Photogeneration of electrons in dust clouds in near space

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This paper presents an investigation of electron density and electron temperature in a dust cloud, subject to radiation, which causes photoelectric emission of electrons. The analysis is based on charge neutrality and number and energy balance of electrons. Appropriate expressions for the photoelectric emission and mean energy of emitted photoelectrons have been employed. The parametric relationship, corresponding to dust of stainless steel (as an illustration) in the near space environment, with dominant Lyman α (1215.7 Å) radiation in the extreme ultraviolet part of the spectrum, has been investigated.

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I. INTRODUCTION

Jung [1] considered the charging of an interstellar grain of dust and concluded that the photoelectric emission and the accretion of electrons by the grain are the inherent dominant processes. Spitzer [2] considered the charging of dust particles in space by photoelectric emission on account of the incident radiation. He postulated that the effect of charge on a particle could be accounted for by an effective threshold frequency ν_{oe}, given by

$$\nu_{oe} = \nu_o + eV/h \quad \text{for} \quad V > 0, \tag{1a}$$

and

$$\nu_{oe} = \nu_o \quad \text{for} \quad V < 0, \tag{1b}$$

where ν_o is the threshold frequency for an uncharged surface, e is the magnitude of the electronic charge, h is Planck's constant, and $V(=Ze/a)$ is the electric potential at the surface of the spherical particle of charge Ze and radius a. He did not mention another condition, viz., Eq. (2), which is mentioned in the next paragraph and should also to be taken into account, as pointed out by Sodha [3,4] and Sodha and Guha [5].

The reasoning is simple and is as follows. If $\mathbf{u}$ denotes the velocity of an electron of mass m just outside the metallic surface at potential V (after it has overcome the surface barrier), the condition for the electron to escape (or get emitted) is

$$\frac{1}{2}mu_n^2 > eV \quad \text{for a plane surface} \quad (V > 0), \tag{2a}$$

and

$$\frac{1}{2}mu^2 > eV \quad \text{for a spherical particle} \quad (V > 0), \tag{2b}$$

where u_n is the component of $\mathbf{u}$ normal to the surface.

It may be appreciated that Eq. (2b) is the condition for an open orbit, synonymous with the escape of the electron. Sodha and co-worker [4,5] obtained the appropriate expression for the photoelectric emission from a charged (positively or negatively) spherical surface, in accordance with condition (2b).

It is common [6–10] to use the following expressions for emission from a spherical particle

$$n_{\text{ph}} = \chi J \pi a^2 \quad \text{for} \quad V < 0, \tag{3a}$$

and

$$n_{\text{ph}} = \chi J \pi a^2 \exp(-eV/kT) \quad \text{for} \quad V > 0, \tag{3b}$$

where n_{ph} is the number of photoelectrons, emitted per unit time from the particle, J is the photon flux ($\nu > \nu_{oe}$) per unit area on the surface of the particle, and χ is the number of photoelectrons, emitted per photon from an uncharged surface.

Equation (3b) seems to be based on the erroneous assumption that the electrons in a metal obey classical statistics and is very different from the rigorous expression [4,5], based on Fowler's theory [11]. This expression [4,5] also takes into account Eqs. (2a) and (2b). Further, the parameter χ [Eqs. (3a) and (3b)] has been assumed to be independent of ν, which is also far from correct.

In their analysis of the electric charging of interstellar dust in the solar system, Kimura and Mann [12] have not considered the effect of charge of the particle on photoelectric emission. Klumov *et al.* [13] have obtained the photoelectric yield of the particle by multiplying χ with the number of incident photons, having a frequency higher then ν_{oe}; the effect of charge on the particle was not considered.

In their analysis of charging of a dust particle in a plasma, Samarian *et al.* [14] made use of the correct expression [4,5] for n_{ph}, the number of photoelectrons, emitted per unit time from a spherical particle. However a little mistake has crept in their [14] final expression; $\phi(E_F/kT_{\text{ph}})$ in Eq. 12 of their [14] paper should be replaced by $\phi(\xi/kT_{\text{ph}})$.

