Photodetachment of H$^-$ in dense quantum plasmas

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We have made an investigation to study the plasma screening effect of dense quantum plasmas on the photodetachment cross section of hydrogen negative ion within the framework of dipole approximation. Plasma screening effect has been taken care of by the exponential cosine-screened Coulomb potential (ECSCP). The asymptotic forms of highly correlated wave functions for the initial bound states of H$^-$ and the plane wave form for the final $e^- - \mathrm{H}$ states are used to evaluate the transition matrix elements. Results for photodetachment cross section in dense quantum plasmas are reported for the plasma screening parameter in the range [0.0,0.6] (in a_0^{-1}). In respect of the photodetachment process of H$^-$, we have also compared the plasma screening effect of a dense quantum plasma with that of a weakly coupled plasma for which plasma screening effect has been represented by the Debye model. Our results for the unscreened case agree nicely with some of the most accurate results available in the literature.

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I. INTRODUCTION

Recently, Kar and Ho [1] reported the results of photodetachment cross section of hydrogen negative ion in weakly coupled plasmas. They have used Debye model to represent the plasma screening effect of weakly coupled plasmas. Of course, Debye model adequately describes the screened interaction potential in classical weakly coupled plasmas. In weakly coupled (collisionless) plasmas, the ratio of the potential energy to the average kinetic energy, called the coupling parameter, is much less than unity. That is, the potential energy of two particle separated by an average interparticle distance is small compared to the average kinetic energy. As a result, long-range self-consistent interactions (described by the Poisson equation) dominate over short-range two-particle interactions (collisions). The effect of such plasmas on a test charge is to replace the Coulomb potential by an effective screened potential. This effective screened Coulomb potential (SCP) is known as the Debye-Hückel potential and is given by [2,3]

$$V(r) = (1/r)e^{-\mu r} \quad (\text{in a.u.}), \tag{1}$$

where $1/\mu(=D=v_T/\omega_p)$ is the Debye length, and v_T and ω_p are the thermal velocity and plasma frequency, respectively. A particular value of D corresponds to a range of plasma conditions. Smaller values of D or larger values of μ correspond to stronger screening. However, the Debye-Hückel model would not be reliable to investigate the physical properties of the plasmas with the increase in plasma density due to the multiparticle cooperative interactions [4]. Recently Shukla and Eliasson [5] showed that the effective screened potential of a test charge of mass m in a dense quantum plasma can be modeled by a modified Debye-Hückel potential or exponential cosine-screened Coulomb potential (ECSCP),

$$V(r) = (1/r)e^{-\mu r}\cos(\mu r) \quad (\text{in a.u.}), \tag{2}$$

rather than Debye-Hückel potential or screened Coulomb potential (1). Here μ is related to the plasma frequency ω_p by means of the relation $\mu = \omega_p/(\hbar\omega_p/m)^{1/2}$. Quantum plasmas are usually characterized by a low temperature and a high number density and essentially composed of electrons and ions. If a plasma is cooled to an extremely low temperature, the de Broglie wavelength of the charge carriers may be comparable to the Debye length $D(=1/\mu)$ of the plasma. In such situations, the ultracold plasma behaves as a Fermi gas and the quantum mechanical effects play a vital role in the behavior of the collective interactions of the charged particles. So, when the de Broglie wavelength becomes larger than the screening length $(1/\mu)$ an electron inside the Debye sphere is screened by the potential outside of the sphere. However, in deriving Eq. (2) it was assumed that the quantum force acting on the electrons dominates over the quantum statistical pressure. In quantum plasmas, the ranges of the electron number density n_e and temperature T are, respectively, known to be about $10^{18}-10^{23}$ cm^{-3} and 10^2-10^5 K, and the coupling plasma parameter $\Gamma > 1$ [6]. The existence of quantum plasma is quite common in different areas, such as, in micro and nanoelectronic devices, in dense astronomical systems (the white dwarfs and the neutron stars), in laser produced plasmas, in nonlinear optics etc [7]. Due to the presence of cos term, ECSCP exhibit stronger screening effect than SCP, and this makes the properties of an atom in a dense quantum plasma different from that in a weakly coupled plasma. Hence, it is expected that the photodetachment processes in these quantum plasmas would be considerably different from those in weakly coupled plasmas.

