

# Maxwell-Boltzmann Distribution for He Ions

Syed Moeez Hassan and Saad Pervaiz  
LUMS School of Science and Engineering

July 24, 2009

## 1 Verification of Maxwell-Boltzmann distribution using Helium Ions

This experiment gives an introduction to statistical mechanics. The main objective of this experiment is to find out the velocity distribution of atoms at a specific temperature and to verify Maxwell-Boltzmann distribution law. This also gives an insight into how systems with large numbers of atoms behave as compared to the behaviour of a single atom (Statistical Mechanics).

### KEYWORDS

Maxwell-Boltzmann distribution · Statistical Mechanics · Field ionization · Velocity selectors · Helium gas · Effusion · Scintillator · Photo-Multiplier Tube

### 1.1 Introduction to Statistical Mechanics

Statistical mechanics deals with systems having a large number of particles. In statistical mechanics, large scale properties (such as temperature, pressure etc) are studied by applying probability theory to a large number of small particles. Hence this is a probabilistic theory and the behaviour of all of the system is studied using the average individual behaviour of particles. With small number of particles, statistical mechanics doesn't produce good results.

Maxwell-Boltzmann distribution deals with the velocity distribution of a system of large number of particles at a certain temperature. The basic idea is that different particles have different velocities but the velocities of majority of the particles lie within a certain range at a given temperature. The Maxwell-Boltzmann distribution law predicts this distribution.

### 1.2 Mechanical Velocity selectors

Mechanical velocity selectors are used to select particles with a certain velocity from a large range of velocities. The velocity selector used in this experiment, consists of two disks (made of PCB sheets). In each disk there is a small slit. These disks are connected to motors. The disks are at a distance  $d$  apart and have an angular velocity  $\omega$ . Both are rotating with some velocity. Initially, both the slits are in phase ( i.e the phase difference between them is zero). Now depending on the distance  $d$  between these disks and the phase difference  $\Delta\phi$  only particles with certain velocity can pass through **both** slits. This is the basic

principle of a velocity selector. Now to get particles of our required velocity, the phase difference between the two slits is adjusted by a certain amount. This can be done in two ways which are described in the following sections.

The phase shift  $\Delta\phi$  for a particle going at a velocity  $v$  is given by :

$$\Delta\phi = 2\pi - \frac{\omega d}{v} \quad (1)$$

### 1. By using DAQ

Most of the modern experiments now-a-days, require the assistance of a computer and without it, they could not be performed. Data Acquisition Card (DAQ) is a device which helps connect the computer to the external experimental setup. It is operated with the help of a software, LabVIEW. The version used for this experiment was 8.5. A program has been designed in LabVIEW which generates two sinusoidal waves as output. These are connected to the two motors. Their frequency, amplitude and phase can be controlled through the program. By this way, the required phase difference is introduced between the two slits. The program is named "2 sin waves generation conts.vi"

### 2. By using an electrical circuit

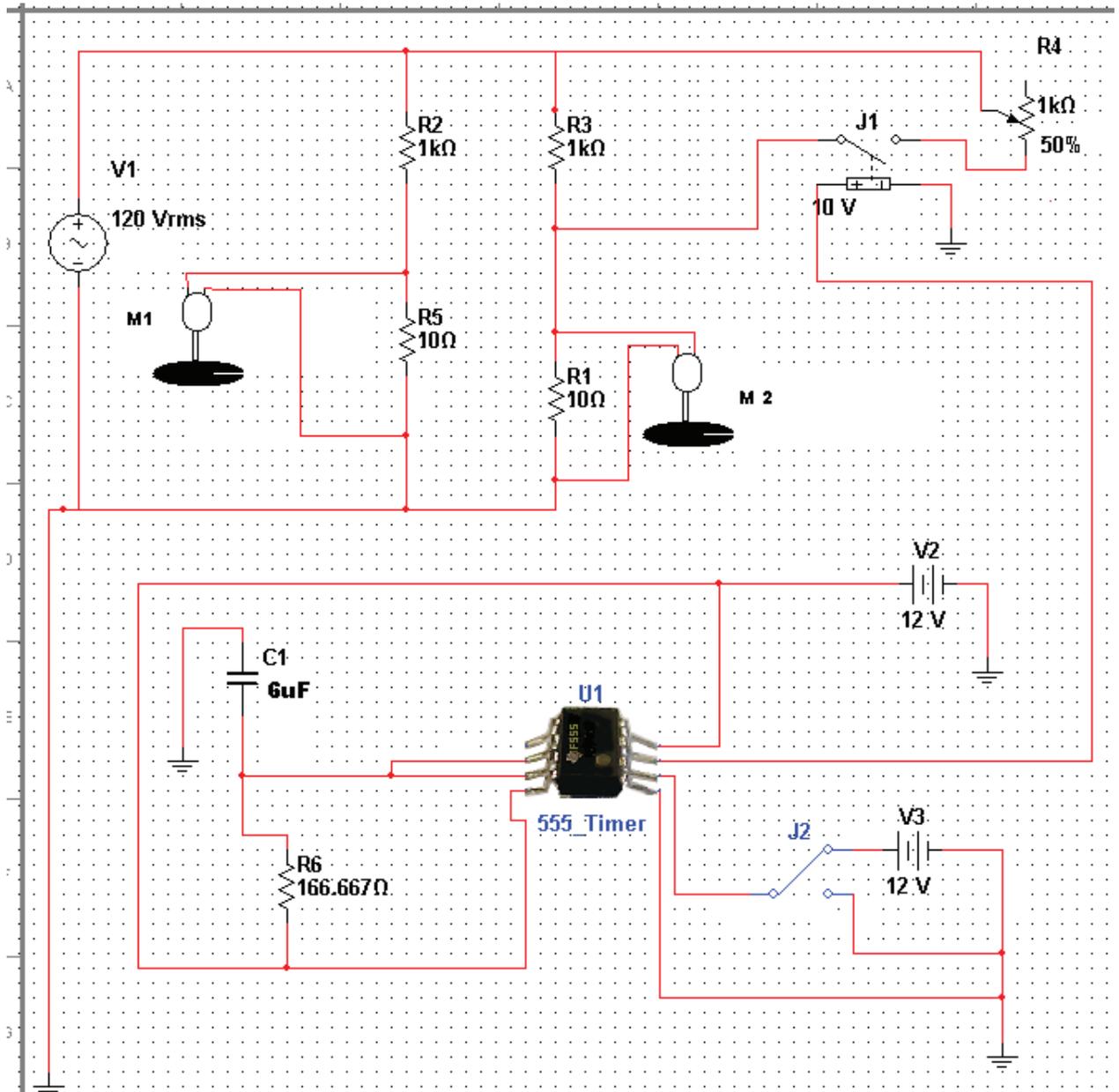
The purpose of this electrical circuit is to add a resistance in parallel with any **one** motor. Due to this resistance in parallel, the overall resistance decreases and hence the potential drop across the motor increases which causes an increase in the angular velocity of that motor for a specific time period. Due to this increase, one of the disks starts rotating faster for a certain period of time, then it returns to its normal velocity. Due to this, a phase difference is introduced between the two slits.

