Effect ultraviolet radiation on charging process of the dust grain in plasma with negative ion.

تأثير الأشعة الفوق البنفسجية على عملية شحن الحبيبة الغبارية في بلازما ذات الايون السالب

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Abstract

This work represents computer simulation to study ultraviolet radiation effect on charging process of the dust grain immersed in to plasma with negative ion. The program of simulation has been written in the MATLAB programing language by basing on discrete model and Orbital Motion Limited theory (OML). Numerical results are presented the dust charge fluctuates with time for different values of ultraviolet rays intensity.

الخلاصة

هذا العمل يمثل محاكاة حاسوبيه لدراسة تأثير الاشعاع الفوق البنفسجي على عملية شحن الحبيبة الغبارية المغمورة في بلازما ذات الايون السالب. برنامج المحاكاة كُتب بلغة البرمجة الماتلاب بالاستناد على النموذج المنفصل ونظرية مدار الحركة المحدد (OML). النتائج العددية تمثل تقلب شحنه الحبيبة الغبارية مع الزمن لقيم مختلفة من شده الأشعة الفوق البنفسجية.

I. 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].The understanding of processes charging 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 the charging process of dust in different situations of plasma, such as study effect of negative ion on charging process of dust particles in a plasma is investigated experimentally and theoretically [2,3]. The random charge fluctuation in a dusty plasma was studied with different charging mechanisms [4].

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

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 Q_d is then related to the particle's surface potential as, with respect to a plasma potential of zero, by [2]

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

Where r is the radius of the dust particle, and V_s is the dust particle surface potential relative to the plasma potential [6]. For the collection of Maxwellian electrons and ions, characterized by temperatures T_e and T_i, the orbit-limited the electron and positive ion currents to the isolated spherical dust grain of radius (r) are given by[5]:

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

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

The negative ion current participates in the charging of a dust grain in a plasma is [6]:

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

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

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

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

When a flux of photons with energy (hν) larger than the photoelectric work function (W_f) of the dust grain incidents on the dust grain surface, the latter emits photoelectrons, where h is Planck's constant and ν is the photon frequency. The photoemission of electrons depends on

(i) The wavelength of the incident photons.
(ii) The surface area of the dust grain.
(iii) The properties of the dust grain material.

This mechanism contributes to a positive charging current and tries to make the dust grain positively charged .The various metals typically have photoelectric work function $W_f < 5$ eV.

As the dust grain surface is positive, i.e. $V_s > 0$, a fraction of the photoelectrons return to the dust grain surface and the most energetic ones overcome the dust grain potential and escape.

Thus, the net current is determined by the balance between the photoelectrons returned to the dust grain surface and the photoelectrons escaped from the dust grain surface. The electron photoemission current for a unidirectional photon flux and for $V_s > 0$ is[7]:

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

Where J_P is the photon flux,

Q_{ab} is the efficiency of the absorption for photon(Qab $\sim$ 1 for $2\pi r/\lambda > 1$ where λ is the wavelength of the incident photons),

Y_P is the yield of the photoelectrons (varies from 0.1 to 1 for metals, and from 0.01 to 0.1 for dielectrics ,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 ($V_S < 0$), no photoelectron returns to the dust grain surface, i.e. all the photoelectrons emitted by the dust grain surface escape into the plasma. This leads to a constant current [7]

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

2. discrete model:-

Discrete charging model considers the electron and ion currents collected by the grain actually consist of individual electrons and ions. The charge on the grain is an integer multiple of the electron charge,

$Q_d = Ne$, where N (charge number) changes by -1 when an electron is collected and by +1 when an ion (ion charge+1) is absorbed.

Electrons and ions arrive at the particle's surface at random times, like shot noise. The charge on a particle will fluctuate in discrete steps (and at random times) about the steady-state value ⟨Q⟩ [9].There are two key aspects of the collection of discrete of plasma particles (the term "plasma particle" is to refer to either electron or ions).

- First is that the time interval between the absorption of plasma particles varies randomly.
- Second is that the sequence in which electrons and ions arrive at the grain surface is random. However, these is not purely random; but they obey probabilities that depend on the grain potential *Vs* [10].

$p_e(V_s)$ and $p_i(V_s)$ are defined the probability per unit time for absorbing an electron or ion, 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]

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

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 .