The effect of screened Coulomb interaction among the charged particles in hot, dense plasmas on the atomic structure and collision properties has long been the subject of interest, even in the recent years it is being investigated with increasing interest [8–28]. The interest is mainly due to the researches in laser produced plasmas, euv and x-ray laser development, inertial confinement fusion, and astrophysics

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(stellar atmospheres and interiors). At the same time, studies on atomic processes in various quantum plasmas have also gained considerable interest [19,29–31]. In this paper our endeavor is to study the plasma screening effect of dense quantum plasmas on the photodetachment of H^-. We also make a comparative study of the photodetachment process in dense quantum plasmas with that in weakly coupled plasmas. Such studies find applications in various fields of physics, such as, atomic physics [32–46], astrophysics [47–52], plasma physics [22,25,52,53], plasma diagnostics [54]. Recently we have been able to obtain sufficiently accurate correlated wave function for H^- in dense quantum plasmas [31]. In the present work, we use that wave function in dipole approximation to determine photodetachment cross section of H^- in dense quantum plasmas. It should be mentioned here that a number of investigations has been made so far to study the photodetachment process of H^- in vacuum [32–46] (and further references therein). More elaborate close-coupling continuum wave functions have also been used to study photoionization or photodetachment in two-electron atomic systems [55–60] (and further references therein). But, to the best of our knowledge, phtodetachment of H^- in dense plasma environments has not been reported in the literature so far. We have designed this paper as follows. Describing the underlying theory and calculations of our investigation in Sec. II we present and discuss our computed results in Sec. III. Finally, in Sec. IV we give our concluding remarks.

II. THEORY AND CALCULATIONS

The nonrelativistic Hamiltonian of the system consisting of two electrons $(\mathbf{r}_1,\mathbf{r}_2)$ and a proton (at the origin) in a plasma environment characterized by the screening parameter μ is given by

$$\mathrm{H} = -\frac{1}{2}\nabla_1^2 - \frac{1}{2}\nabla_2^2 - \left[\frac{e^{-\mu r_1}}{r_1}\cos(\delta\mu r_1) + \frac{e^{-\mu r_2}}{r_2}\cos(\delta\mu r_2)\right] + \frac{e^{-\mu r_{12}}}{r_{12}}\cos(\delta\mu r_{12}), \tag{3}$$

where the constant $\delta=0$ for weakly coupled plasmas and $\delta=1$ for dense quantum plasmas. Here atomic nucleus and bound electrons are thought to have been screened in the same way and the same μ is used to represent electron-electron and electron-nucleus screening for the sake of computational purpose. Of course, different μ can also be used to represent electron-electron and electron-nucleus screening. In this work, we determine the photodetachment cross section of H^- within the framework of dipole approximation which requires the evaluation of dipole transition matrix element from an initial state i to a final state f. Here, in the initial state we have the bound H^- and in the final state we have the $e^-{-}\mathrm{H}$ system. In order to determine sufficiently accurate initial wave function for the bound ionic state in a plasma environment we solve the Schrodinger equation, $\mathrm{H}\Psi=E\Psi$ and $E<0$, in the framework of Ritz's variational principle by employing the following correlated wave function [31]:

$$\Psi_i(\mathbf{r}_1,\mathbf{r}_2) = \sum_{n=1}^{N} C_n\psi_n = \sum_{n=1}^{N} C_n(1+P_{12})e^{-A(r_1+r_2)}r_1^{l_n}r_2^{m_n}r_{12}^{n_n},$$

$$l_n,m_n,n_n = 0,1,2,\ldots,l_i \geq m_i, \tag{4}$$

where N denotes the number of terms in the expansion, A is a nonlinear variational parameter, $C_n(n=1,2,3,\cdots,N)$ are linear expansion coefficients and P_{12} is an exchange operator such that $P_{12}f(\mathbf{r}_1,\mathbf{r}_2)=f(\mathbf{r}_2,\mathbf{r}_1)$ for an arbitrary function f. We expand this wave function by generating the powers of r_1, r_2, and r_{12} in such a way that the terms of which $l_i+m_i+n_i=\omega=0(N=1)$ come first then $\omega=1(N=3)$, $2(N=7)$ and so on.

The final state which involves the motion of a free electron relative to the hydrogen atom must be a p state. In this work, we assume the final state wave function is a properly symmetrized product of the hydrogen wave function (denoted by ϕ) and the p-wave part of a plane wave,

$$\Psi_f = \frac{1}{\sqrt{2}}[\phi(\mathbf{r}_1)e^{i\mathbf{k}\cdot\mathbf{r}_1} + \phi(\mathbf{r}_2)e^{i\mathbf{k}\cdot\mathbf{r}_2}] \quad \text{with } E=\frac{k^2}{2}, \tag{5}$$

where $\mathbf{k}$ is the wave vector in the direction of the motion of the free electron. Now, given the initial and final states wave function, Ψ_i and Ψ_f, the photodetachment cross section can be written as [48]

$$\sigma_V = \frac{2k\alpha a_0^2}{3\omega}|\langle\Psi_f|Q_V|\Psi_i\rangle|^2, \tag{6}$$

where α is the fine structure constant, ω is the energy of the incident light, and

$$Q_V = 2\hat{k}\cdot(\nabla_{r_1}+\nabla_{r_2}),$$

is the dipole transition operator in the velocity form. The cross section can also be written in the length form as [48]

$$\sigma_L = \frac{2k\omega\alpha a_0^2}{3}|\langle\Psi_f|Q_L|\Psi_i\rangle|^2, \tag{7}$$

where

$$Q_L = \hat{k}\cdot(\mathbf{r}_1+\mathbf{r}_2)$$

is the dipole transition operator in the length form.