Mention should be made of an interesting experiment [15] on the dusty plasma, induced by the incidence of solar radiation on dust suspended in a buffer gas; the experiment was conducted aboard the Mir orbiting space station. The charge on the particles was obtained by the balance of the rate of photoelectron emission from a spherical particle to the num-

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ber of electrons recombining with it. However an erroneous equation [Eq. (3b)] was used for the photoelectric emission and the temperature of the electrons was assumed to be the temperature of the emitted photoelectrons, for which no expression was given. It may have been implied that the temperature of the photoelectrons is $(h\nu-\varphi)/k$, where φ is the work function of the metal and k is the Boltzmann constant; this corresponds to the maximum energy of an emitted photoelectron and not the average energy.

It may be noticed that there has been no attempt to analytically obtain the electron temperature from the energy balance of electrons, let alone use it consistently. In this paper the authors have developed a formalism for getting the electron temperature, electron density, and charge on the particles from the data on radiation, incident on a cloud of dust; all particles have been assumed to have the same charge. Computations have been made corresponding to a dust cloud of iron particles in the upper atmosphere, where the photoelectric emission is assumed to occur on account of extreme ultraviolet (EUV) radiation, particularly that corresponding to the Lyman Alpha spectral line (1215.7 Å).

In the present paper photoelectric emission by the dust particles is assumed to be the sole mechanism for electron generation. The other mechanisms, viz., thermionic and secondary electron emission are important under many situations in space, laboratory, and other applications; this theory is obviously not applicable to these situations. However there are many situations, where the theory is indeed applicable, particularly in space.

The theory is a steady-state theory and the results should be independent of the initial conditions; the initial conditions only determine the time to arrive at the steady state.

II. PHOTOELECTRIC EMISSION BY CHARGED SPHERICAL PARTICLES

Sodha and co-worker [4,5] have derived the following expressions for the number of photoelectrons n_{ph} emitted from a charged spherical particle per unit time:

$$n_{\mathrm{ph}}(Z) = \pi a^2 \beta(\nu)(4\pi m k^2 T^2/h^3)\Lambda(\nu)\Phi(\xi) \quad \text{for } Z \leq -1, \tag{4a}$$

and

$$n_{\mathrm{ph}}(Z) = \pi a^2 \beta(\nu)(4\pi m k^2 T^2/h^3) \times \Lambda(\nu)\Psi(\xi,\overline{Z+1}\alpha) \quad \text{for } Z \geq -1, \tag{4b}$$

where

$$\Phi(\mu) = \int_0^{\exp(\mu)} [\ln(1+\Omega)/\Omega] d\Omega, \tag{4c}$$

$$\Psi(\xi,\overline{Z+1}\alpha) = \Phi(\xi - \overline{Z+1}\alpha) + (Z+1)\alpha \ln[1+\exp(\xi-\overline{Z+1}\alpha)],$$

$$\xi = (h\nu - \varphi)/kT, \quad \alpha = e^2/akT, \tag{4d}$$

$\Lambda(\nu)$ is the number of photons incident per unit area per unit time, $\beta(\nu)$ is the probability of absorption of a photon by an electron inside the particle and incident on the surface, h is Planck's constant, and T is the temperature of the dust particle. If the radiation is isotropic, $\pi a^2\Lambda(\nu)$ in Eqs. (4a) and (4b) may be replaced by $4\pi a^2 c u(\nu)/h$, where $u(\nu)$ is the energy density of radiation and c is the speed of light in free space.

The first term on the right-hand side (RHS) of Eq. (4d) is in accordance with Eq. (1a), suggested by Spitzer [2]. Since the charge on the particle becomes $(Z+1)e$ after emission of an electron, $(Z+1)$ occurs in Eqs. (4b) and (4d).

Starting from the expression for the mean energy $\varepsilon_{\mathrm{ph}}$ of the emitted photoelectron [4,5] (including a double integral), one obtains

$$(\varepsilon_{\mathrm{ph}}/kT) = \left\{ \int_0^\infty \eta^2[1+\exp(\eta-\xi)]^{-1} d\eta + 2(Z+1)\alpha\Phi(\xi) + (Z+1)^2\alpha^2 \ln[1+\exp(\xi)] \right\} \Big/ \Psi(\xi,\overline{Z+1}\alpha) = F_1(\xi,\overline{Z+1}\alpha), \tag{4e}$$

by using the identity

$$\int_{0,\xi_1+\xi_2>Z\alpha}^\infty \int_0^\infty (\xi_1+\xi_2)\{1+\exp(\xi_1+\xi_2-Z\alpha)\}^{-1} d\xi_1 d\xi_2 = \int_{Z\alpha}^\infty \eta^2[1+\exp(\eta-Z\alpha)]^{-1} d\eta.$$

In case of white light, Eqs. (4a), (4b), and (4e) can be suitably modified.