II. The Model Description

We simulate a charging process dust grain (made of glass) with radius r (0.1 μm) immersed into plasma with negative ion (The negative ions has a mass approximately larger than the mass of the positive ion) , which initially uncharged. After that electrons and ions arrive at the dust's surface at random times so that the dust acquires electric charge by collecting 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 grain actually consist of individual electrons and ions. The probability per unit time for absorbing an electron or ion is 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 10^3 in this plasma with negative ions.

III. Program of Model

We translated this model to program by using MATLAB 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 $\langle N \rangle$ by employing histogram for charge number

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

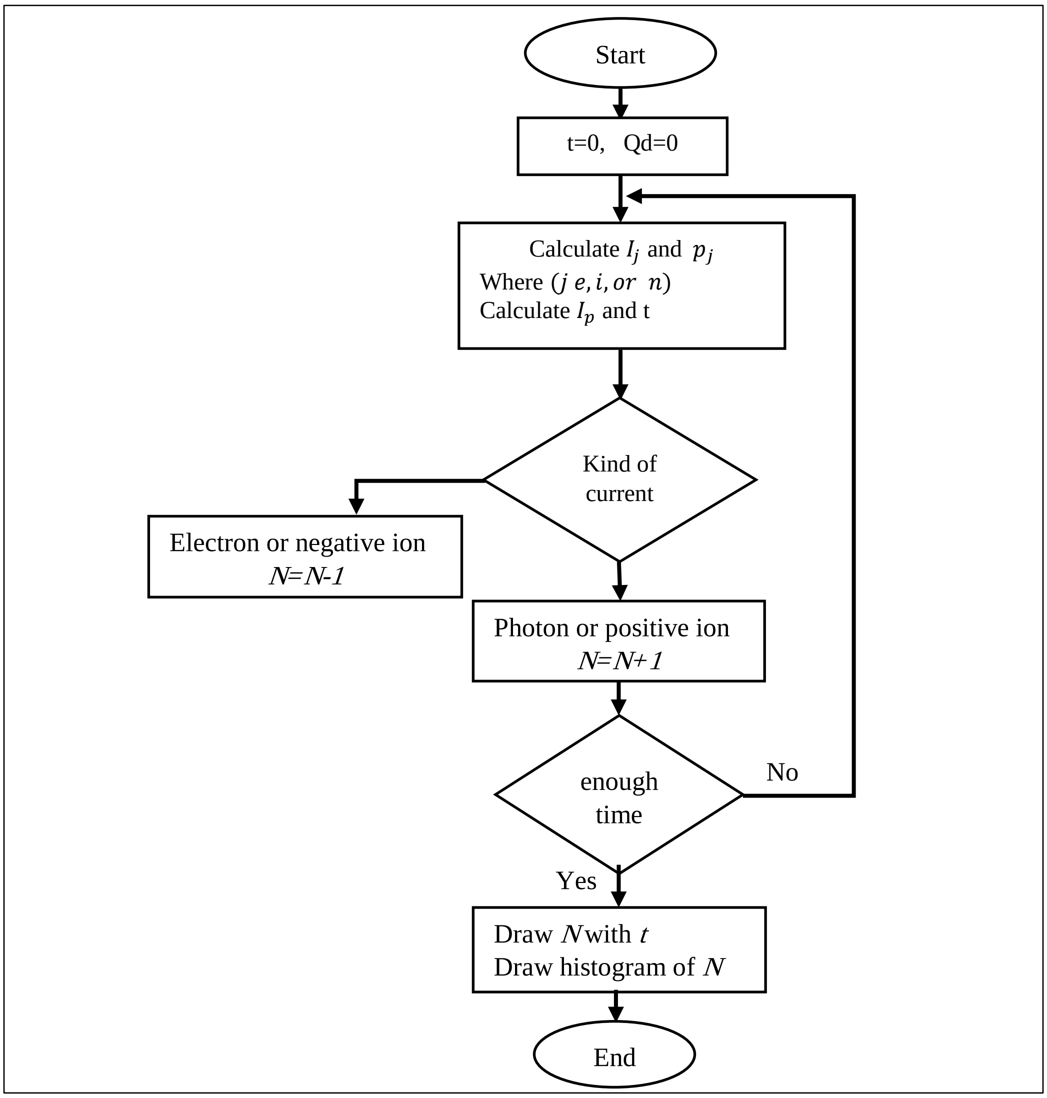

Figure (1): The flow chart

IV. Numerical Results and Discussion

First result of program shows the charge number (N) on dust grain (the charge on the dust is an integer multiple of the electron charge, $Q_d = Ne$) varies with time. Figure(2) shows the charging process for a dust by collecting electrons, negative ions, and positive ions from plasma(as data in the blue color) .