The time for which that resistance (in parallel) is activated is controlled by using a 555-timer (as a monostable multivibrator) and a comparator. A trigger is given to this timer circuit and it outputs a pulse of certain duration ( $1.1 \cdot R \cdot C$ ) which in our case is nearly, 4.3 seconds. Then, the output of this circuit is given to a relay which switches on the resistance for that pulse time and then again, switches off so that the motor returns to its normal state.

The phase difference to be introduced is controlled using a variable resistor. Depending on required phase difference, and the duration of the pulse a specific resistor is used whose resistance can be calculated. (See Figure)

$$R_v = R \frac{2\pi k \Delta t V}{\Delta\phi} \left( 1 - \frac{\Delta\phi}{2\pi k \Delta t V} \right) \quad (2)$$

where,  $R_v$  is the variable resistance,  $R$  is the resistance added to both motors,  $\Delta t$  is the time for which the pulse is received,  $V$  is the voltage of the source,  $k$  is a constant which depends on the motor used. (Using the assumption that  $f = kV$ , the frequency of the motor is directly proportional to voltage across it.) By varying the resistance  $R_v$ , different phase differences can be achieved.



This circuit is used to introduce a phase difference between two disks mounted upon motors M1 and M2. A 555 timer is used as a monostable multivibrator. It is triggered by using switch J2. Initially it is at high, it is triggered by giving an instantaneous low and then again high. Once triggered, it switches the relay (J1) on for a certain time which effectively decreases the resistance before the motor M2 because a variable resistance R4 is added in parallel to R3. This changes the potential across M2 which changes its angular velocity and causes a phase shift between the two slits. The amount of phase shift can be controlled by the variable resistance and is given by (2).

### 1.3 Field Ionization of Helium

Field ionization means to ionize an atom by using electric fields. The basic idea is that when a strong enough electric field is applied, which is greater than the ionization potential of the outermost electron of that atom, that electron gets out of the atom and hence that atom is ionized. We considered (theoretically) two possible ways of ionization of Helium which are mentioned below.

#### 1. By using cathode ray tube

In this setup, a cathode ray tube is used (which was used by J.J.Thomson). A potential of 30V is applied (The ionization potential of Helium is 24.6V). Due to this potential, the electrons in the outermost orbital of helium get stripped off and go towards anode while the He(+1) ions go towards the cathode. Helium enters the chamber, (which is at a very low pressure, there is vacuum inside it), gets ionized and singly-ionized helium is then collected.

#### 2. By using micro-scale tungsten tips

In this setup, a very fine micro-scale tungsten tip is used. A potential of 5kV (depending on the size and shape of tip) is applied on the tip which creates a corresponding electric field of  $3-5V/\text{\AA}$ . With this high electric field, helium is passed over this tip. The electrons are immediately stripped of the atoms while the singly ionized helium atoms are accelerated away from the tip which are then used in the experiment. Such a technique has been used in *Helium Ion Microscopy*.

### 1.4 Helium Ion Detection

The procedure used for the detection of Helium ions is by using a PMT(Photo Multiplier Tube) coupled with a Scintillator. In the scintillator, the He ions will produce flashes (photons). These photons will be fed to the PMT that will give the concentration of the ions of a particular velocity.

## References

- [1] NI DAQ M series user manual
- [2] <http://www.sciencedirect.com/>
- [3] J Piskur, L Borg et al : Science Direct 254 (2008) 4365-4369
- [4] Heetae Kim and Soon-Jae Yu : Journal of Information Display, Vol. 10, No. 1, March 2009 (ISSN 1598-0316)
- [5] John Morgan, John Nott et al : MICROSCOPY TODAY, Volume 14, Number 4, July 2006.
- [6] M Rocca, F Pirani et al : REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 75, NUMBER 2 FEBRUARY 2004
- [7] J Notte, R. Hill et al : Microsc Microanal 12(Supp 2), 2006 (Microscopy Society of America)

[8] <http://www.fairchildsemi.com/>

[9] <http://en.wikipedia.org/>