Assignment 6: simulations

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1 Introduction

In this assignment, we model a tube-light 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 tube-light is simulated for a certain number of time steps from an initial state of having no electrons. The results obtained are plotted and observed.

2 Simulation of tubelight

The tube light consists of a cathode(ejects electrons) and anode and group of atoms between. The arrangement of cathode and anode creates an electric field which accelerates the elctrons from cathode(where electrons are momentarily at rest). So that the elctrons gain velocity and they can undergo inelastic collision with atoms thus ejecting an photon creationg light.
In our model, we will assume that the relaxation is immediate. The electron loses all its energy and the process starts again. Electrons reaching the anode are absorbed and lost. Each "time step", an average of N electrons are introduced at the cathode. The actual number of electrons is determined by finding the integer part of a random number that is "normally distributed" with standard deviation of 1 and mean 5.

The python code to simulate the tubelight is shown:-

```
    n=100  # spatial grid size
M=5    # no. of electrons injected per turn
nk=500 # no. of turns to simulate
u0=5   # threshold velocity
p=0.25 # probability that ionization will occur
Msig=1 # Standard deviation
```

```
try:
len(argv)==1 and len(argv)==6
except ioerror:
print('Invalid:')
exit(0)

if len(argv)==6:
n=int(argv[1])
M=int(argv[2])
nk=int(argv[3])
u0=float(argv[4])
p=float(argv[5])
Msig=float(argv[6])
# Initialize position, velocity, change of distance vectors of electrons at a given
xx = np.zeros(n*M) #
u = np.zeros(n*M)
dx = np.zeros(n*M)

# Initialize intensity, velocity, position lists containing values of all elctrons a
I=[]
V=[]
X=[]


for k in range(nk):
    m=int(np.random.rand()*std+M)
    jj=np.where(xx==0)[0]
    xx[jj[:m]]=1

    ii=np.where(xx>0)[0]

    dx[ii]=u[ii]+0.5
    xx[ii]=xx[ii]+dx[ii]
    u[ii]=u[ii]+1

    X.extend(xx[ii].tolist())
    V.extend(u[ii].tolist())

    zz=np.where(xx>=n)[0]
    xx[zz]=0
    u[zz]=0

    kk=np.where(u>=u0)[0]
    ll=np.where(np.random.rand(len(kk))<=p)
```

```
    kl=kk[ll]

    xx[kl]+= -1*(dx[kl]*np.random.rand(n*M)[kl]) # can also use xx[kl]=xx[kl]-dx[kl]
    u[kl]=0

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

3 Plotting of graphs

The results are plotted as given below:-

```
    plt.figure()
plt.hist(X,bins=np.arange(1,n))
plt.title("Electron density")
plt.xlabel(r"$x\rightarrow$")
plt.ylabel(r"Number of electrons$\rightarrow$")

plt.figure()
ints,bins,trash = plt.hist(I,bins=np.arange(1,n))
plt.title('Emission Intensity')
plt.xlabel(r'$x\rightarrow$')
plt.ylabel(r"Intensity$\rightarrow$")