We now assume that the initial bound-state wave function has the following asymptotic form:

$$\Psi_i = C\left[\frac{e^{-\gamma r_1}}{r_1}\phi(r_2) + \frac{e^{-\gamma r_2}}{r_2}\phi(r_1)\right], \tag{8}$$

where γ is related to the binding energies of H^- and H, ϵ_{H^-}, ϵ_{H}, by

$$\gamma = \sqrt{2(\epsilon_{\mathrm{H}}-\epsilon_{\mathrm{H}^-})} \tag{9}$$

and C is a constant to be determined. This simplifying approximation was first introduced by Bethe [61] for deuteron

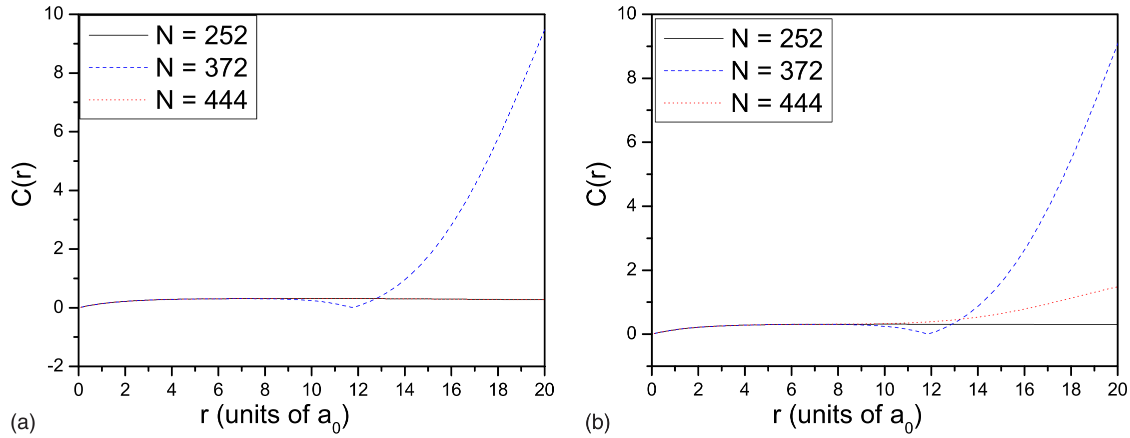

FIG. 1. (Color online) The constant C as a function of coordinate r in dense quantum plasmas for different expansion lengths of the wave function (4) for (a) $\mu=0$ and (b) $\mu=0.05$.

photodisassociation. Its justification lies on the fact that the weakly bound deuteron is almost always outside the range of the forces. There the asymptotic form is quite accurate, particularly for low energies which do not probe the inner parts of the system in detail. Since then it has been used several times, particularly in the case of similar weakly bound ground state such as H^- and Ps^-. With this approximation the photodetachment cross sections in the velocity form and in the length form are identical and are given by [45]

$$\sigma_V = \sigma_L = 4.302\,552\,25 \times 10^{-17} \frac{C^2 k^3}{(k^2+\gamma^2)^3}\ \mathrm{cm}^2. \quad (10)$$

In terms of wavelength λ of the incident light, using the relation

$$\lambda = \frac{911.267\,057}{k^2+\gamma^2}\ \text{Å}, \quad (11)$$

the above relation becomes

$$\sigma = 4.302\,552\,25 \times 10^{-17} \frac{C^2}{\gamma^3}\left[\frac{\lambda}{\lambda_0}\right]^{3/2}\left[1-\frac{\lambda}{\lambda_0}\right]^{3/2}\ \mathrm{cm}^2 \quad (12)$$

with $\lambda \le \lambda_0$ and $\lambda_0 = 911.267\,057/\gamma^2$ Å.

It now remains to determine the constant C from the ground state wave function $\Psi(\mathbf{r}_1,\mathbf{r}_2,\mathbf{r}_{12})$ of H^-. Having set $r_1=r_{12}=r$ and $r_2=0$, or, $r_2=r_{12}=r$ and $r_1=0$, we define $C(r)$ as

$$C(r) = Gre^{\gamma r}\Psi(r,0,r), \quad (13)$$

where G is some normalization constant. Then it is seen that over a wide range in the asymptotic region $C(r)$ remains constant. Finally, in order to determine γ we need to know the bound-state energies of hydrogen. This is done by solving the Schrodinger equation $\mathrm{H}\Psi=E\Psi$ and $E<0$, with

$$\mathrm{H} = -\frac{1}{2}\nabla^2 - \frac{e^{-\mu r}}{r}\cos(\delta\mu r), \quad (14)$$

in the framework of Ritz's variational principle by employing the wave function of the form

$$\Psi(\mathbf{r}) = \sum_i C_i\psi_i = \sum_i C_i e^{-B_i r} r^{l_i}, \quad l_i = 0,1,2,\ldots, \quad (15)$$

where B_i's are nonlinear variational parameters, and $\mathbf{r}$ denotes the coordinates of the electron relative to the nucleus.

