Journal University of Kerbala , Vol. 15 No.4 Scientific . 2017

The Effect of ultraviolet rays on the charging of the dust grain in multi-ions plasma

تأثير الاشعة الفوق بنفسجية على حبيبة غبارية في بلازما متعددة الايونات

Zainab A. Mankhi
Department of Physics, College of Science, University of Karbala, Karbala-Iraq

Abstract

In this work, A computer simulation was implemented to study ultraviolet radiation effect on charging process for a dust grain was immersed in to plasma ($K^+$and electron) with negative ion (SF_6^-). The simulation based on discrete model and Orbital Motion Limited theory (OML). The numerical results were illustrated charge fluctuation of dust with time for different values of ultraviolet rays intensities and appeared increase of positive charge of dust when rays intensity increased.

الخلاصة

في هذا العمل تم تطبيق محاكات حاسوبية في دراسة في تأثير الأشعة الفوق بنفسجية على عملية الشحن الحبيبة الغبارية مغمورة في بلازما (ايون البوتاسيوم الموجب والكترون) مع وجود ايون سالب (ايون سداسي فلوريد الكبريت السالب).

المحاكات اعتمدت على الموديل المنفصل نظريه المسار الحركي المحدد. ان النتائج العددية صورت تذبذب شحنة الحبيبة مع الزمن لقيم مختلفة من شدة الأشعة الفوق بنفسجية وكذلك أظهرت زياد موجبيه شحنة الحبيبة عندما شدة الأشعة زادت.

1. Introduction

The computer simulations are playing an important role in theoretical studies in various branches of sciences in recent years. Similar is the situation in the research of dusty plasma that is interesting for astronomers (interstellar clouds, comet tails etc.) [1].for understanding of charging processes and dynamics of dusty particles is necessary for the effective developing of technological devices and studying properties of the interstellar space (the space between the stars).

Many researchers had be interesting in study of the charging process of dust in different situations of plasma, such as study effect of negative ions on charging process of dust in a plasma was investigated experimentally and theoretically [2,3]. The charge fluctuation in a dusty plasma was studied with different charging mechanisms [4].

In this work, we will investigate the effect of VU on charging process of a micrometer-sized dust grain in a negative ion plasma. The dust acquires electric charges by collecting ions (positive or negative), electrons, and by emitting electrons when ultraviolet irradiation is presented. In the space, photoelectron emission is often the dominant charging mechanism from dust grains exposed to UV rays [2]. This study represents computer simulation by basing on Orbital Motion Limited theory (OML) and discrete model shown as blow

1. Orbital Motion Limited theory (OML):-

The OML model typically assume that the particle is spherical shape, and its surface is an equipotential. In this case, even if the particle is not made of a conductive material, it can be modeled as a capacitor [5]. The charge on dust's surface (Q_d) is given by [2]

$$Q_d = 4\pi\varepsilon_\circ r V_s \quad \dots\dots \quad (1)$$

Where r is the radius of the dust grain, and V_s is the dust grain surface potential relative to the plasma potential [6]. According to the orbit-limited theory, the electron and positive ion currents to the isolated spherical dust grain of radius (r) are given by [5]:

$$I_e = I_{eo}\begin{cases} 1+\dfrac{eV_S}{kT_e} & V_s > 0 \\ e^{\frac{eV_S}{kT_e}} & V_s < 0 \end{cases} \quad \dots\dots \ (2)$$

$$I_i = I_{io}\begin{cases} e^{e\frac{V_S}{k\,T_i}} & V_s > 0 \\ 1+\dfrac{e\,V_S}{k\,T_i} & V_s < 0 \end{cases} \quad \dots\dots \ (3)$$

For the collection of Maxwellian ions and electrons, characterized by temperatures T_i and T_e .
The negative ion current participates in the charging of a dust grain in a plasma is [6]:

$$I_n = I_{no}\begin{cases} 1+\dfrac{eV_S}{kT_n} & V_s > 0 \\ e^{eV_S/kT_n} & V_s < 0 \end{cases} \quad \dots\dots\dots (4)$$

The coefficients I_{e0} , I_{io} and I_{n0} represent the current that is collected for $V_s = 0$, and are given by[1]

$$I_{jo} = q_j n_j \left(\frac{kT_j}{m_j}\right)^{1/2} 4\pi r^2 \qquad \dots\dots \ (5)$$

Where n_j is density of particles j ($j = e, i, or\ n$)

