Assignment6-EE2703

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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 turns from an initial state of having no electrons.

Constants

- n: Length Of Tubelight
- M: Average Number Of Electrons Generated Per Turn
- nk: Total Number Of Turns To Stimulate
- u0: Threshold Velocity For Ionization
- p: Probability Of Ionization (Electron Is Travelling With Velocity Greater Than The Threshold Velocity)
- Msig: Stddev Of Number Of Electrons Generated Per Turn

Tube Light

A uniform electric field is present, that accelerates electrons. Electrons are emitted by the cathode with zero energy, and accelerate in this field. When they get beyond a threshold energy E_0, they can drive atoms to excited states. The relaxation of these atoms results in light emission. 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.

A tube light is simulated with the default parameters of n=100, M=5, nk=500 and Msig=1. A threshold speed of u0=5, and an ionization probability of p=0.25 are chosen.

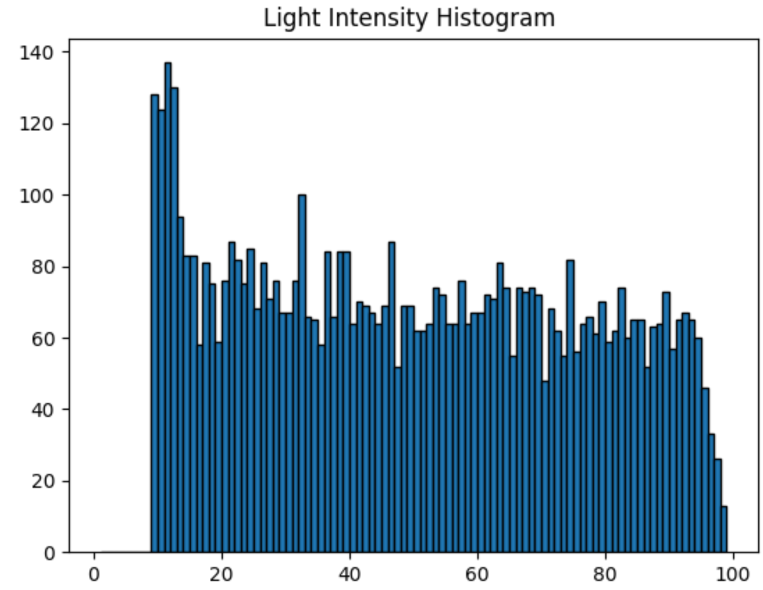

Figure 1: Light Intensity Histogram

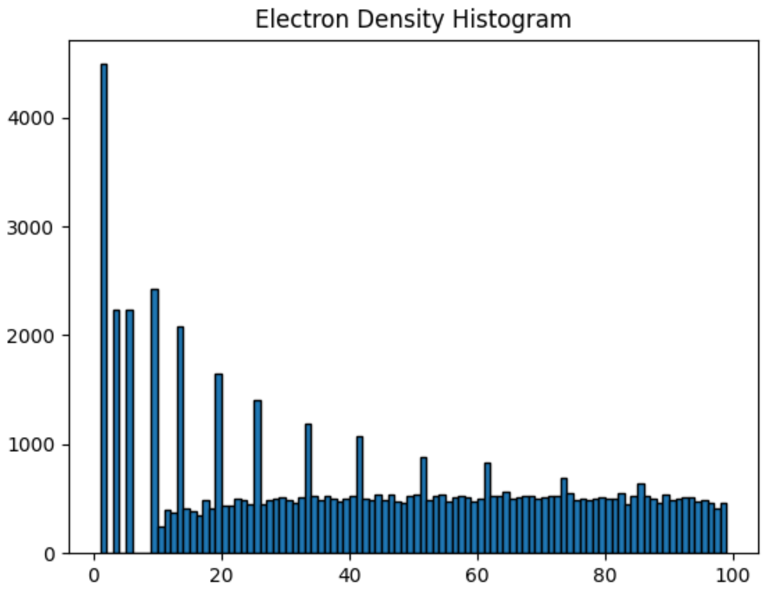

Figure 2: Electron Density Histogram

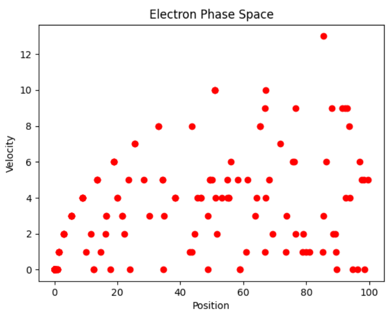

Figure 3: Electron Phase Space

	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	50.0
94	95.5	26.0
95	96.5	44.0
96	97.5	27.0
97	98.5	18.0

Figure 4: Intensity

We can make the following observations from the above plots:

- The electron density is peaked at the initial parts of the tube light 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 time steps they experience.