III. RESULTS AND DISCUSSION

First we have determined γ for various values of the screening parameter μ by using the variationally determined wave functions (4) and (15). The ground state energies of hydrogen and hydrogen negative ion in dense quantum plasmas for various values of the screening parameter have been reported in our earlier work [31]. We then use these values of γ and the wave function (4) in relation (13) to determine the constant C. It is found that $C(r)$ remains nearly constant when r varies from a value $r_{\min}$ to a higher value $r_{\max}$. Also with the increase in the terms in the wave function (4) this range of r as well as the constant remain almost the same. For large values of r, $C(r)$ shows an oscillation which is ultimately damped at "infinity" due to the square-integrable nature of the bound-state wave function. In Figs. 1(a) and 1(b) we have shown C as a function of r for $\lambda=0.0$ and $\lambda=0.05$ respectively for three different expansions of the wave function (4). From these figures it is seen that a stable plateau for C exits in the range $4\le r\le 9$. The parameter γ and the constant C for various values of the screening parameter in both weakly coupled and dense quantum plasmas are shown in Figs. 2(a) and 2(b) respectively. From these figures it is seen that both γ and C are larger in weakly coupled plasmas than in dense quantum plasmas for strong screening effect. This is what is expected due to stronger screening effect of ECSCP than SCP. But for very small screening effect both γ and C are slightly larger in dense quantum plasmas than in weakly coupled plasmas. It thus follows that electron-electron correlation is more effective in weakly coupled plasmas than in dense quantum plasmas for small screening effect.

Having determined γ and C for various values of μ we now calculate the photodetachment cross section by means of the relation (12). First we have calculated the cross section

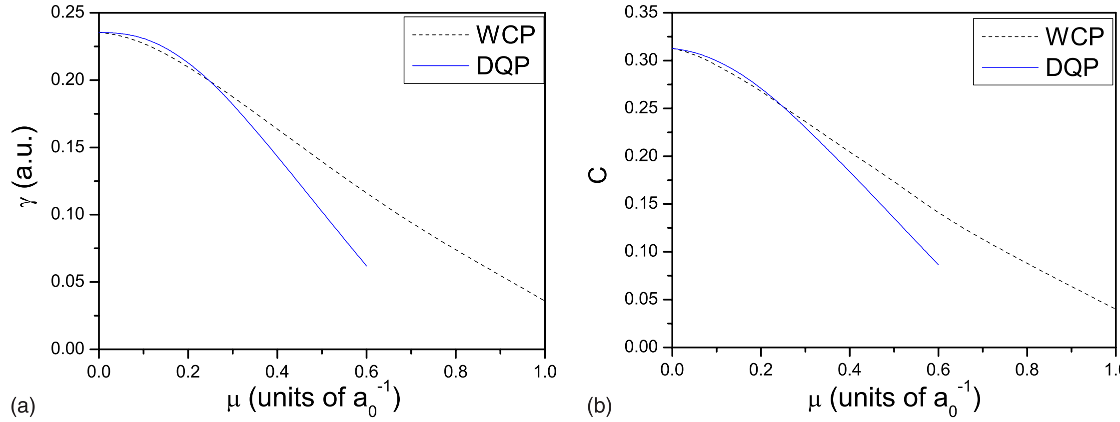

FIG. 2. (Color online) (a) The parameter γ as a function of the screening parameter μ in weakly coupled plasmas and dense quantum plasmas. (b) The constant C as a function of the screening parameter μ in WCP and DQP.

by using the wave function (4) in weakly coupled plasma in which results are available for comparison. Moreover, by this we can also compare the effect of screening in two types of plasmas. In Table I our present photodetachment cross section, for free H^-, as a function of outgoing electron momentum is compared with various theoretical calculations. These theoretical calculations include multiconfiguration Hartree-Fock method, polarized-orbital method, perturbation-variation method, etc. From this table we notice that our present photodetachment cross sections of various electron momenta are in nice agreement with these calculations. Of course, it should be mentioned here that close-coupling predictions are significantly more accurate in certain energy regions. Our present maximum photodetachment cross section σ_{max}, for free H^-, is compared with various other calculations in Table II. This comparison shows that our results for free ion are reasonably accurate. It is to be noted that most of the calculation predict σ_{max} to lie approximately in $[39-41]\times 10^{-18}$ cm^2.