The photoelectric emission n_p per unit area from a plane uncharged surface is usually expressed as

$$n_p = \Lambda(\nu)\chi(\nu) = \beta(\nu)(4\pi m k^2 T^2/h^3)\Lambda(\nu)\Phi(\xi), \tag{5a}$$

where $\chi(\nu)=\beta(\nu)(4\pi m k^2 T^2/h^3)\Phi(\xi)$ is called the photoelectric efficiency.

Hence Eqs. (4a) and (4b) may be expressed as

$$n_{\mathrm{ph}}(Z) = \pi a^2 n_p = \pi a^2 \Lambda(\nu)\chi(\nu), \quad \text{for } Z \leq -1, \tag{5b}$$

and

$$n_{\mathrm{ph}}(Z) = \pi a^2 n_p F_2(\xi,\overline{Z+1}\alpha) = \pi a^2 \chi(\nu)\Lambda(\nu)F_2(\xi,\overline{Z+1}\alpha), \quad \text{for } Z \geq -1, \tag{5c}$$

πa^2 being the cross-sectional area of the particle, normal to the direction of incident radiation.

Data is usually available in terms of either n_p or $\chi(\nu)$, or both; from either of these, an estimate for $\beta(\nu)$ can be obtained, using Eq. (5a).

III. CONSERVATION EQUATIONS

Consider a cloud of dust particles (at temperature T) having a charge Ze and electrons at a temperature T_e in steady state, when irradiated by electromagnetic radiation.

The conservation of charge requires

TABLE I. $F_1(\xi,\overline{Z+1}\alpha)$ for $1\leq\xi\leq 8$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	1	2	3	4	5	6	7	8
1	3.449377	3.74104	4.25385	4.86532	5.52343	6.20287	6.89062	7.57990
2	13.2414	11.3543	10.2266	9.75800	9.73210	9.96693	10.8332	10.8232
3	44.8599	33.4327	25.0760	20.0384	17.38033	16.0970	15.5570	15.4267
4	146.859	101.230	66.7833	45.2072	33.3312	27.1715	23.9795	22.3006
5	469.770	310.930	190.592	114.406	71.9726	50.1580	39.1477	33.3854
6	1472.92	953.749	562.520	315.257	176.711	105.446	70.5339	53.3130
7	4540.81	2901.88	1675.89	906.469	476.060	253.836	145.648	94.4610
8	13805.4	8744.98	4985.94	2645.79	1344.49	673.307	345.825	192.580
9	41498.4	26116.4	14759.2	7741.69	3866.66	1877.27	907.114	452.684
10	123582	77378.2	43438.2	22602.8	11173.8	5669.98	2505.15	1177.52

$$n_e = Zn, \tag{6}$$

where n_e is the electron density and n is the number of dust particles per unit volume.

Conservation of the number of electrons requires that the number of photoelectrons emitted per unit time from a dust particle equals the electron collection current [5,10,16] n_{ec} by the particle; thus

$$n_{\rm ph}(Z) = n_{ec} = \pi a^2 n_e (8kT/\pi m)^{1/2}(T_e/T)^{1/2}[1 + Z\alpha/(T_e/T)],$$

where $n_{\rm ph}(Z)$ is given by Eqs. (5a)–(5c).

Substituting for $n_{\rm ph}(Z)$ from Eq. (5c), the above equation can be put in the form

$$1/Y = (n_e/n_p)(8kT/\pi m)^{1/2} = \frac{F_2(\xi,\overline{Z+1}\alpha)}{(T_e/T)^{1/2}[1 + Z\alpha/(T_e/T)]}, \tag{7}$$

where Y is a convenient parameter.

Furthermore the energy conservation of electrons requires

$$\varepsilon_{\rm ph}(Z) = kT(T_e/T)[2 + Z\alpha/(T_e/T)]/[1 + Z\alpha/(T_e/T)], \tag{8}$$

where $\varepsilon_{\rm ph}(Z)$ is the mean energy of photoelectrons for monochromatic radiation given by Eq. (4e) (it may be suitably modified for continuous radiation) and the RHS of Eq. (8) denotes the mean energy [5] of the recombining electrons.