The dust grain surface emits photoelectrons, when the dust exposed to UV rays have energy (hν) larger than work function (W_f) of the dust grain. This mechanism makes the dust positively charged. The current of electrons photoemission is calculated by the balance between the photoelectrons escaped from the dust surface and the photoelectrons returned to the dust grain surface. The electron photoemission current for $V_s > 0$ is[7]:

$$I_P = \pi r^2\, e\, J_P\, Q_{ab}\, Y_P\, exp\left(-\frac{eV_S}{k_B T_P}\right) \qquad \dots\dots\dots \ (6)$$

Where J_P is the flux of photons,
Q_{ab} is the efficiency of the absorption for incident photons (Qab ~ 1 for $2\pi r/\lambda > 1$ where λ is the wavelength of the incident photons),
Y_P is the yield of the photoelectrons (the yield varies from 0.01 to 0.1 for dielectrics ,and from 0.1 to 1 for metals, for glasses $Y_P = 0.1$, $W_f = 4 - 5$)
T_P is the photoelectrons average temperature[8].

If the dust grain potential is negative ($V_S < 0$), all the photoelectrons emit from the dust surface and escape into the plasma. This leads to a constant current [7]

$$I_P = \pi r^2\, e\, J_P\, Q_{ab}\, Y_P \quad \dots\dots\dots..(7)$$

1.2. Discrete charging model:-

The discrete charging model considers the ion and electron currents collected by the dust grain consist of individual electrons and ions. The charge on the grain is an integer multiple of the electron charge value, $Q_d = Ne$, where N (charge number) changes by +1 when an ion (ion charge+1) is absorbed and by -1 when an electron is absorbed.

The charge on a dust grain fluctuates in discrete steps about the steady-state value ⟨Q⟩ at random times [9].There are two key aspects of the collection of discrete of plasma particles (the term "plasma particle" is referred to either electron or ions).

- First is that the time interval varies randomly between the collections of plasma particles.
- Second is that the electrons and ions arrive at the grain surface is not purely random; but they obey probabilities that depend on the potential Vs of dust grain [10].

$p_e(V_s)$ and $p_i(V_s)$ are defined the probability per unit time for collecting an ion or electron , respectively. As the grain potential becomes more positive, more ions will be repelled and more electrons will be attracted to the grain, so p_i should decrease with V_s and p_e should increase. $p_j(V_s)$ (j refers to the ions, electrons) was calculated from the OML currents $I_j(V_s)$

$$p_j = \frac{I_j}{q_j} \qquad \dots\dots\dots (8)$$

The total probability per unit time of collecting plasma particle is [9]

$$p_{tot} = \sum p_j \qquad \dots\dots\dots\dots (9)$$

The currents I_j depend on the grain surface potential V_s, so p_{tot} also depends on V_s and hence on charge Q_d .

2. Description of our model

We simulate a charging process dust grain (made of glass) with size (0.4 µm) immersed into plasma of potassium with negative ion SF_6^- (The negative ions have a mass approximately larger than the mass of the positive ion), which initially uncharged. After that electrons and ions collect the dust's surface at random times so that the dust will acquire electric charge by absorbing electrons and ions (positive or negative), and emits electrons when ultraviolet irradiation is presented. The charge on a dust will fluctuate around an equilibrium value ⟨Q⟩.

The computer simulation based on Discrete charging model by considering the dust grain actually has charge consist of individual ions and electrons. The probabilities per unit time for collecting an electron or ion are calculated from eq. (8), and eq. (9).

The computer simulation based also on The OML model by calculating currents from eq.(2), eq.(3), eq.(4), eq.(5), eq.(6), and eq.(7).

We assume the ratio of number density of electron to number density of positive ion (η_e) equals to 10^{-2} in this plasma with negative ions.

3. Programing of the Model

We translated this model to program by using MATLAB language to simulate fluctuations charge on dust with time and. The numerical results of program illustrates:

1. fluctuations charge number($N=Qd\,/e$) with time
2. calculate equilibrium charge number ⟨N⟩ by employing histogram for charge number for each time.