In Table II we also compare our present results in weakly coupled plasmas with the results of Kar and Ho [1] obtained by using exponential bound-state wave function of H^- in the

TABLE I. Comparison of the photodetachment cross section (in units of 10^{-18} cm^2) as a function of outgoing electron momentum k for various theoretical calculations in the length formulation.

k^2 (a.u.)	λ (10^3 Å)	Present	(A)	(B)	(C)	(D)	(E)	(F)	(G)
0.01	13.912	14.99	15.54	12.21	12.34	15.55	15.7		15.31
0.02	12.069	27.68	28.68	25.59	26.0		28.6		28.1
0.03	10.658	35.02	35.83	34.61	35.4		35.8		35.2
0.04	9.542	38.69	39.11	39.20	40.5	39.30	39.1	39.8	38.6
0.05	8.637	40.11	40.07	41.00	42.31		40.1		39.7
0.0555	8.209	40.27[a]							
0.06	7.890	40.18	39.68	40.80	42.1		39.8	39.6	39.4
0.07	7.261	39.47	38.57	39.50	40.6		38.7		38.4
0.08	6.725	38.32	37.07	36.63	38.6		37.2	37.6	37.0
0.09	6.263	36.93	35.38	34.09	36.40	36.70	35.5		35.3
0.1	5.860	35.43	33.64						
0.16	4.229	26.94	24.43	23.35	24.47	25.27	24.5	24.1	24.6
0.25	2.983	18.47	15.99	15.41	16.43	16.47	15.95	15.91	
0.36	2.193	12.68	10.65	10.64	11.29	11.60	10.58	10.72	10.94
0.5	1.640	8.69	7.22						
0.64	1.310	6.41	5.53	5.23	5.31	6.46	5.47	5.60	5.84

[a]Denotes the maximum photoionization cross section for the present calculation. (A): results of Saha [43] obtained by using multiconfiguration Hartee-Fock method, (B): results of Daskhan and Ghosh [39] obtained by using polarized-orbital method, (C): results of Bell and Kingston [41] obtained by representing symmetrized continuum function in polarized orbital, (D): results of Bhatia [46] obtained by using the optical potential approach based on the Feshbach projection operator formalism, (E): results of Stewart [37] obtained by using perturbation-variation method, (F): Results of Broad and Reinhardt [36] obtained by solving the pseudostate close-coupling equations for H^- photodetachment, (G): results of Ajmera and Chung [35] obtained by using Kohn-Feshbach variational method.

TABLE II. Comparison of the parameter γ, the asymptotic constant C, the maximum value of the photodetachment cross section σ_{max}, and the corresponding value of the wavelength λ_{max} for various values of the screening parameter μ in a weakly coupled plasma. L and V respectively denote the cross sections obtained by using length form and velocity form. (A) Results of Kar and Ho obtained by using bound state of H^- in the initial state and plane wave in the final state [1], (B) perturbation-variation method of Stewart [37], (C) Hartree-Fock method of Saha [43] and (D), close-coupling pseudostate expansion method of Wishardt [38].

	γ (a.u.)		C		λ_{max} (10^3 Å)		σ_{max} (10^{-18} cm^2)		
							Present	Other results	
μ	Present	Other results	Present	Other results	Present	Other results	($L=V$)	L	V
0.00	0.2356	0.2359(A)	0.3129	0.3158(A)	8.209	8.209(A)	40.27	41.02(A)	41.02(A)
								40.10(B)	40.40(B)
								40.07(C)	39.90(C)
								39.65(D)	38.91(D)
0.10	0.2276	0.2276(A)	0.2952	0.2990(A)	8.798	8.798(A)	39.75	40.80(A)	40.80(A)
0.20	0.2098	0.2098(A)	0.2682	0.2701(A)	10.349	10.349(A)	41.89	42.44(A)	42.44(A)
0.25	0.1991	0.1991(A)	0.2515	0.2544(A)	11.496	11.496(A)	43.11	44.12(A)	44.12(A)
0.50	0.1394	0.1394(A)	0.1741	0.1761(A)	23.464	23.459(A)	60.22	61.54(A)	61.54(A)
1.00	0.0360	0.0366(A)	0.0402	0.0456(A)	353.667	339.76(A)	187.51	231.73(A)	231.73(A)

initial state and plane wave in the final state. From this table we see that our computed results for weakly coupled plasmas are in nice agreement with those of Kar and Ho. For $\mu=1.0$ our computed photodetachment cross section is little less than that of Kar and Ho. In this regard, it is to be mentioned that screened Coulomb potential supports a bound state for proton-electron system up to around $\mu=1.1$. So, for very strong screening effect, such as $\mu=1.0$, the wave function is about to be diffused.

