# Control of the photodetachment of $H^-$ near a metallic sphere surface by an elastic interface*

Li Shao-Sheng(李绍晟) and Wang De-Hua(王德华)†

*School of Physics and Optoelectronic Engineering, Ludong University, Yantai* 264025, *China*

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According to the closed-orbit theory, we study the influence of elastic interface on the photodetachment of $H^-$ near a metallic sphere surface. First, we give a clear physical description of the detached electron movement between the elastic interface and the metallic sphere surface. Then we put forward an analytical formula for calculating the photodetachment cross section of this system. Our study suggests that the photodetachment cross section of $H^-$ is changed with the distance between the elastic interface and $H^-$. Compared with the photodetachment cross section of $H^-$ near a metallic sphere surface without the elastic interface, the cross section of our system oscillates and its oscillation is strengthened with the decrease of the distance from the elastic interface to $H^-$. In additon, our calcuation results suggest that the influence of the elastic interface becomes much more significant when it is located in the lower half space rather than in the upper half space. Therefore, we can control the photodetachment of $H^-$ near a metallic sphere surface by changing the position of the elastic interface. We hope that our work is conducive to the understanding of the photodetachment process of negative ions near interfaces, cavities and ion traps.

**Keywords:** photodetament, elastic interface, closed orbit theory, metallic sphere surface

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## 1. Introduction

Photodetachment of negative ions in various environments has been studied in detail by many authors. Since the discovery of the negative ion, it has been discussed both experimentally and theoretically, because negative ions play an important role in a wide range of physical processes and have many practical interest. The binding energy of the negative ion is used as one of the input parameters to model ionic crystals.[1] Chandrasekhar[2] and Bethe and Salpeter[3] have shown that the hydrogen negative ion is an important prototype in atomic physics and astrophysics. Early experiments and theories showed that the photodetachment of $H^-$ in the presence of an external electric field has wide applications. For example, it provides a primitive model to study the photodetachment microscopy;[4,5] it can control the dynamic characteristics of the micro-systems. In addition, it can be used as an instrumentation tool to exactly measure the magnetic fields.[6]

In 1987, Bryant discussed that the photodetachment cross section of $H^-$ in an electric field displays oscillatory structures.[7] Du[8] and Du and Delos[9] interpreted the oscillatory structures using the closed orbit theory. They pointed out that the oscillation is the consequence of interference between the direct going wave and the reflected wave from the ion. Since the closed orbit theory provides a clear physical description of the classical movement and oscillatory structures of the detached electron in the photodetachment cross section of a negative ion, many researchers have used this theory to study the photodetachments of $H^-$ in different external fields, such as in parallel electric and magnetic fields, crossed electric and magnetic fields, and electric and magnetic fields with arbitrary orientations.[10–22] Recently, with the development of surface physics, the closed orbit theory has been used to study the photodetachments of negative ions near surfaces. In 2006–2007, Yang,[23,24] Wang,[25] and Afaq and Du[26] applied the closed orbit theory to study the photodetachment of $H^-$ near an elastic interface. The assumptions about the elastic interface are consistent with both experimental and theoretical studies in microjunctions.[27–30] But in reality, an elastic interface is different from a metal surface. Then in 2009, Rui and Yang[31] and Zhao and Du[32] studied the photodetachment of $H^-$ near a metal surface[31,32] and showed that the photodetachment of $H^-$ near a metal surface can be modified by an external electric field. Very recently, Haneef *et al.*[33] studied the photodetached electron spectra near an elastic spherical surface using the theoretical imaging method and derived a more general equation for the photodetachment cross section of the plane wall. Our group[34] studied the photodetachment of $H^-$ in the presence of a metallic sphere surface. In our recently published work, we[35] studied the photodetachment of hydrogen negative ions inside a circular microcavity. In these previous studies, they all studied the photodetachment of negative ions near a single sphere surface or an elasitc surface. As to the photodetachment of $H^-$ between a metallic sphere surface and an elastic interface, no reports have been given up to

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†Corresponding author. E-mail: lduwdh@163.com

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now. But it is necessary to study this system, because in some typical experimental investigations of the van der Walls interaction, the surface of the macroscopic body is often considered to be a flat elastic surface.[36–38] The assumption is evidently reasonable if the particle is located very near the surface of the macroscopic body. However, if the particle is located at a distance comparable to the surface curvature radius, the strength of the van der Walls interaction can differ from that for a flat surface. Under this condition, the flat surface can be considered as a spherical surface.