- The peaks slowly smooths out as x increases beyond 10. This is because the electrons achieve a threshold speed of 5 only after traversing a distance of 10 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=10.

For a threshold speed of u0=7, and an ionization probability of p=0.5 the following graphs are obtained:

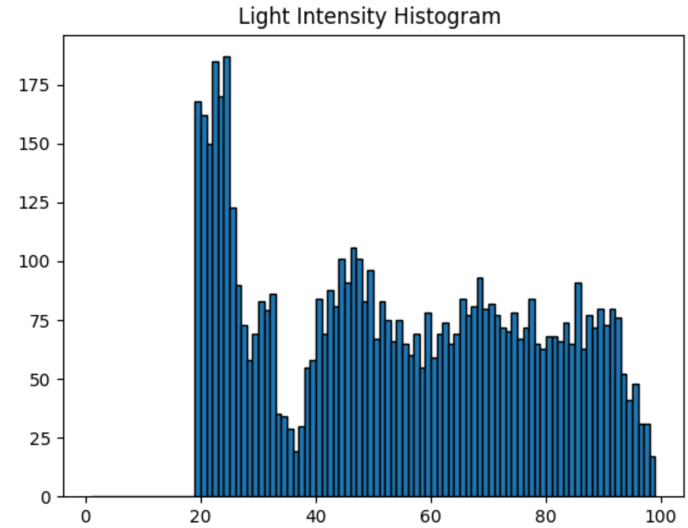

Figure 5: Light Intensity Histogram

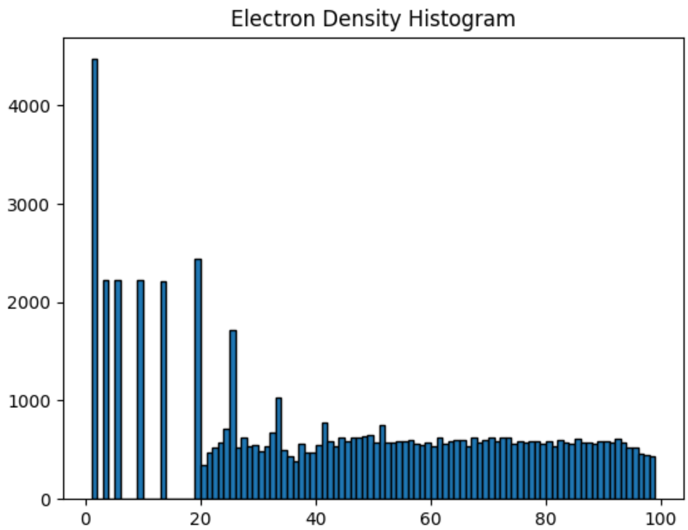

Figure 6: Electron Density Histogram

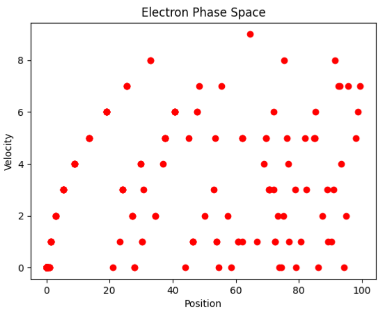

Figure 7: Electron Phase Space

	Position	Count
0	1.5	0.0
3	4.5	0.0
4	5.5	0.0
..	...	...
93	94.5	50.0
94	95.5	26.0
95	96.5	44.0
96	97.5	27.0
97	98.5	18.0

Figure 8: Intensity

We can make the following observations from the above plots:

- Since 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.
- 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 tube light, as it provides more uniform and a higher amount of photon emission intensity
- Coming to the case where the ionization probability is 1, we observe that the emission intensity consists of distinct peaks. The reason that these peaks are diffused is that we perform the actual collision at some time instant within the interval between two time steps. This also explains the slightly diffused phase plot as well.