The flow chart of program is illustrated in figure (1)

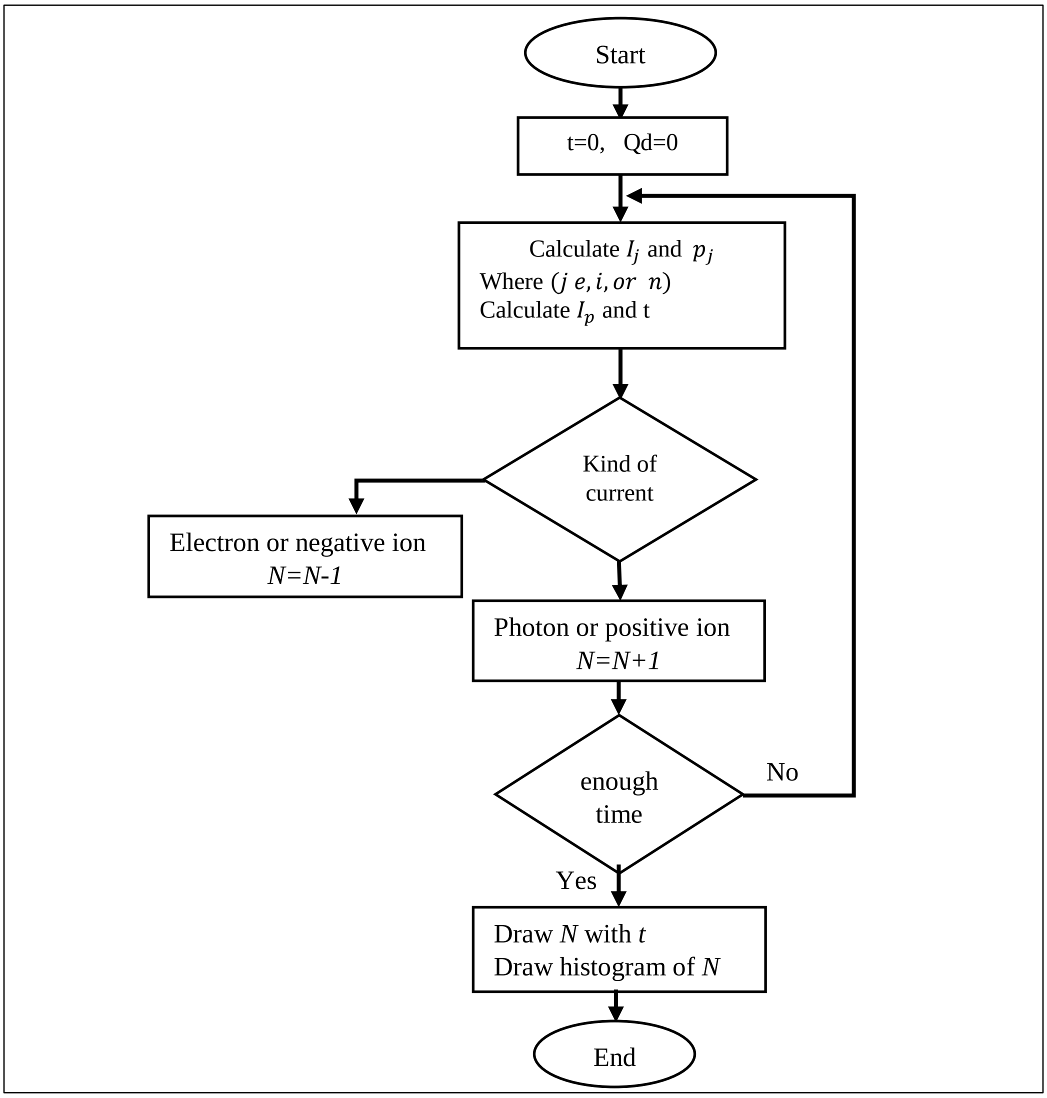

Figure (1): The flow chart

4. Results and Discussion

First result of program shows the charge number (N) on dust grain (Q_d = Ne) varies with time. Figure(2) :the charging process for a dust by collecting electrons, negative ions, and positive ions from plasma, and the ratio of number density of electron to number density of positive ion (η_e) equals to 10^{-2} (as data in the greyish color).

When the dust exposes to ultraviolet radiation (the photon flux $J_P = 1 \times 10^{20} w/m^2$), the dust emits photoelectrons if the energy of UV rays larger than work function of dust surface therefor positive of dust charge increase (as data in blue color).

Whenever the intensity of UV rays increases, the positive of dust charge increases also because the dust emits more photoelectrons (as data in green color and data in red color).