Substituting for $\varepsilon_{\rm ph}(Z)$ from Eq. (4e), the above equation can be put in the form

$$F_1(\xi,\overline{Z+1}\alpha) = (T_e/T)\{\{2 + [Z\alpha/(T_e/T)]\}/[1 + Z\alpha/(T_e/T)]\}. \tag{9}$$

The functions F_1 and F_2 have been tabulated for a range of values of $\xi=(h\nu-\varphi)/kT$ and $\overline{Z+1}\alpha$ in Tables I–VI; F_1 and F_2 for any intermediate values of ξ and $\overline{Z+1}\alpha$ may be obtained by interpolation. These tables should be useful for computations over a wide range of parameters.

The energy conservation of dust particles requires

$$\pi a^2 S\alpha_0 = 4\pi a^2 \varepsilon\sigma(T^4 - T_0^4), \tag{10}$$

where the left-hand side of Eq. (10) denotes the radiant energy absorbed by a dust particle, the RHS denotes the energy

TABLE II. $F_1(\xi,\overline{Z+1}\alpha)$ for $9\leq\xi\leq 60$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	9	10	15	20	30	40	50	60
1	8.26750	8.95162	12.3193	15.6324	22.2292	28.48428	35.4789	42.1220
2	11.3484	11.9069	14.9210	18.0705	22.5124	31.0521	37.6437	44.2567
3	15.5347	15.7839	18.0273	20.8525	27.0051	33.4117	39.9221	46.4844
4	21.4304	21.0230	21.7617	24.0350	29.7275	35.9319	42.3278	48.8170
5	30.1999	28.3621	26.2992	27.7758	32.7039	38.6247	44.8685	51.2614
6	44.3164	39.2548	31.8940	31.9140	35.9627	41.5032	47.5452	53.8158
7	69.6674	56.7715	38.9279	36.8293	39.5377	44.5824	50.3643	56.4769
8	121.937	88.2086	47.9975	42.6032	48.4692	47.8796	53.3404	59.2530
9	246.238	152.958	60.0877	49.4629	47.8796	51.4140	56.4850	62.1607
10	574.409	306.610	76.9349	57.7268	51.4140	55.2080	59.8050	65.2112

TABLE III. $F_1(\xi,\overline{Z+1}\alpha)$ for $70\leq\xi\leq 300$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	70	80	90	100	150	200	250	300
1	48.7673	55.3778	62.0046	68.9181	101.259	134.160	169.621	202.689
2	50.8864	57.4854	64.1459	70.9167	103.322	136.326	171.477	205.007
3	53.0848	59.6777	66.3593	72.9740	105.431	138.530	173.357	207.356
4	55.3676	61.9487	68.6345	75.0963	107.588	140.772	175.260	209.733
5	57.7386	64.2908	70.9532	77.2819	103.793	143.054	177.188	212.142
6	60.2009	66.6943	73.3030	79.5518	112.047	145.376	179.140	214.581
7	62.7571	69.1636	75.6931	81.8913	114.353	147.739	181.117	217.051
8	65.4102	71.7136	78.1442	84.3093	116.711	150.144	183.119	219.553
9	68.1677	74.3568	80.6735	86.8091	119.122	152.593	185.146	222.087
10	71.0369	77.0982	83.3937	89.3937	121.590	155.085	187.200	224.600

lost by radiation, S is the total irradiance, α_0 is the mean absorption coefficient for the radiation, ε is the emissivity of the surface of the particle, and T_0 is the temperature of the surroundings. Energy conservation of electrons, viz., Eq. (9) ensures that the net temperature of the dust particles is given by Eq. (10).

