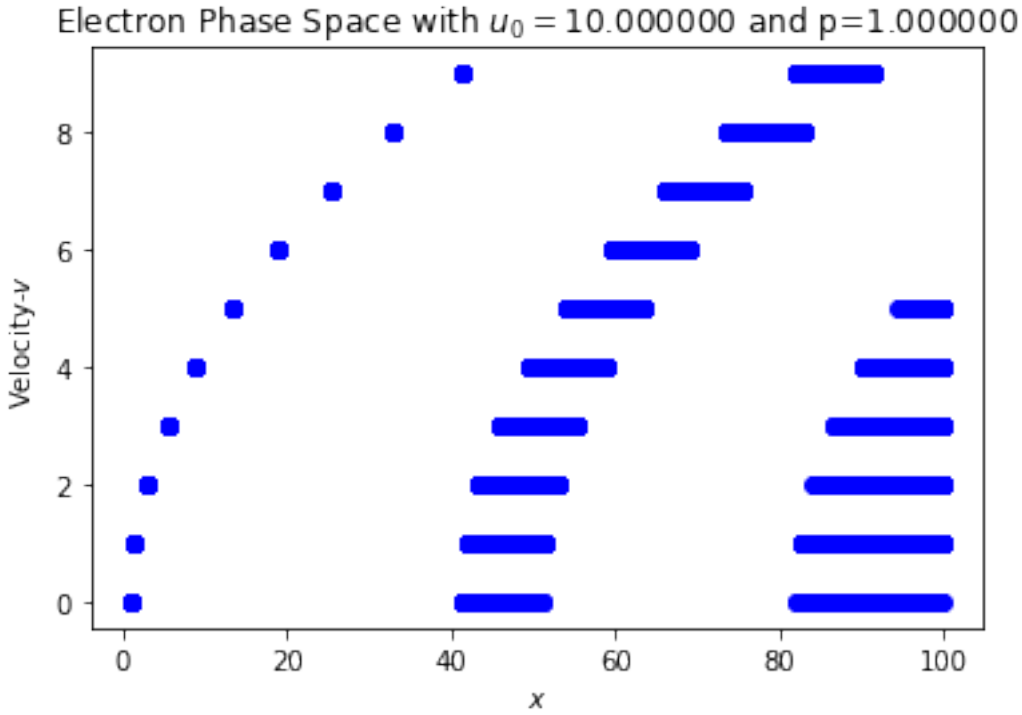

Electron Phase Space with $u_0 = 10.000000$ and p=0.500000
Velocity-v
x
0
2
4
6
8
10
12
14
0
20
40
60
80
100