In this work, we study the influence of the elastic interface on the photodetachment of $H^-$ near a metallic sphere surface based on the closed orbit theory. We discuss two different cases: the elastic interface located in the upper half space and the interface located in the lower half space. Our results suggest that the influence of the elastic interface on the photodetachment of $H^-$ near a metallic sphere surface depends on the location of the elastic interface sensitively.

The rest of this paper is organized as follows. In Section 2, we study the classical motion of a detached electron between a metallic sphere surface and an elastic interface and identify the closed orbits of this system. In Section 3, we derive the photodetachment cross section of this system on the basis of the closed orbit theory. Then, in Section 4, we calculate the cross sections for different positions of the elastic interface. Some discussion is also given in this section. Finally, in Section 5, we give some of the conclusions of this study. Atomic unit (abbreviated as a.u.) is used throughout this paper, unless otherwise stated.

## 2. Hamiltonian and closed orbits

The schematic plot of the system is given in Fig. 1. The hydrogen atom sits at the origin. The radius of the metallic nanosphere surface is $R$ and the distance between the hydrogen negative ion and the top of the nanosphere surface is $d$. An elastic interface is perpendicular to the $z$ axis. Figure 1(a) is the case with the elastic interface located in the $z > 0$ space, the distance between the elastic interface and $H^-$ is denoted as $d_2$. Figure 1(b) is the case with the elastic interface located in the $z < 0$ space, the distance between the elastic interface and $H^-$ is denoted as $d_3$. As in the previous study, $H^-$ is regarded initially as a one-electron system loosely bound by a short-ranged spherically symmetric potential $V_b(r)$ of the hydrogen atom, where $r$ is the distance between the active electron and the nucleus. A $z$-polarized laser is used for inducing the photodetachment.

According to the electrostatic image method,[39,40] there are four images inside the sphere: the images of the hydrogen atom are represented by two large dotted circles and the images of the detached electron are represented by two small dotted circles. The potential acting on the active electron can be considered as follows:

$$V = V_b + V_c + V_i, \tag{1}$$

in which $V_b(r)$ is the short-range spherically symmetric potential between the active electron and the nucleus and $V_c(r)$ is the interaction potential between the detached electron and the two image electrons. These two terms can be ignored after the electron has been detached. As in our previous study,[34] the interaction potential between the detached electron and its two images can be described as follows:

$$V_i = \frac{eR^2}{2l^2} - \frac{eR^2}{2(l^2 - R^2)}. \tag{2}$$

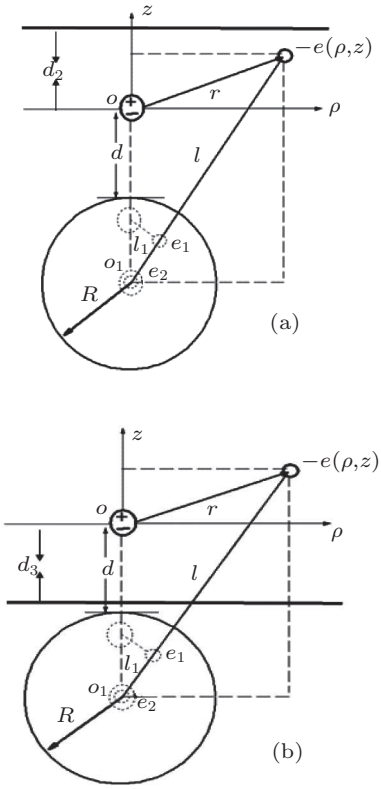



**Fig. 1.** Schematic representation of $H^-$ between a metalic sphere surface and an elastic interface in the cases where (a) the elastic interface is located in the upper half space and (b) the elastic interface is located in the lower half space.

In the cylindrical coordinates $(\rho, z, \phi)$, the Hamiltonian of the detached electron is[34]

$$H = \frac{1}{2}P_\rho^2 + \frac{1}{2}P_z^2 + \frac{R}{2}\left[\frac{1}{\rho^2 + R^2 + (z+d+R)^2]^2} - \frac{1}{\rho^2 - R^2 + (z+d+R)^2}\right] + V_0, \tag{3}$$

where

$$V_0 = -\frac{R}{2}\left[\frac{1}{(d+R)^2} - \frac{1}{(d+R)^2 - R^2}\right]$$

is an additional term to ensure that $V(\rho = 0, z = 0) = 0$, which has no influence on the photodetachment process of $H^-$.