In Table III we make a list of the parameter γ, asymptotic constant C, and the maximum value of the photodetachment cross section σ_{max} with the corresponding value of the wave-

TABLE III. The parameter γ, asymptotic constant C, and the maximum value of the photodetachment cross section σ_{max} with the corresponding value of the wavelength λ_{max} for various values of the screening parameter μ. Weakly coupled plasmas (WCP) and dense quantum plasmas (DQP), respectively, denote weakly coupled plasma and dense quantum plasma.

			λ_{max} (10^3 Å)		σ_{max} (10^{-18} cm^2)	
$\mu(a_0^{-1})$	γ (a.u.) DQP	C (a.u.) DQP	DQP	WCP	DQP	WCP
0.00	0.23558857	0.3129	8.209	8.209	40.274	40.274
0.01	0.23558273	0.3076	8.210		38.928	
0.02	0.23554309	0.3074	8.212	8.237	38.884	39.799
0.04	0.23525312	0.3071	8.233		38.954	
0.05	0.23495997	0.3066	8.253	8.370	38.986	39.902
0.08	0.23331362	0.3037	8.370	8.598	39.052	39.451
0.10	0.23149276	0.3002	8.502	8.798	39.071	39.754
0.15	0.22424463	0.2878	9.061		39.497	
0.20	0.21330361	0.2713	10.014	10.349	40.784	41.888
0.25	0.19915362	0.2521	11.488	11.496	43.263	43.112
0.30	0.18240355	0.2302	13.695		46.968	
0.35	0.16368990	0.2084	17.005		53.240	
0.40	0.14364795	0.1845	22.081	17.018	61.740	51.166
0.45	0.12290266	0.1607	30.165		74.787	
0.50	0.10205206	0.1350	43.750	23.464	92.269	60.218
0.55	0.08161535	0.1096	68.408		118.910	
0.60	0.06186407	0.0864	119.107	34.006	169.553	67.511

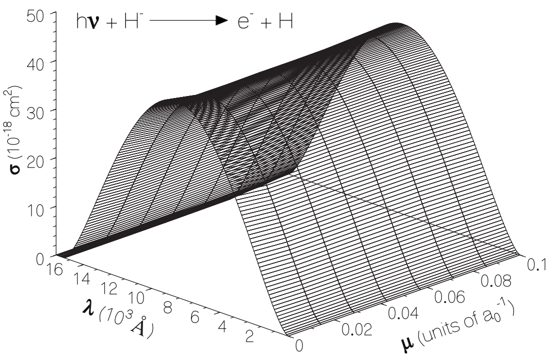

FIG. 3. Photodetachment cross section of H^- in dense quantum plasmas as a function of the wavelength of the incident light λ (in units of 10^3 Å) and plasma screening parameter μ (0.0–0.1).

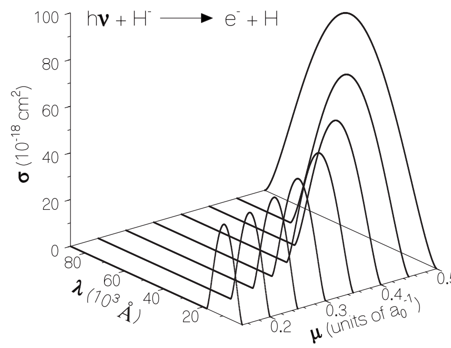

FIG. 4. Photodetachment cross section of H^- in dense quantum plasmas as a function of the wavelength of the incident light λ (in units of 10^3 Å) and plasma screening parameter μ (0.15–0.5).

length of the incident light λ_{max} for various values of the screening parameter μ in dense quantum plasmas. In this table we also include σ_{max} with corresponding λ_{max} for some selective values of μ in weakly coupled plasmas for the sake of comparison. From this table we notice that the trend of the maximum photodetachment cross section and the corresponding wavelength of the incident light are same in both plasmas. The plots in Figs. 3 and 4 demonstrate the nature of σ as a function of λ and the screening parameter μ in dense quantum plasmas. As with the increase in the screening effect the ion becomes more and more loosely bounded, it is expected that λ_{max} should increase with increasing screening effect. We see that this is quite true for both types of plasmas. The amount of the maximum photodetachment cross section and the corresponding λ in two different plasmas can be interpreted from the nature of γ ($\gamma^2/2$ is the electron affinity of hydrogen) in these two plasmas. As we have seen that for small screening effect, where electron-electron correlation is more effective in weakly coupled plasmas than dense quantum plasmas, γ is larger in dense coupled plasmas than in weakly coupled plasmas, so it is expected that more energetic light is required to eject electron in dense quantum plasma than in weakly coupled plasma. As a result, for small screening effect σ_{max} and λ_{max} are larger in weakly coupled plasmas than in dense quantum plasmas. For strong screening effect (beyond μ=0.25) σ_{max} and λ_{max} are larger in dense quantum plasmas than in dense weakly coupled plasmas owing to stronger screening effect of ECSCP than SCP.