plt.figure()
plt.scatter(X,V,marker='x')
plt.title("Electron Phase Space")
plt.xlabel(r"$x\rightarrow$")
plt.ylabel(r"$v\rightarrow$")
plt.show()
```

4 The observations and plots of simulation

The tubelight is set with default parameters of n =100, M=5 ,nk=500 and Msig=1,u0=5, p=0.25

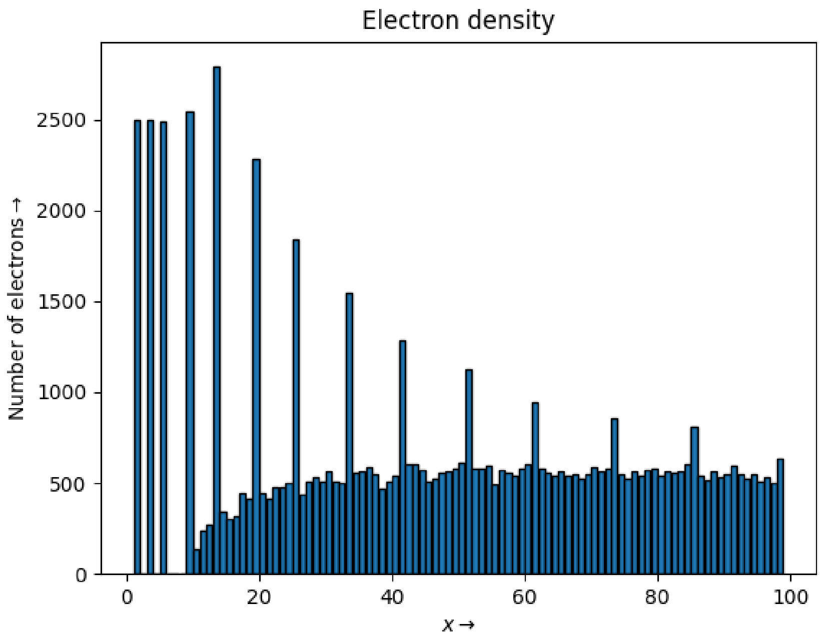

Figure 1: Electron density vs no. of electrons

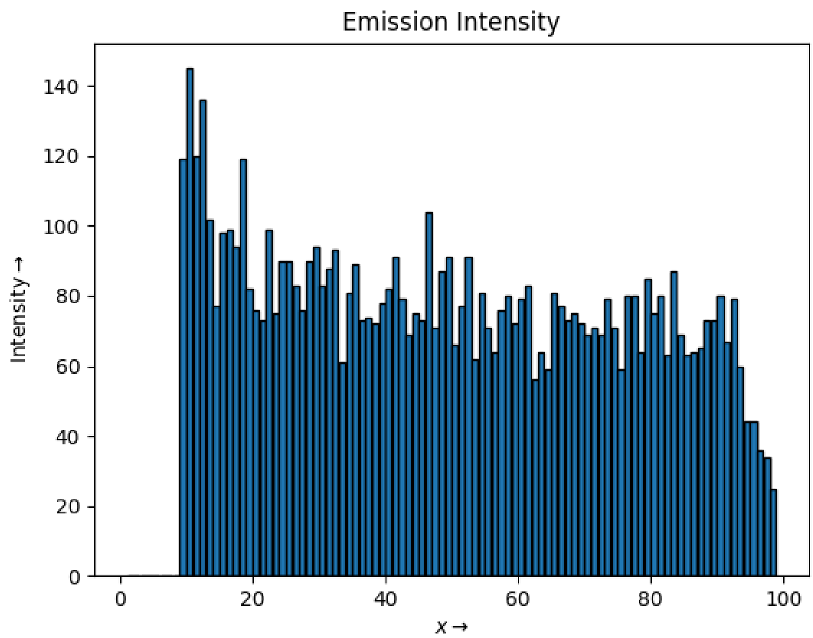

Figure 2: Emission intensity vs intensity

- The electron density is more at the starting parts of the tubelight as the electrons are acquiring speed but not above the threshold. This means that the peaks are the positions of the electrons at the first few timesteps.

- The peaks slowly smooths out as x increases beyond 10. This is becausethe electrons achieve a threshold speed of 5 only after traversing a distanceof 10 units. This means that they start ionizing the gas atoms and losetheir 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.

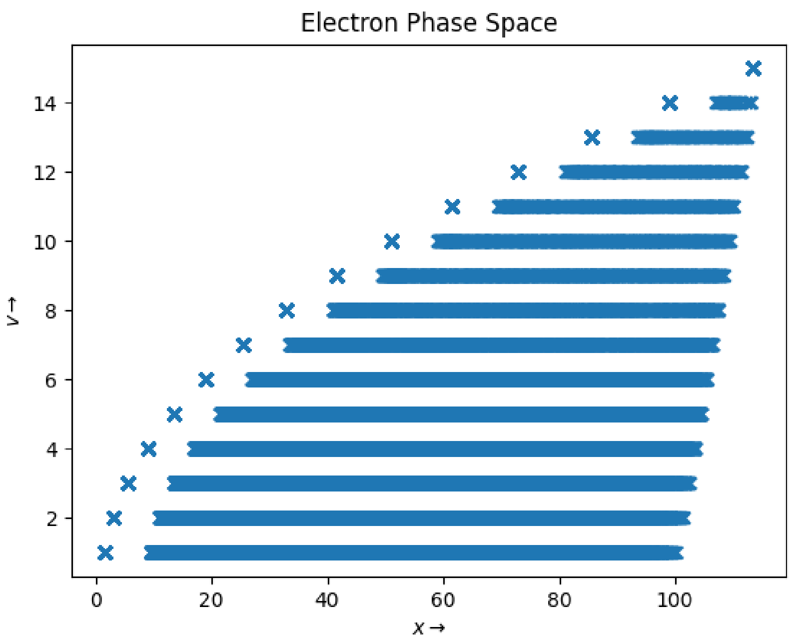

Figure 3: Electron phase vs v

- 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 $x = 19$.

Now, if we consider the fact that an electron will collide after a dt amount of time, and then accelerate after its collision for the remaining time period, we need to perform a more accurate update step. This is done by taking time as the uniformly distributed random variable. Say dt is a uniformly distributed random variable between 0 and 1. Then, the electron would have traveled an actual distance of dx' given by

$$dx'_i = u_i + \frac{1}{2}dt^2$$

as opposed to $dx_i = u_i + 0.5$

We update the positions of collisions using this displacement instead. We also consider that the electrons accelerate after the collision for the remaining $1 - dt$ period of time. We get the following equations for position and velocity updates:

$$dx''_i = \frac{1}{2}(1 - dt)^2$$

$$u_{i+1} = 1 - dt$$

With the following update rule:

$$xx_{i+1} = xx_i + dx'_i + dx''_i$$

We can change the parameters and get different plots.

The emission count for each value of x , the python code is given below:-