The physical picture of the photodetachment of $H^-$ in this system can be described using the semiclassical closed

orbit theory. When $H^-$ is irradiated by a laser, photon energy $E_{ph}$ is absorbed to detach the valence electron from the bound of the hydrogen atom. Sufficiently far from the hydrogen atom, the waves propagate along classical trajectories semiclassically. Due to the effects of the elastic interface and the metallic sphere surface, some of these waves cannot travel to infinity and eventually return to the vicinity of the core region after a period of time. The returning waves interfere with the outgoing waves to give the oscillatory structure in the photodetachment cross section. The orbits, which begin and finally end at the core, are called closed orbits and have significant contributions to the oscillations in the photodetachment cross section.

Now we seek all the closed orbits for this system. Assuming that the electron is initially located on a sphere of radius $R$ ($R \approx 5.0$ a.u.), centered at the core and emanated with momentum $k$ in the direction of $\theta$, $k = \sqrt{2E}$. By solving Eq. (3) we can determine the closed orbits of the detached electron. Owing to the attractive image petential of the metallic sphere surface, one closed orbit always exits with $\theta = 0$. Thus, its momentum along the $+z$ axis is[34]

$$P_z = \sqrt{2\left\{E - V_0 - \frac{R}{2}\left[\frac{1}{(z+d+R)^2} - \frac{1}{(z+d+R)^2 - R^2}\right\}\right.}. \quad (4)$$

Since the position of the elastic interface can effect the detached electron movement, we describe the closed orbits according to the position of the elastic interface separately.

**Case 1 Elastic interface located in the upper half space**

By integrating the Hamiltonian motion equations, we can find out the closed orbits of the detached electron. Because the elastic interface is perpendicular to the $z$ axis, it has no influence on the $\rho$ motion. For $0 < \theta < \pi$, the elelctron trajectory is similar to a parabola before hitting the interface. However, when an electron hits the elastic interface, it bounces back and changes the sign of the momentum in the $z$ direction but keeps its magnitude. Figure 2(a) shows a family of classical trajectories of the detached electron. From this figure, we can see that only the orbit emitting up along the $z$ axis can be drawn back by the electrostatic potential of the metallic sphere or bounced back by the elastic interface to the origin. There is only one fundamental closed orbit. From Fig. 2(a), we find not all the electron trajectories can hit the upper interface, which depends on the initial momentum of the electron. The maximum distance that the electron can reach along the $+z$ axis is

$$z_{max} = \sqrt{\frac{R^2 + \sqrt{R^4 - 2R^3/(E+V_0)}}{2}} - d - R, \quad 0 < E \le E_c, \quad (5)$$

in which $E_c = V_0$ is the cirtical value of the detached electron energy. Given the radius $R$ of the sphere and the distance $d$ from the sphere to the $H^-$, using Eq. (5) we calculate the maximum height that the electron can reach along the $+z$ axis in a region $0 < E < E_c$ without the elastic interface. The result is shown in Fig. 3. This figure suggests that with the increase of the initial energy $E$ of the detached electron, $Z_{max}$ increases. Figure 4 shows the closed orbit of this system. From Fig. 4(a), we find that when $Z_{max} < d_2$, the electron cannot hit the upper interface before it has been pulled back by the electrostatic potential of the metallic sphere. Under this condition, the closed orbit is the same as the ones given in Ref. [34], the upper elastic interface has no influence on the photodetachment of the negative ion. On the other hand, if $Z_{max} > d_2$, the electron can hit the upper interface and return back to the origin as can be seen from Fig. 4(b). Therefore, the peorid and action of the closed orbit can be described as follows:

$$T = \begin{cases} 2\int_0^{z_{max}} \frac{1}{P_z}\mathrm{d}z, & Z_{max} < d_2, \\ 2\int_0^{d_2} \frac{1}{P_z}\mathrm{d}z, & Z_{max} \ge d_2, \end{cases} \quad 0 < E \le E_c, \quad (6a)$$

$$S = \begin{cases} 2\int_0^{z_{max}} P_z\mathrm{d}z, & Z_{max} < d_2, \\ 2\int_0^{d_2} P_z\mathrm{d}z, & Z_{max} \ge d_2, \end{cases} \quad 0 < E \le E_c. \quad (6b)$$