When the dust exposes to ultraviolet radiation (the photon flux $J_P = 2 \times 10^{18} w/m^2$), 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 red 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 magenta color).

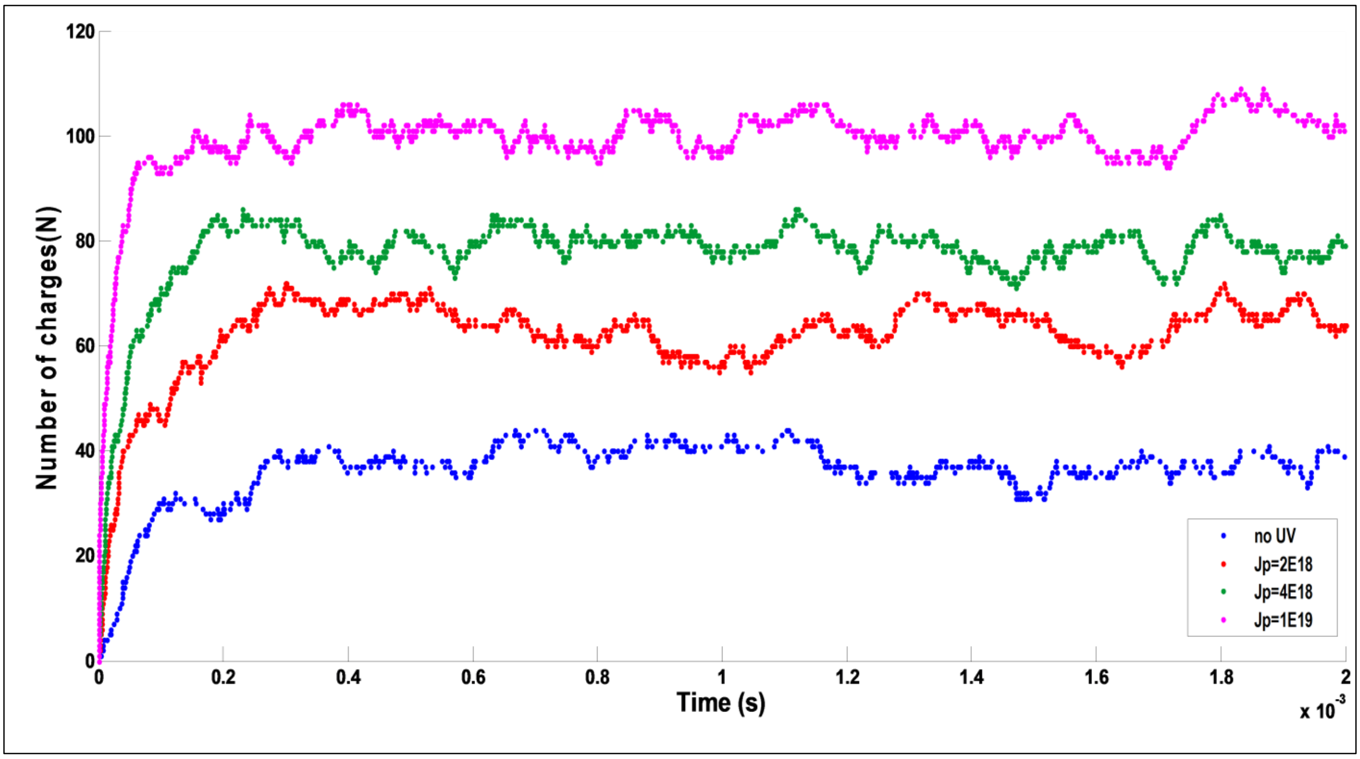

Figure (2): number of charges on dust surface as a function Time: 1- blue data represents charging process with absence UV 2- Red data represents charging process with presence UV and $J_p=2\times10^{18}$w/m^2. 3- Green data represents charging process with presence UV and $J_p=4\times10^{18}$w/m^2. 4- Magenta data represents charging process with presence UV and $J_p=1\times10^{19}$w/m^2

Second result of program represents 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 $J_P = 2\times\frac{10^{18}w}{m^2}$, $J_P = 4\times10^{18}w/m^2$,and$J_P = 1\times10^{19}w/m^2$,respectively