Code

```
"""
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Assignment 6
"""

import argparse
import numpy as np
import pandas
import pylab
```

```python
"""
n: Length Of Tubelight
M: Average Number Of Electrons Generated Per Turn
nk: Total Number Of Turns To Stimulate
u0: Threshold Velocity For Ionization
p: Probability Of Ionization (Electron Is Travelling With A Velocity Greater Than The Threshold Velocity)
Msig: Stddev Of Number Of Electrons Generated Per Turn
"""
parse=argparse.ArgumentParser()
parse.add_argument('--n',default=100,type=int,help='Spatial Grid Size')
parse.add_argument('--M',default=5,type=int,help='Number Of Electrons Injected Per Turn')
parse.add_argument('--nk',default=500,type=int,help='Number Of Turns To Stimulate')
parse.add_argument('--u0',default=7,type=int,help='Threshold Velocity')
parse.add_argument('--p',default=0.5,type=float,help='Probability Of Ionization')
parse.add_argument('--Msig',default=0.2,type=float,help='Variance of probability distribution')
args=parse.parse_args()
n,M,nk,u0,p,Msig=args.n,args.M,args.nk,args.u0,args.p,args.Msig

# Electron Position
xx=np.zeros(n*M)
# Electron Velocity
u=np.zeros(n*M)
# Displacement In Current Turn
dx=np.zeros(n*M)
# Intensity Of Emitted Light
I=[]
# Electron Position
X=[]
# Electron Velocity
V=[]

for i in range(nk):
    # Electrons Ejected From Cathode
    ii=np.where(xx>0)[0]          # Returns Elements Where xx>0
    dx[ii]=u[ii]+0.5              # Updating Displacement
    xx[ii]=xx[ii]+dx[ii]          # Updating Position
    u[ii]=u[ii]+1                 # Updating Velocity

    # Electrons Absorbed At Anode
    jj=np.where(xx>n)[0]          # Returns Elements Where xx>n
    xx[jj]=0                      # Setting Position To 0
    u[jj]=0                       # Setting Velocity To 0
    dx[jj]=0                      # Setting Displacement To 0

    # Electrons With Velocity Greater Than Threshold
    kk=np.where(u>=u0)[0]         # Returns Elements Where u>u0 (Threshold)
    ll=np.where(np.random.rand(len(kk))<=p)[0]
    kl=kk[ll]

    # Electrons After Collision
    xx[kl]=xx[kl]-dx[kl]*np.random.rand()             # Setting Position
    u[kl]=0                                           # Setting Velocity

    I.extend(xx[kl].tolist())             # Excited Electrons
    m=int(np.random.randn()*Msig+M)       # Injected Electrons
    empty=np.where(xx==0)[0]              # Empty Slots
    if len(empty)>=m:
        random_start=np.random.randint(len(empty))
        xx[empty[random_start:m+random_start]]=1
        u[empty[random_start-m:random_start]]=0
    else:
        xx[empty]=1
        u[empty]=0
    occupied=np.where(xx>0)[0]
    X.extend(xx[occupied].tolist())
    V.extend(u[occupied].tolist())

# Light Intensity Histogram
pylab.figure(0)
a,bins,c=pylab.hist(I,bins=np.arange(1,100),ec='black')          # Plotting Histogram
pylab.title("Light Intensity Histogram")                         # Setting Title Of The Graph
pylab.show()                                                     # Displaying The Figure

# Electron Density Histogram
pylab.figure(1)
pylab.hist(X,bins=np.arange(1,100),ec='black')                   # Plotting Histogram
pylab.title("Electron Density Histogram")                        # Setting Title Of The Graph
pylab.show()                                                     # Displaying The Figure

xpos=0.5*(bins[0:-1]+bins[1:])
d={'Position':xpos,'Count':a}
p=pandas.DataFrame(data=d)
print(p)
```

```
# Electron Phase Space
pylab.figure(2)
pylab.plot(xx,u,'or')                          # Plotting y vs x As Lines And Markers
pylab.title("Electron Phase Space")            # Setting Title Of The Graph
pylab.xlabel("Position")                       # Setting The Label For The x-axis
pylab.ylabel("Velocity")                       # Setting The Label For The y-axis
pylab.show()                                   # Displaying The Figure
```

Conclusion

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.

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.