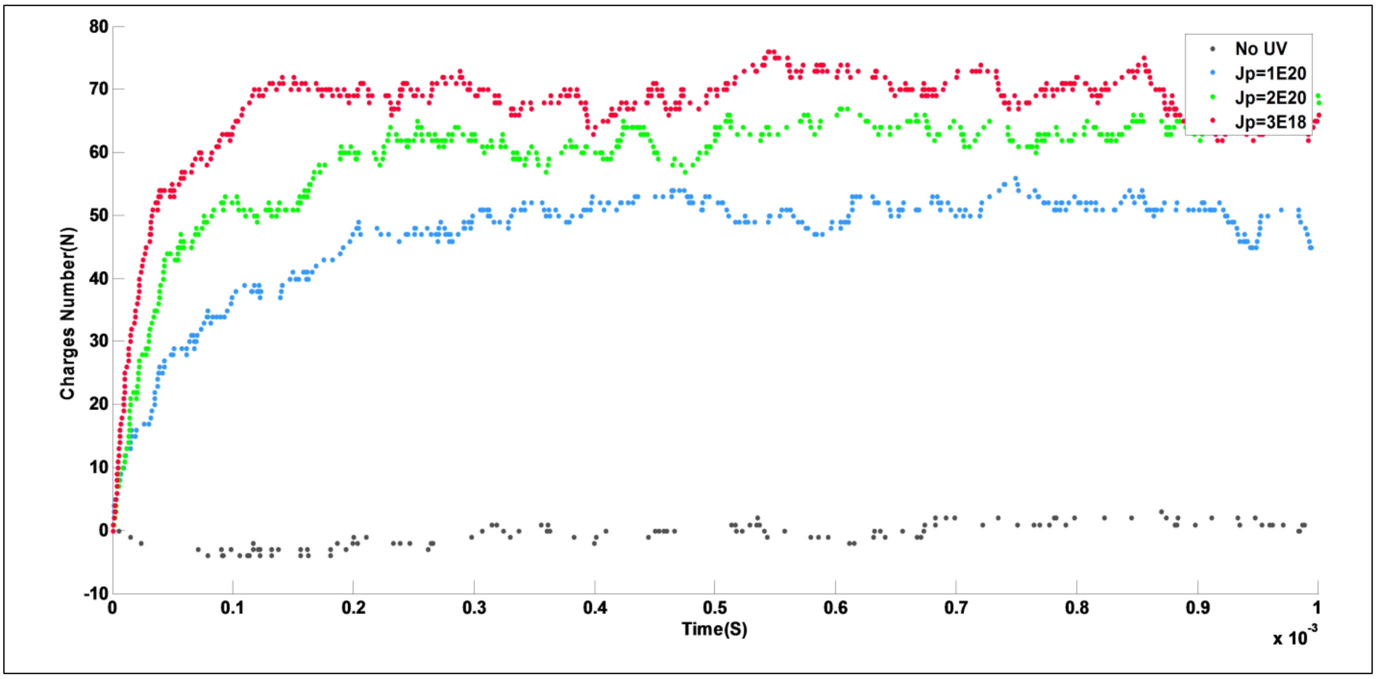

Figure (2): number of charges on dust surface as a function Time: 1- Greyish data represents charging process with absence UV .2- Blue data represents charging process with presence UV and $J_p=1\times10^{20} w/m^2$. 3- Green data represents charging process with presence UV and $J_p=2\times10^{20} w/m^2$. Red data represents charging process with presence UV and $J_p=3\times10^{20} w/m^2$

Second results represent histogram for the charge number (*N*) on dust grain to calculate charge number equilibrium <*N*>. The equilibrium charge number takes larger repetition in computer experiment time. Figure (3) displays histogram of charge number for charging process with absence UV.

Figures (4), (5), and (8) show histogram of charge number for charging process with presence UV and the photon flux equal $J_P = 1 \times 10^{20} w/m^2$, $J_P = 2 \times 10^{20} w/m^2$,and $J_P = 3 \times 10^{20} w/m^2$,respectively