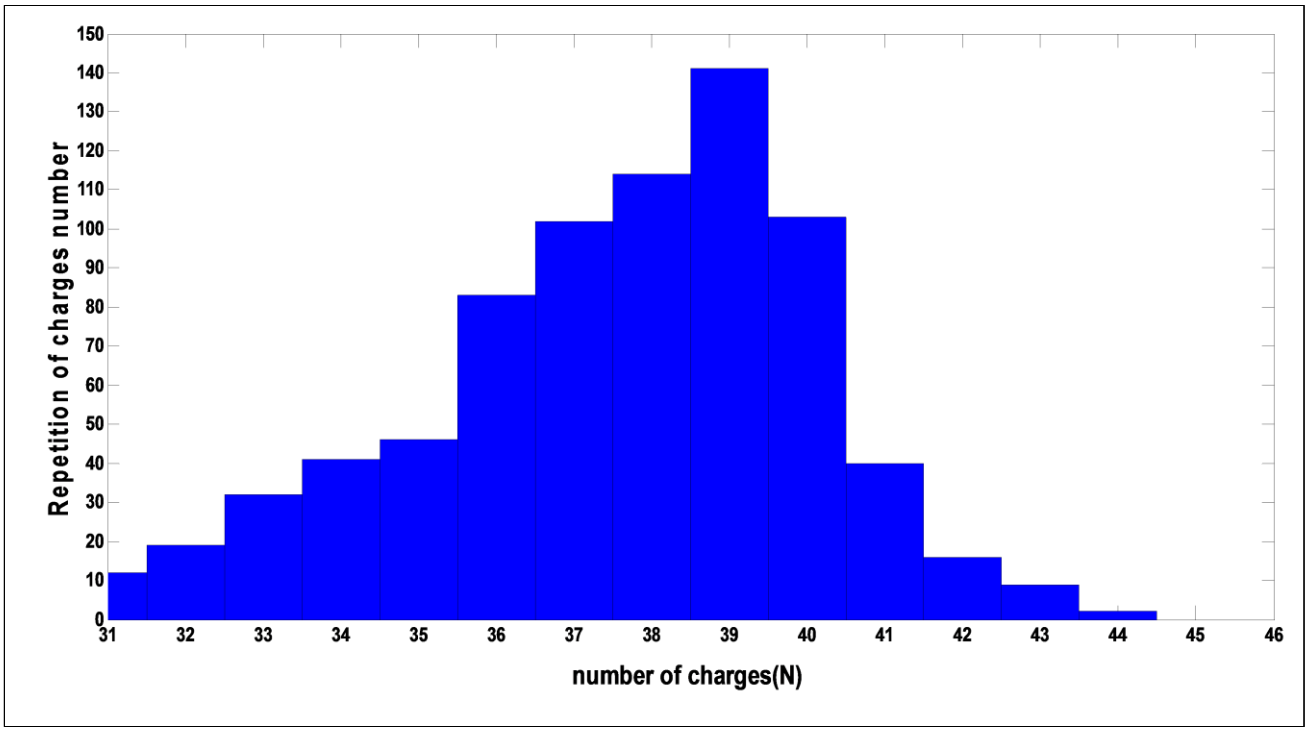

Figure (3): The histogram of charge number for charging process with absence UV. The charge number equilibrium equals=39