The computation may conveniently involve the following steps: (1) the temperature T of the particles is determined from Eq. (10), knowing the total intensity S of radiation (of all wavelengths), emissivity ε and absorption coefficient α_0 of the surface of the particles, and the background temperature T_0 (given S, α_0, ε, and T_0). (2) From knowledge of the frequency of radiation ν, the work function φ of the materials of the particles, and the temperature T of the particle, the parameter $\xi=(h\nu-\varphi)/kT$ is obtained. The parameters $\alpha=e^2/akT$ is known with a knowledge of the radius of the particle and the temperature of the particle. With ξ and α so known, Eq. (9) reduces to a quadratic function in (T_e/T) for a given value of Z; the positive root gives the corresponding value of (T_e/T) (further input of ν, φ, and a). (3) Substituting for any value of Z and the corresponding value of (T_e/T) (as obtained in step 2), the corresponding value of the normalized electron density $(n_e/n_p)(8kT/\pi m)^{1/2}=Y^{-1}$ may be obtained. (4) As per Eq. (6), the normalized number of dust particles $(n/n_p)(8kT/\pi m)^{1/2}$ is obtained by dividing $(n_e/n_p)(8kT/\pi m)^{1/2}$ by Z. (5) Thus one can generate a table giving mutually consistent values of (T_e/T), $(n_e/n_p)(8kT/\pi m)^{1/2}$, and $(n/n_p)(8kT/\pi m)^{1/2}$ for a set of values of Z. This table of course gives Z, (T_e/T), and $(n_e/n_p)(8kT/\pi m)^{1/2}$ as a function of the normalized dust particle density $(n/n_p)(8kT/\pi m)^{1/2}$ given ν, φ, a, and T (obtained from the knowledge of S, α, ε, and T_0).

The parameter n_p for a given material is proportional to the intensity of radiation and the constant of proportionality is known from experiments. Since n_p and T are also known for a given situation, the table can be converted to one giving Z, (T_e/T), and n_e as a function of n_p.

To summarize, for the evaluation of the charge Ze on the particles and the temperature/density of electrons one has to know (1) total irradiance S, (2) emissivity ε of the material, (3) absorption coefficient α_0 of the surface of the material, (4) temperature of the surroundings T_0, (5) frequency ν of the radiation, (6) work function φ of the material, (7) radius a of the particle, and (8) the number n_p of electrons emitted

TABLE IV. $F_2(\xi,\overline{Z+1}\alpha)$ for $1\leq\xi\leq 8$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	1	2	3	4	5	6	7	8
1	0.839078	0.887760	0.925374	0.949896	0.965100	0.974670	0.980910	0.985150
2	0.534340	0.628570	0.727196	0.806901	0.862410	0.899220	0.92379	0.940640
3	0.283342	0.363810	0.476054	0.059689	0.699856	0.775940	0.829300	0.866660
4	0.134824	0.181770	0.261115	0.373447	0.499309	0.612023	0.699590	0.763850
5	0.060334	0.083130	0.125604	0.197883	0.303306	0.426250	0.541180	0.634240
6	0.026030	0.036170	0.05589	0.09272	0.156890	0.253600	0.370480	0.483750
7	0.010965	0.015290	0.023833	0.040439	0.072110	0.128878	0.217050	0.326920
8	0.004541	0.006340	0.009916	0.016977	0.030970	0.058365	0.108810	0.189260
9	0.001856	0.002590	0.004061	0.006977	0.012843	0.024766	0.048710	0.093860
10	7.52×10^{-4}	0.001050	0.001645	0.002829	5.23×10^{-3}	0.010168	0.020470	0.041620

TABLE V. $F_2(\xi,\overline{Z+1}\alpha)$ for $9\leq\xi\leq 60$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	9	10	15	20	30	40	50	60
1	0.988129	0.990330	0.995620	0.99752	0.998890	0.999400	0.999460	0.999660
2	0.952560	0.961280	0.982480	0.990080	0.995570	0.997520	0.998300	0.998880
3	0.893337	0.912900	0.960580	0.977680	0.990040	0.994400	0.996430	0.997630
4	0.810651	0.845240	0.929910	0.960330	0.982290	0.990030	0.993650	0.995700
5	0.705120	0.758480	0.890490	0.938010	0.972320	0.984420	0.989970	0.993080
6	0.578649	0.653220	0.842320	0.910730	0.960150	0.977560	0.985550	0.959920
7	0.436643	0.531240	0.785380	0.878500	0.09458	0.969450	0.980400	0.986350
8	0.292142	0.397510	0.719710	0.841310	0.929150	0.960100	0.974430	0.982320
9	0.167535	0.263830	0.645360	0.799150	0.910330	0.949490	0.967600	0.977660
10	0.082364	0.150140	0.562490	0.752040	0.889290	0.937640	0.960000	0.972290

per unit area per unit time from an uncharged plane surface with incidence of light of the same frequency and irradiance as on the particles. The method is illustrated by a significant example in Secs. IV and V.