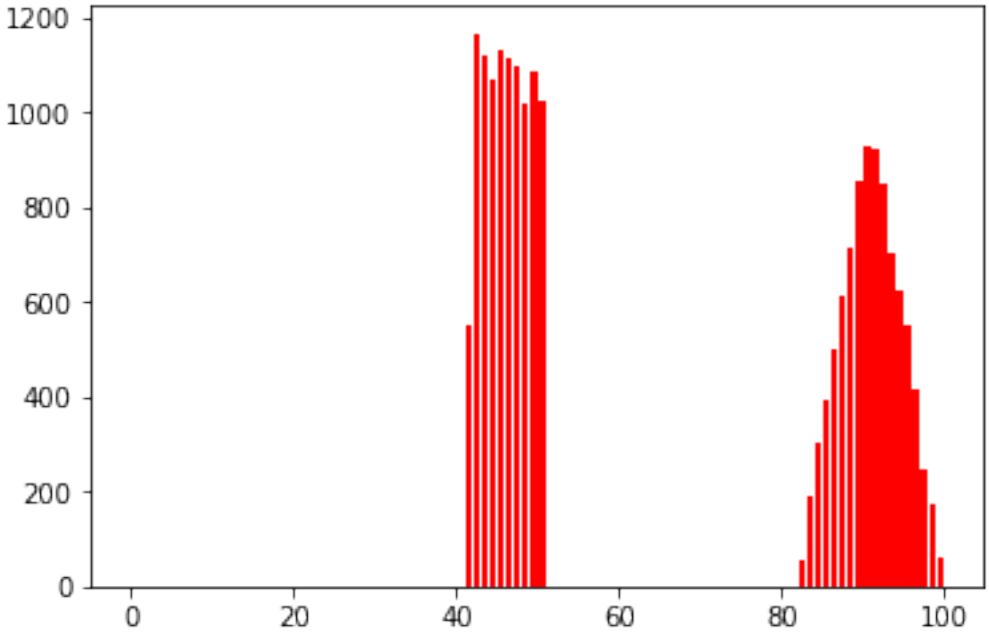

0
100
200
300
400
500
600
0
20
40
60
80
100

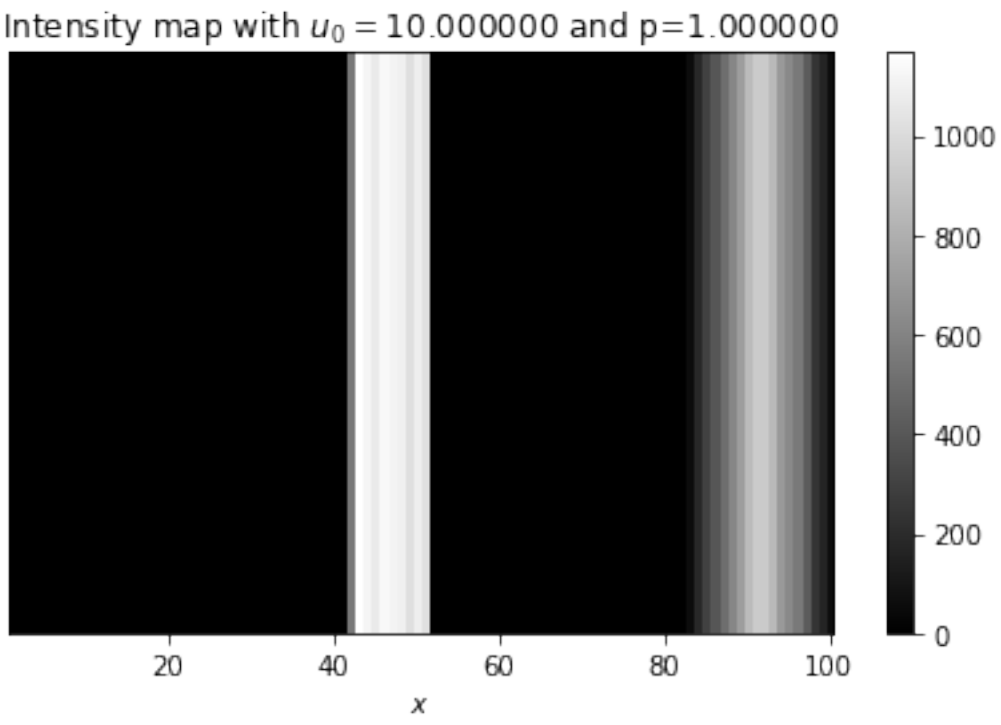

Intensity map with $u_0 = 10.000000$ and p=0.500000
600
500
400
300
200
100
0
20
40
60
80
100
x


Intensity histogram with $u_0 = 10.000000$ and p=1.000000
Intensity
600
500
400
300
200
100
0
0
20
40
60
80
100
x


Number of Electrons vs x with $u_0 = 10.000000$ and p=1.000000
Number of electrons
0
2000
4000
6000
8000
10000
0
20
40
60
80
100
x


Electron Phase Space with $u_0 = 10.000000$ and p=1.000000
Velocity-v
0
2
4
6
8
0
20
40
60
80
100
x


1200
1000
800
600
400
200
0
0
20
40
60
80
100


Intensity map with $u_0 = 10.000000$ and p=1.000000
1000
800
600
400
200
0
20
40
60
80
100
x