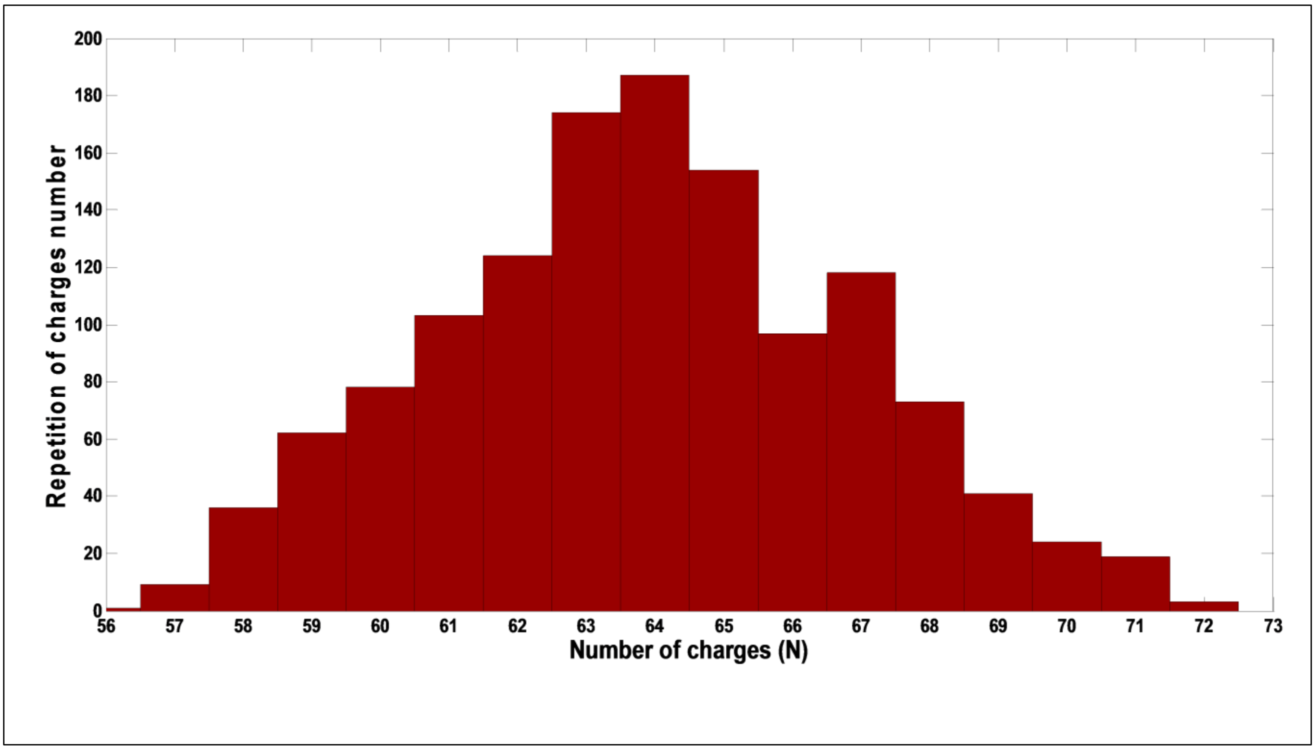

Figure (4): The histogram of charge number for charging process with presence UV (J_p=2×10^{18}w/m^2). The charge number equilibrium equals=64