IV. DUST CLOUDS IN NEAR SPACE

The importance [16] of photoemission from dust particles in space in generation of electrons is a consequence of large photoelectric yields $\chi(\nu)$ for many materials in the extreme ultraviolet (<1300 Å) part of the spectrum and significant energy (or photon flux) in the same region of solar radiation. According to Bauer [17] more than 80% of the photons and 60% of energy in the EUV part of spectrum (<1300 Å) are accounted for by photons, corresponding to the Lyman α spectrum line (1215.7 Å); this is also in fair agreement with the earlier data, given by Hinteregger *et al.* [18]. Hence the computations are based on the assumption of monochromatic Lyman α radiation, which is not far from truth.

Feuerbacher and Fitton [19] measured photoemission properties for a number of materials, with surfaces treated to simulate space conditions. These measurements were used along with the data for solar radiation in near space to compute the photoelectron current density n_p for uncharged plane surfaces of different materials, which were in reasonable agreement with measured values in space for some surfaces. The present computations are based on a photoelectron current density of 2.4×10^{-9} A/cm^2 (corresponding to $n_p=1.5\times10^{10}/\text{cm}^2$ s) for stainless steel; the choice of stainless steel is only by way of illustration. It should be appreciated that the photon flux and the corresponding value of n_p (corresponding to Lyman α radiation, 1215.7 Å) may vary [20] by a factor of 2 or more.

V. NUMERICAL RESULTS

The following basic data has been used in this investigation; material of dust-stainless steel with work function of 7.8 eV, radius of dust particles $a=250$ Å, $n_p=1.5\times10^{10}/\text{cm}^2$ s, and temperature of dust particles $T=200$ K.

The dependence of the charge Z on the particles, the electron density n_e, and the electron temperature T_e on the number density n of dust particles was computed for the above set of data by obtaining a solution of simultaneous Eqs. (6),

TABLE VI. $F_2(\xi,\overline{Z+1}\alpha)$ for $70\leq\xi\leq 300$.

$\xi\rightarrow$ $(Z+1)\alpha$ $\downarrow$	70	80	90	100	150	200	250	300
1	0.999711	1.000000	0.999290	1.00100	0.999950	0.999120	1.001030	0.998600
2	0.999060	0.999440	0.998150	1.001800	0.999720	0.998130	1.002010	0.997160
3	0.998056	0.998340	0.996660	1.002380	0.999320	0.997050	1.002910	0.995680
4	0.996600	0.996840	0.995020	1.002550	0.998740	0.995870	1.003750	0.994150
5	0.994800	0.995130	0.993510	1.002340	0.997980	0.994590	1.004530	0.992570
6	0.992550	0.993370	0.992270	1.001730	0.997050	0.993210	1.005240	0.990950
7	0.989900	0.991520	0.991170	1.000720	0.995940	0.991730	1.005890	0.989290
8	0.986878	0.989370	0.989930	0.999310	0.994660	0.990150	1.006470	0.987580
9	0.983410	0.986810	0.988360	0.997510	0.993200	0.988471	1.006990	0.985830
10	0.979486	0.983820	0.986360	0.995300	0.991560	0.986710	1.007450	0.984030

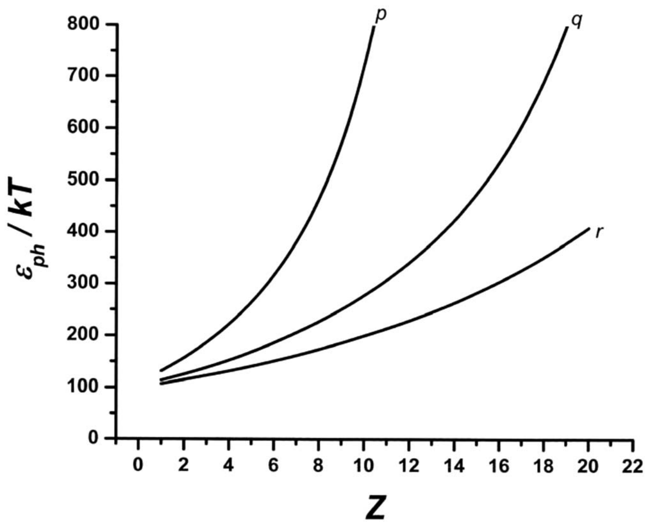

FIG. 1. Dependence of mean energy ε_{ph}/kT of emitted photoelectrons from a stainless-steel particle of charge Ze, irradiated by Lyman α radiation of 1215.7 Å; the letters p, q, and r refer to a =100, 175, and 250 Å.