```
[commandchars=\\\{\}]
      xpos=0.5*(bins[0:-1]+bins[1:])
print('Intensity Data:')
```

```
print('xpos','count')
for i in range(len(xpos)):
    print(xpos[i],ints[i])
```

Intensity xpos	Data count
9.5	135.0
10.5	117.0
11.5	142.0
12.5	147.0
13.5	109.0
14.5	74.0
15.5	80.0
16.5	75.0
17.5	78.0
18.5	95.0
19.5	68.0
20.5	78.0
21.5	97.0
22.5	94.0
23.5	92.0
24.5	114.0
25.5	82.0
26.5	79.0
27.5	79.0
28.5	64.0
29.5	64.0
30.5	81.0
31.5	83.0
32.5	93.0
33.5	65.0
34.5	89.0
35.5	93.0
36.5	92.0
37.5	87.0
38.5	66.0
39.5	85.0
40.5	85.0
41.5	75.0
42.5	76.0
43.5	70.0
44.5	66.0
45.5	89.0
46.5	73.0
47.5	86.0
48.5	78.0
49.5	73.0
50.5	77.0
51.5	83.0
52.5	73.0
53.5	94.0
54.5	69.0
55.5	72.0

56.5	67.0
57.5	83.0
58.5	82.0
59.5	87.0
60.5	76.0
61.5	81.0
62.5	84.0
63.5	94.0
64.5	73.0
65.5	70.0
66.5	71.0
67.5	73.0
68.5	83.0
69.5	67.0
70.5	61.0
71.5	86.0
72.5	69.0
73.5	61.0
74.5	86.0
75.5	78.0
76.5	60.0
77.5	83.0
78.5	64.0
79.5	83.0
80.5	65.0
81.5	77.0
82.5	77.0
83.5	66.0
84.5	65.0
85.5	65.0
86.5	69.0
87.5	71.0
88.5	77.0
89.5	74.0
90.5	70.0
91.5	57.0
92.5	80.0
93.5	59.0
94.5	73.0
95.5	43.0
96.5	42.0
97.5	31.0
98.5	23.0

By Varying Parameters:-

Set of plots for a different value of threshold velocity and ionization probability to explain the effevt of varying the parameters. **u0=7 and p=0.5**

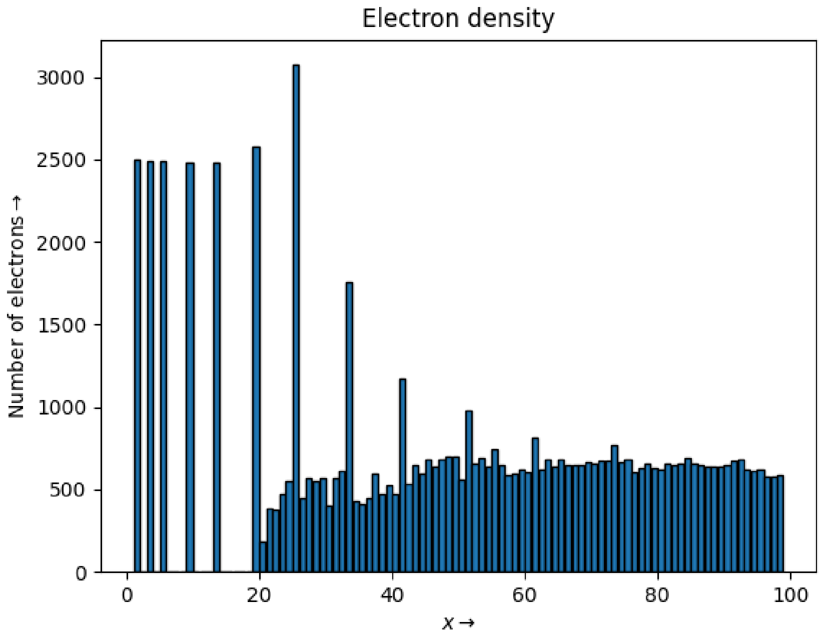

Figure 4: Electron density vs no. of electrons

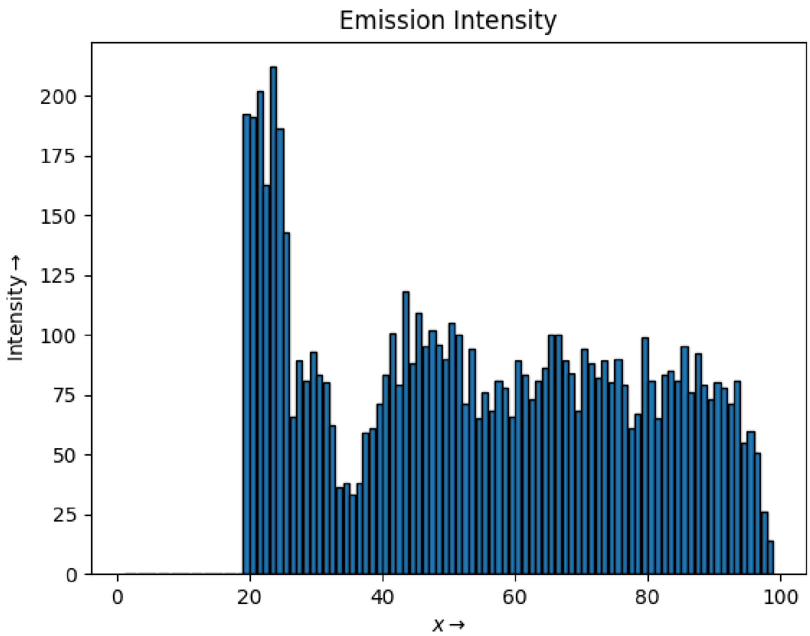

Figure 5: Emission intensity vs intensity

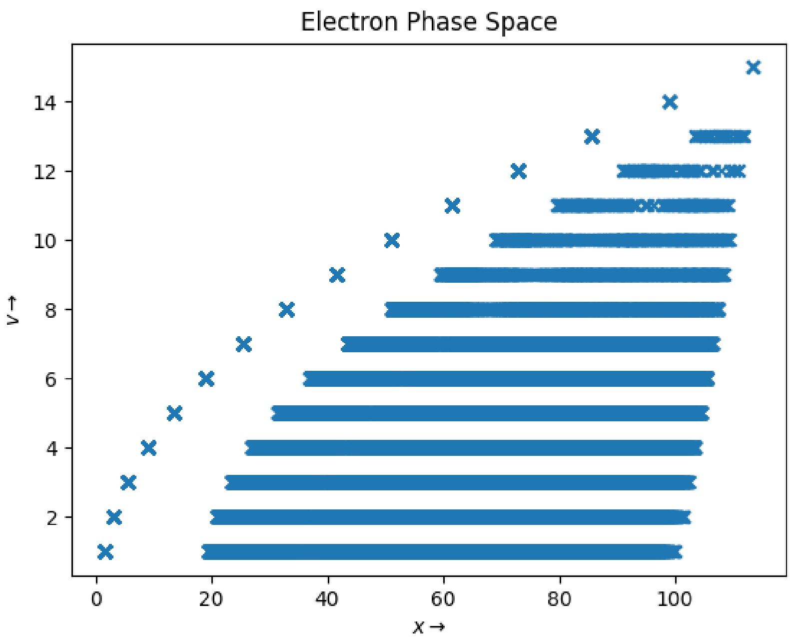

Figure 6: Electron phase vs v

- The threshold speed is much higher in the second set of parameters,photon emission starts occurring from a much higher value of x. This means that the electron density is less evenly spread out. It also means that the emission intensity is not very smooth, and the emission peaks are not very diffused.
- 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 tube light, as it provides more uniform and a higher amount of photon emission intensity

5 Conclusion

We can make the following conclusions from the above sets of plots:

- In this assignment we stimulated the Light Intensity, Electron Density, Electron Phase Space and the Intensity of a tube light. We observed the dependence of the characteristics of tube light on threshold velocity and probability of ionization.
- The Light Intensity is zero initially as the electrons coming from the cathode have zero initial velocity. As the electrons achieve the threshold velocity, they undergo inelastic collision and emit light. For lower threshold velocity, the electrons start emitting light closer to the cathode.
- Since the threshold speed is much lower if you increase threshold velocity and probability , 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..
- 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 tube-light, as it provides more uniform and a higher amount of photon emission intensity.
- The Light Intensity is very low for low probability of ionization as most of electrons do not undergo collision even after attaining threshold velocity.As the probability of ionization increases the Light Intensity also increases.In a tube light there exists an initial peak followed by a few dark patches.The position of the initial peak and the dark patches are determined by the initial parameters.