IV. CONCLUSIONS

In this paper, we have made an investigation, for the first time in the literature, to study the plasma screening effect of a dense quantum plasma on the photodetachment of hydrogen negative ion. Highly correlated and extensive wave functions for H^- has been used to calculate the photodetachment cross section within the framework of dipole approximation. Of course, it is essential to use elaborate bound-state wave functions to determine the asymptotic forms of the system, from which the values of constant C can be extracted. In other words, we need to know the value of the wave function when it has reached the "physical" asymptotic region, but before the damping factor of the "mathematical" nature of the bound-state type basis becomes dominant. A simple two-electron wave function cannot fulfill such purpose. From the comparison of our numerical results to others in the literature for the pure Coulomb case, it indicates that our approach by taking the outgoing free-wave approximation is reasonably accurate for a weakly bound system such as an H^- ion. Of course for a more definitive calculation, one has to use a highly correlated outgoing wave function. But such an approach presents another stage of technical challenging problem for exponential cosine-screened Coulomb potentials and is outside the scope of our present investigation.

We have found that the wavelength of the incident light for which the photodetachment cross section is maximum increases steadily with increasing screening effect for both weakly coupled and dense quantum plasmas. Moreover, for small screening effect, σ_{max} and λ_{max} are larger in weakly coupled plasmas than in dense quantum plasmas. For strong screening effect (beyond μ=0.25) σ_{max} and λ_{max} are larger in dense quantum plasmas than in dense weakly coupled plasmas. We hope that our present investigation will provide useful information to the research community of atomic physics, astrophysics, and plasma physics.