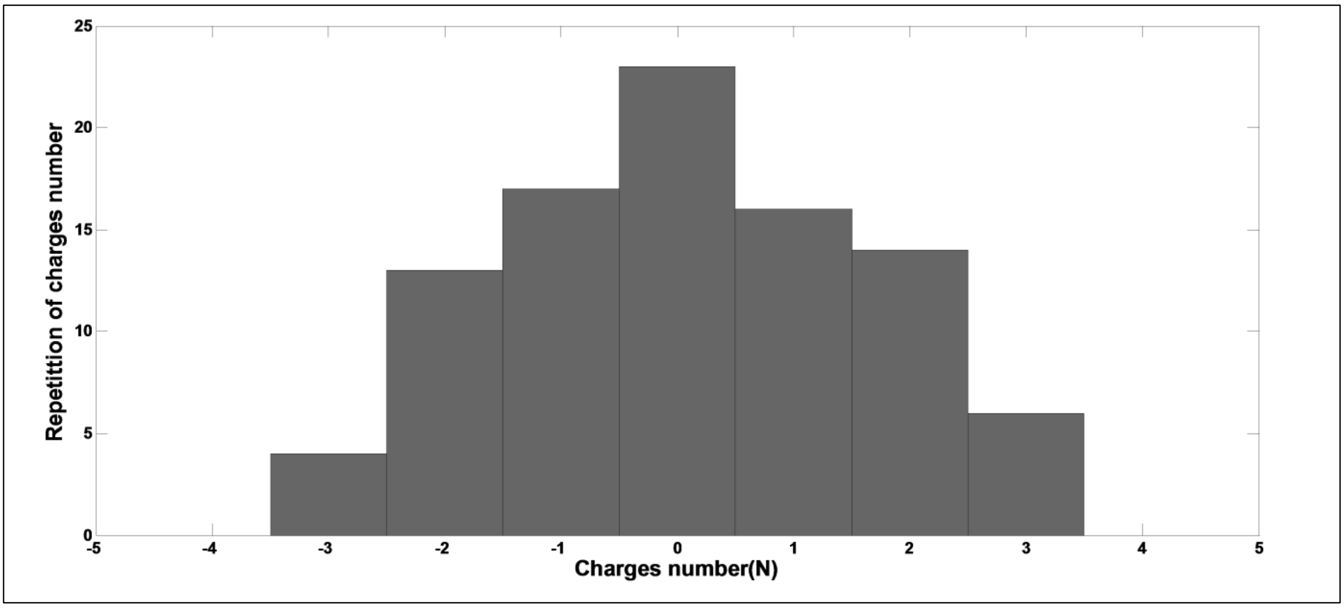

Figure (3): The histogram of charge number for charging process with absence UV. The charge number equilibrium equals=zero