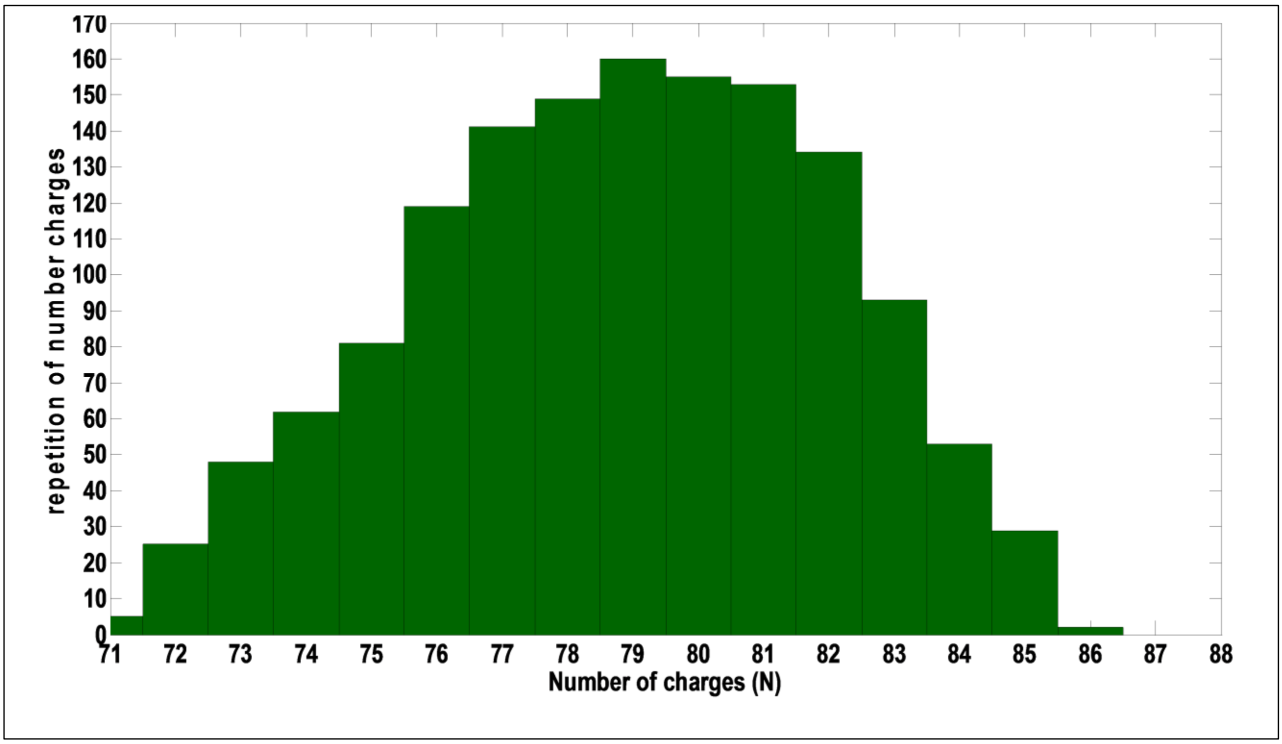

Figure (3) The histogram of charge number for charging process with presence UV (J_p=4×10^{18}w/m^2). The charge number equilibrium equals=79

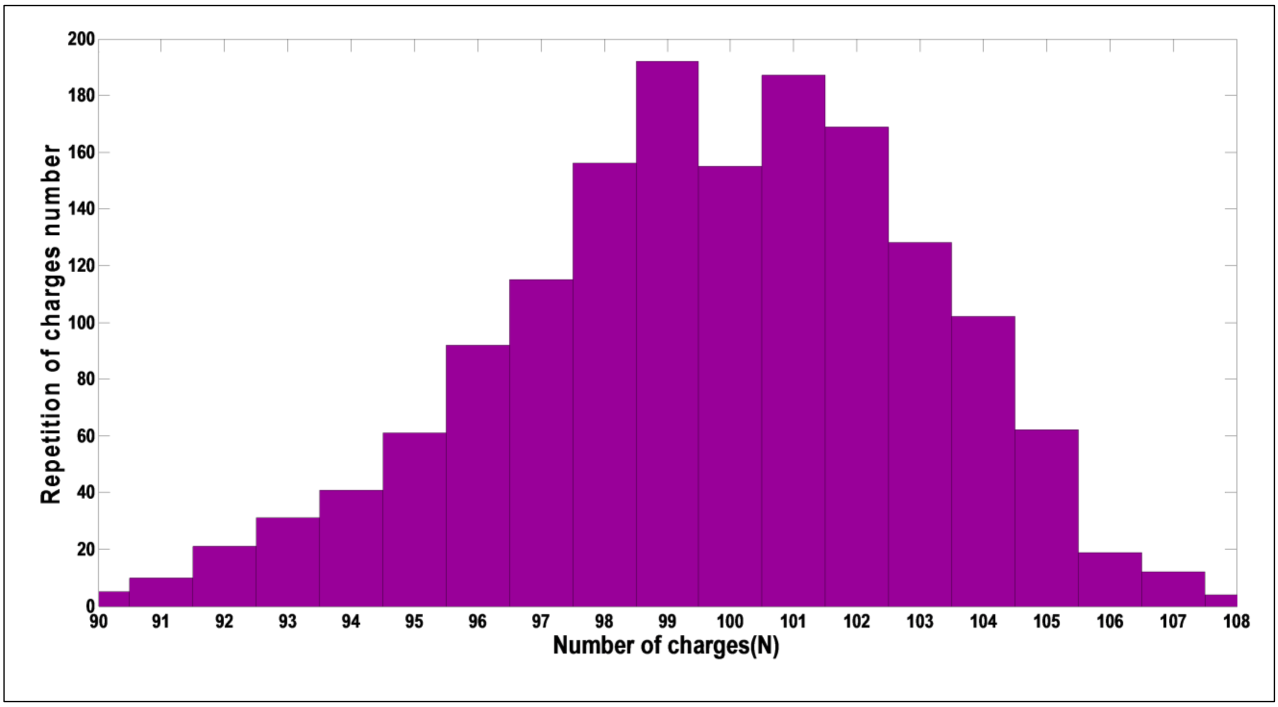

Figure (4): The histogram of charge number for charging process with presence UV (J_p=1×10^{19}w/m^2). The charge number equilibrium equals=99

V. Conclusions

The numerical results illustrate effect 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 nanoparticle increases gradually. We can consider photoelectric emission plays important rule in charging process of dust if UV rays presences and has enough energy.

VI. 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).