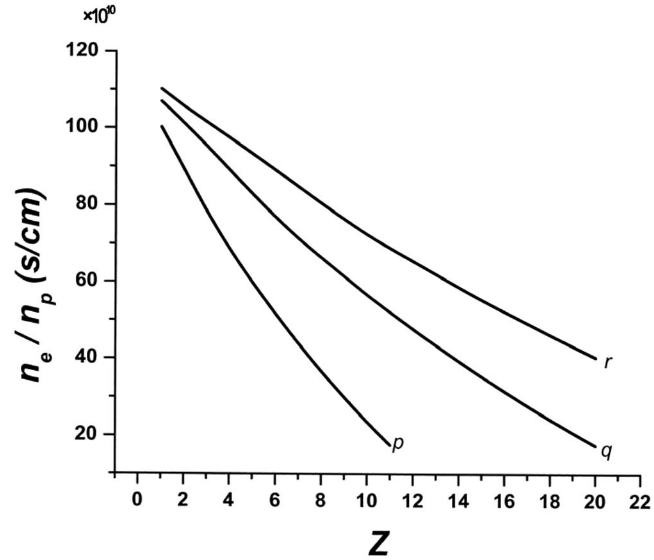

FIG. 3. Dependence of electron density n_e/n_p on Z for spherical particles, irradiated by Lyman α radiation; the letters p, q, and r refer to a=100, 175, and 250 Å.

(7), and (9). The effect of change in any one of a, n_p, and T, keeping the other two constant has also been computed.

Figure 1 illustrates the dependence of the mean energy $\varepsilon_{\mathrm{ph}}$ of the emitted photoelectrons as a function of the charge Ze on a spherical particle of stainless steel of radius a at a temperature of 200 K corresponding to $n_p=1.5\times10^{10}$ cm^{-2} s^{-1}, typical of the conditions in near space (dominant Lyman α radiation); it may be noticed that the mean energy of the photoelectrons increases with increasing Z and decreasing a. Figure 2 illustrates the relationship between temperature of the electrons and the charge Z on the dust particle. It is seen that the electron temperature increases with increasing Z and decreasing a; this can be appreciated by the qualitative similar behavior of $\varepsilon_{\mathrm{ph}}/kT$. Figure 3 illustrates the dependence of the electron density n_e/n_p on the charge on the particle Z. It is seen that n_e/n_p decreases with increasing Z; this is due to the decrease in the n_{ph} with increasing Z. Further the increase in n_e with increasing a can be ascribed to increased area of photoemission of electrons and reduced electric potential for given Z.

Figure 4, a consequence of Fig. 3 ($n_p=n_e/Z$), represents the dependence of the charge on the particles on the number density of particles n_p. It may be appreciated as follows. When n_p is small, there are fewer electrons recombining with the particles on account of the corresponding low electron density and hence Z has a larger value. Furthermore α is lower for higher values of a and hence Z decreases with increasing a. It is also seen that $Z\approx1$ at (n/n_p) s/cm

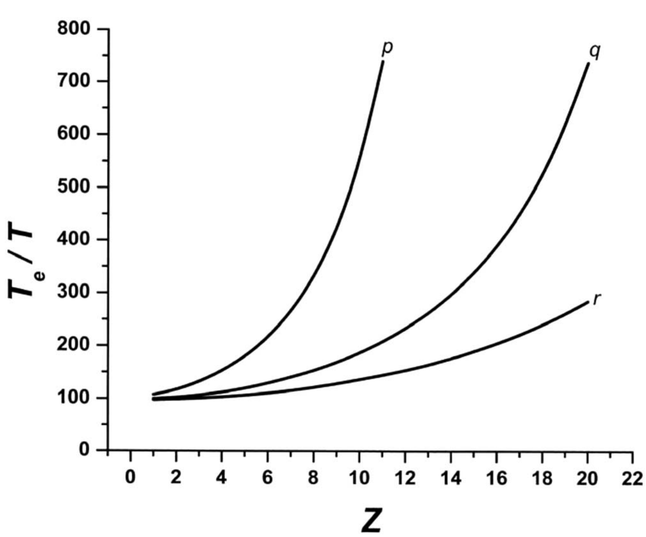

FIG. 2. Dependence of electron temperature T_e/T on Z for stainless-steel spherical particles irradiated by Lyman α radiation; the letters p, q, and r refer to a=100, 175, and 250 Å.