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[1] S. Kar and Y. K. Ho, Phys. Plasmas **15**, 013301 (2008).
[2] J. C. Weisheit, *Applied Atomic Collision Physics*, edited by C. F. Barnett and M. F. A. Harrison (Academic, New York, 1984), Vol. 2.
[3] J. C. Weisheit, Adv. At. Mol. Phys. **25**, 101 (1989).
[4] F. B. Baimbetov, Kh. T. Nurekenov, and T. S. Ramazanov, Phys. Lett. A **202**, 211 (1995).
[5] P. K. Shukla and B. Eliasson, Phys. Lett. A **372**, 2897 (2008).
[6] T. Ramazanov, K. Galiyev, K. N. Dzhumagulova, G. Ropke, and R. Redmer, Contrib. Plasma Phys. **43**, 39 (2003).
[7] S. Ali and P. K. Shukla, Phys. Plasmas **13**, 102112 (2006).
[8] Y. Y. Qi, Y. Wu, J. G. Wang, and Y. Z. Qu, Phys. Plasmas **16**, 023502 (2009).
[9] L. Liu, J. G. Wang, and R. K. Janev, Phys. Rev. A **77**, 032709 (2008); **77**, 042712 (2008).
[10] Y. Y. Qi, J. G. Wang, and R. K. Janev, Phys. Rev. A **78**, 062511 (2008).
[11] H. Zhang, J. G. Wang, B. He, Y. B. Qiu, and R. K. Janev, Phys. Plasmas **14**, 053505 (2007).
[12] S. Kar and Y. K. Ho, Phys. Rev. A **77**, 022713 (2008).
[13] S. Paul and Y. K. Ho, Phys. Rev. A **78**, 042711 (2008); Phys. Plasmas **15**, 073301 (2008).
[14] S. Kar and Y. K. Ho, Phys. Rev. A **75**, 062509 (2007).
[15] M. S. Pindzola, S. D. Loch, J. Colgan, and C. J. Fontes, Phys. Rev. A **77**, 062707 (2008).
[16] D. Kremp, M. Schlanges, and W.-D. Kraeft, *Quantum Statistics of Nonideal Plasmas* (Springer, Berlin, 2005).
[17] P. K. Shukla, L. Stenflo, and R. Bingham, Phys. Lett. A **359**, 218 (2006).
[18] B. Saha and S. Fritzsche, Phys. Rev. E **73**, 036405 (2006).
[19] M. Marklund and P. K. Shukla, Rev. Mod. Phys. **78**, 591 (2006).
[20] D. Bielinska-Waz, J. Karwowski, B. Saha, and P. K. Mukherjee, Phys. Rev. E **69**, 016404 (2004).
[21] S. Kar and Y. K. Ho, Phys. Rev. E **70**, 066411 (2004).
[22] L. B. Zhao and Y. K. Ho, Phys. Plasmas **11**, 1695 (2004).
[23] I. Silanes, J. M. Mercero, and J. M. Ugalde, Phys. Rev. E **66**, 026408 (2002).
[24] S. T. Dai, A. Solovyova, and P. Winkler, Phys. Rev. E **64**, 016408 (2001).
[25] Y.-D. Jung, Phys. Plasmas **5**, 3781 (1998); **8**, 3111 (2001).
[26] Y. D. Jung, Phys. Rev. E **55**, 3369 (1997).
[27] P. Winkler, Phys. Rev. E **53**, 5517 (1996).
[28] A. Ghoshal and Y. K. Ho, Eur. Phys. J. D **55**, 581 (2009).
[29] S.-C. Na and Y.-D. Jung, Phys. Lett. A **372** 5605 (2008); Sang-Chul Na and Young-Dae Jung, Phys. Scr. **78**, 035502 (2008).
[30] A. Ghoshal and Y. K. Ho, J. Phys. B **42**, 075002 (2009); Phys. Rev. A **79**, 062514 (2009); Few-Body Syst. **46**, 249 (2009); Phys. Plasmas **16**, 073302 (2009); Eur. Phys. J. D **56**, 151 (2009).
[31] A. Ghoshal and Y. K. Ho, J. Phys. B **42**, 175006 (2009).
[32] S. J. Smith and D. S. Burch, Phys. Rev. Lett. **2**, 165 (1959); Phys. Rev. **116**, 1125 (1959).
[33] T. Ohmura and H. Ohmura, Phys. Rev. **118**, 154 (1960).
[34] B. H. Armstrong, Phys. Rev. **131**, 1132 (1963).
[35] M. P. Ajmera and K. T. Chung, Phys. Rev. A **12**, 475 (1975).
[36] J. T. Broad and W. P. Reinhardt, Phys. Rev. A **14**, 2159 (1976).
[37] A. L. Stewart, J. Phys. B **11**, 3851 (1978).
[38] A. W. Wishart, J. Phys. B **12**, 3511 (1979).
[39] M. Daskhan and A. S. Ghosh, Phys. Rev. A **28**, 2767 (1983).
[40] A. K. Bhatia and R. J. Drachman, Phys. Rev. A **32**, 3745 (1985).
[41] K. L. Bell and A. E. Kingston, Proc. Phys. Soc. Lond. **90**, 31 (1967).
[42] S. J. Ward, J. W. Humberston, and M. R. C. McDowell, J. Phys. B **20**, 127 (1987).
[43] H. P. Saha, Phys. Rev. A **38**, 4546 (1988).
[44] W. H. Kuan, T. F. Jiang, and K. T. Chung, Phys. Rev. A **60**, 364 (1999).
[45] A. M. Frolov, J. Phys. B **37**, 853 (2004).
[46] A. K. Bhatia, Phys. Rev. A **73**, 012705 (2006).
[47] R. Wildt, Astrophys. J. **89**, 295 (1939).
[48] S. Chandrasekhar, Astrophys. J. **102**, 223 (1945); S. Chandrasekhar and D. D. Elbert, *ibid.* **128**, 633 (1958).
[49] R. J. Gould, Astrophys. J. **235**, 650 (1980).
[50] R. J. Gould and Y.-D. Jung, Astrophys. J. **373**, 271 (1991).
[51] R. J. Gould and Y.-D. Jung, Astrophys. J. **391**, 403 (1992).
[52] J. C. Weisheit and B. W. Shore, Astrophys. J. **194**, 519 (1974).
[53] S. Sahoo and Y. K. Ho, Phys. Plasmas **13**, 063301 (2006).
[54] V. P. Shevelko and L. A. Vainshtein, *Atomic Physics for Hot Plasmas* (Institute of Physics, London, 1993), Chap. 1.
[55] H. A. Hyman, V. L. Jacobs, and P. G. Burke, J. Phys. B **5**, 2282 (1972).
[56] M. J. Conneely, K. Smith, and L. Lipskey, J. Phys. B **3**, 493 (1970).
[57] A. Igarashi, S. Nakazaki, and A. Ohsaki, Phys. Rev. A **61**, 032710 (2000); A. Igarashi, I. Shimamura, and N. Toshima, New J. Phys. **2**, 17 (2000).
[58] Jian-Zhi Tang, Y Wakabayashi, M. Matsuzawa, S. Watanabe, and I. Shimamura, Phys. Rev. A **49**, 1021 (1994).
[59] D.-S. Kim, H.-L. Zhou, and S. T. Manson, Phys. Rev. A **55**, 414 (1997).
[60] M. Venuti and P. Decleva, J. Phys. B **30**, 4839 (1997).
[61] H. A. Bethe and R. Peieris, Proc. R. Soc. Lond. A **148**, 146 (1935); H. A. Bethe and C. Longmire, Phys. Rev. **77**, 647 (1950).