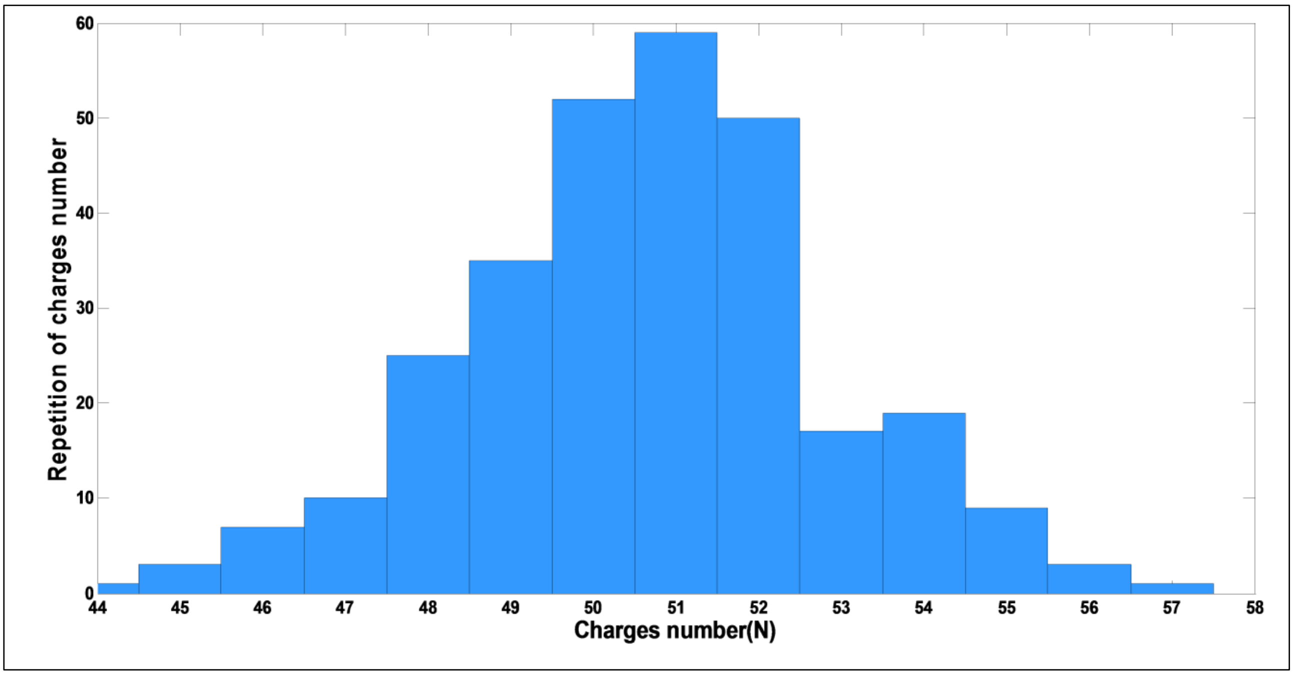

Figure (4): The histogram of charge number for charging process with presence UV ($J_p=1\times1^{20}w/m^2$). The charge number equilibrium equals=51

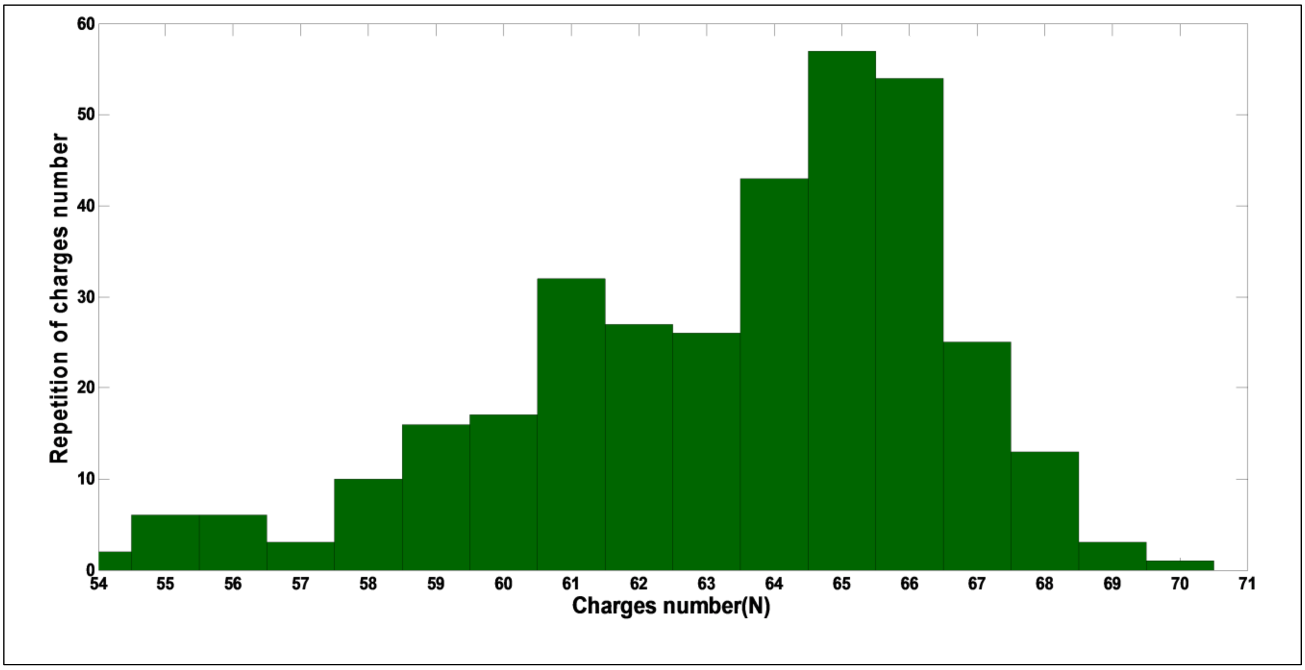

Figure (5) The histogram of charge number for charging process with presence UV ($J_p=2\times10^{20}w/m^2$). The charge number equilibrium equals=65