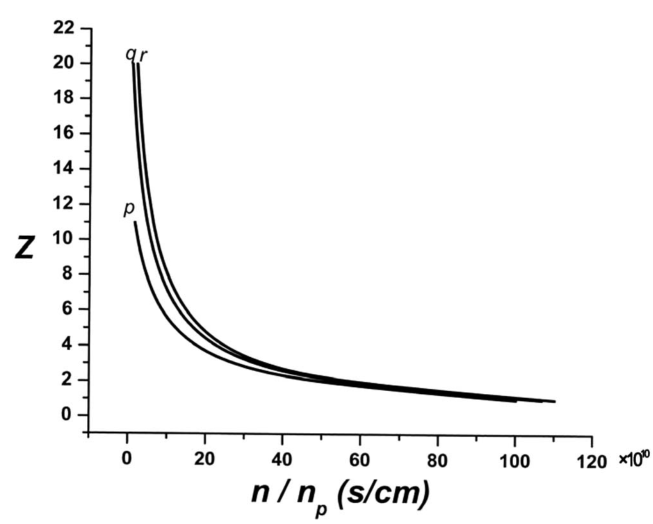

FIG. 4. Dependence of electron density Z on n/n_p for spherical particles, irradiated by Lyman α radiation; the letters p, q, and r refer to a=100, 175, and 250 Å.

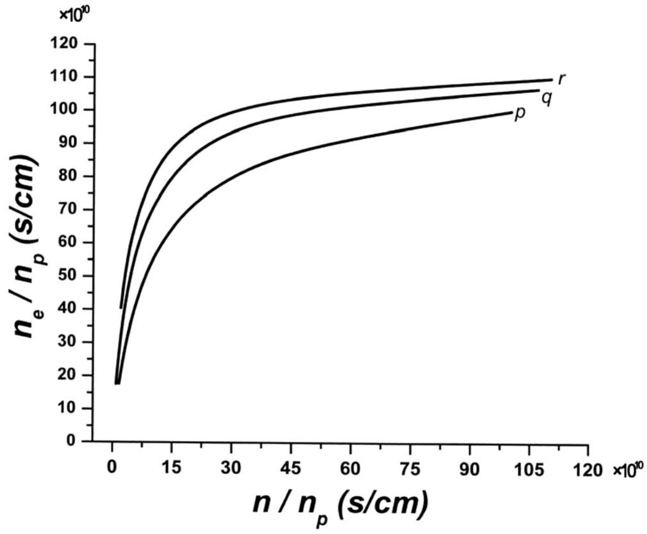

FIG. 5. Dependence of electron density n_e/n_p on n/n_p for spherical particles irradiated by Lyman α radiation; the letters p, q, and r refer to $a=100$, 175, and 250 Å.

$\geq 100\times 10^{10}$ and the Z vs (n/n_p) curve has a very small negative slope, for higher values of n/n_p.

Figure 5 is also a consequence of Fig. 3. The interesting result is that, for large particle densities $[(n/n_p)\geq 100\times 10^{10}$ s/cm], (n_e/n_p) tends to saturate asymptotically to 115×10^{10} s/cm. A similar result is obtained [4] when the dusty plasma gets created on account of thermionic emission from dust particles.

VI. CONCLUSIONS

This paper presents a formalism for evaluation of electron density and charge on a particle in a cloud of dust, irradiated by radiation, which causes photoelectric emission of electrons from the dust particles. The formalism is based on conservation of electron density and electron energy in the steady state. Unlike earlier investigations appropriate expressions for the number per unit time and mean energy of photoelectrons, emitted from a positively charged dust particles, have been given and used. Numerical computations have been made for the case of a dust cloud in near space. Six tables to aid in computation have also been given.

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