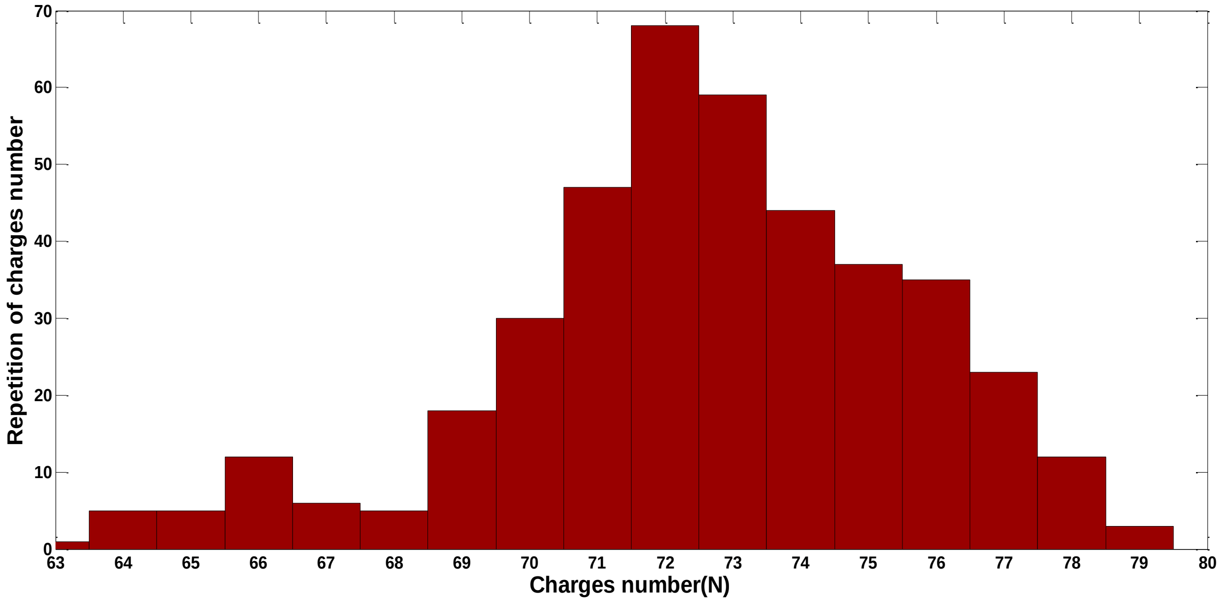

Figure (6): The histogram of charge number for charging process with presence UV ($J_p=3\times10^{20} w/m^2$). The charge number equilibrium equals=72

5. Conclusions

The numerical results illustrate the effect of UV radiation on dust charge, the dust emits photoelectrons if the energy of UV rays larger than work function of dust surface. When the intensity of UV rays increases positivity of charge number on dust increases gradually. We can refer that photoelectric emission plays important rule in charging process of dust if UV rays presences and has enough energy.

6. References

1. A. A. Mamun and P. K. Shukla, Phys. Plasmas, Vol. 10, No. 5, (2003).
2. S.-H. Kim and R. L. Merlino, Phys. Plasmas, Vol. 13, No. 052118 (2006).
3. Z.A.Mankhi,"Dust Grain Charge process in Negative Ion Plasma", M.Sc. thesis, Baghdad University (2012).
4. S. A. Khrapak, A. P. Nefedov, O. F. Petrov, and O. S. Vaulina, PHYSICAL REVIEW E, Vol. 59, No. 5, (1999).
5. J. Goree, "charging of particles in plasma", plasma science, vol.3 pp. 400 -406(1994).
6. R. L. Merlinoa, and S. -H. Kim, Appl. Phys. Lett., Vol. 89, No. 091501 (2006).
7. P. Shukla, and A. Mamun, "Introduction to Dusty Plasma Physics",Institute of Physics Publishing, Bristol and Philadelphia, (2002).
8. A. Samarian, O. Vaulina, A. Nefedov, V. Fortov, B. James and O.Petrov, " Positively charged particles in dusty plasmas", Phys. Rev. E., 64, 056407(2001)
9. P. Shukla, and A. Mamun, "Introduction to Dusty Plasma Physics", Institute of Physics Publishing, Bristol and Philadelphia, (2002).
10. A. Samarian, O. Vaulina, A. Nefedov, V. Fortov, B. James and O. Petrov, " Positively charged particles in dusty plasmas", Phys. Rev. E., 64, 056407(2001).
11. A. Melzer, and J. Goree, "6 Fundamentals of Dusty Plasmas", WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany (2008).
12. C. Cui and J. Goree, "Fluctuation of the charge on a dust grain in plasma", IEEE Transactions on plasma science, vol.22, No.2, pp. 151 -158 (1994).