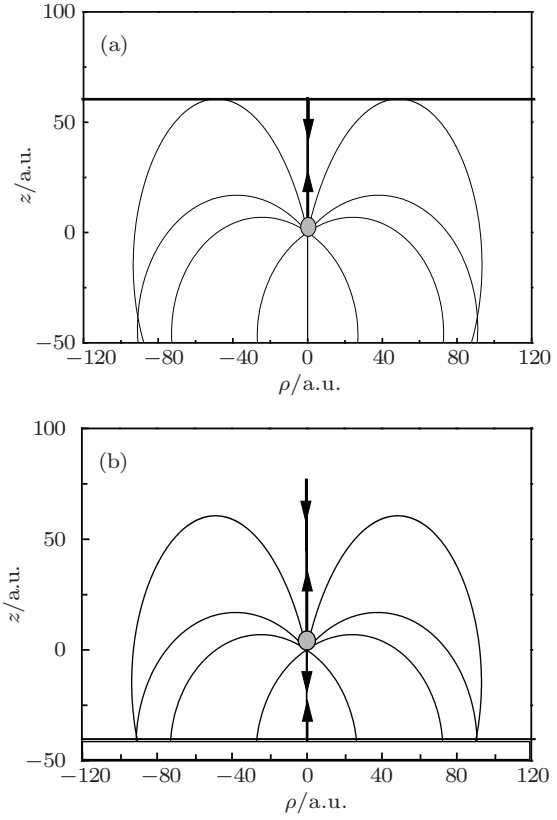



**Fig. 2.** A family of the detached electron trajectories between a metalic sphere surface and an elastic interface, with the detached electron energy $E = 0.046$ eV, the radius of the sphere $R = 500$ a.u. and the ion-sphere surface distance $d = 50$ a.u. in the cases where (a) the elastic interface is located in the upper half space, with the ion-interface distance $d_2 = 55$ a.u. and (b) the elastic interface is located in the lower half space, with the ion-interface distance $d_3 = 40$ a.u.

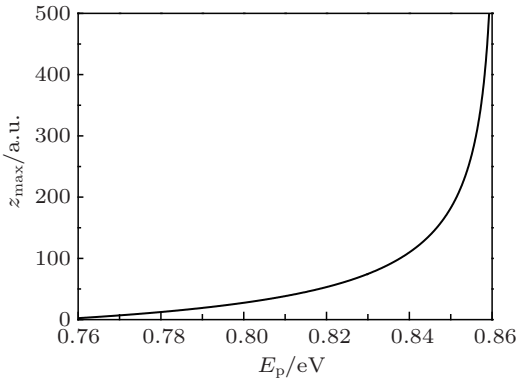



**Fig. 3.** Maximal distance the detached electron can reach along the $+z$ axis versus the distance between the elastic interface and $H^-$ ($E_p$ (eV)) when the energy of the detached electron is less than $E_c$. The distance between the interface and the ion and the ion-surface distance are both fixed to be 50 a.u. and the radius of the sphere is $R = 500$ a.u.

When the detached-electron energy $E$ is larger than $E_c$, the electron momentum $p_z$ is always greater than zero as the electron moves along the $+z$ direction, hence no closed orbit appears when the elastic interface is absent. But when there is an elastic interface that is perpendicular to the $+z$ axis, the electron can hit the upper interface as it travels along the $+z$ direction. After bouncing back by the interface, it returns to the origin and forms a closed orbit. Under this condition, the period and action of the closed orbit can be described by the following formula:

$$T = 2\int_0^{d_2} \frac{1}{P_z}\mathrm{d}z, \quad E \geq E_c, \tag{7a}$$

$$S = 2\int_0^{d_2} P_z \mathrm{d}z, \quad E \geq E_c. \tag{7b}$$

Maslov index is related to the topological structure of the trajectory manifold and can be obtained simply by counting the singular points, such as caustics and foci, along the trajectory.[41] For the current system, the Maslov index can easily be found by counting the returning points and $\mu = 1$.

Using Eqs. 6(a), 6(b) and 7(a), 7(b), we caculate the period and action for the detached electron near a metallic sphere surface when the elastic interface is perpendicular to the $+z$ axis. The results are shown in Fig. 5. The ion-sfurface distance $d = 50$ a.u. and the radius of the sphere $R = 500$ a.u. From this figure, we find that as the distance between the elastic interface and the metallic sphere surface varies from 100 a.u. to 1000 a.u., the period $T$ and the action $S$ change accordingly. When the distance between the ion and the elastic interface is fixed $d_2$=100 a.u., because of $Z_{max} > d_2$, the detached electron will be bouced back to the origin in a little time and the period $T$ and the action $S$ are both small. But with the increase of the distance between the ion and the elastic, the period $T$ and the action $S$ are enlarged because of the attraction of the elastic interface.

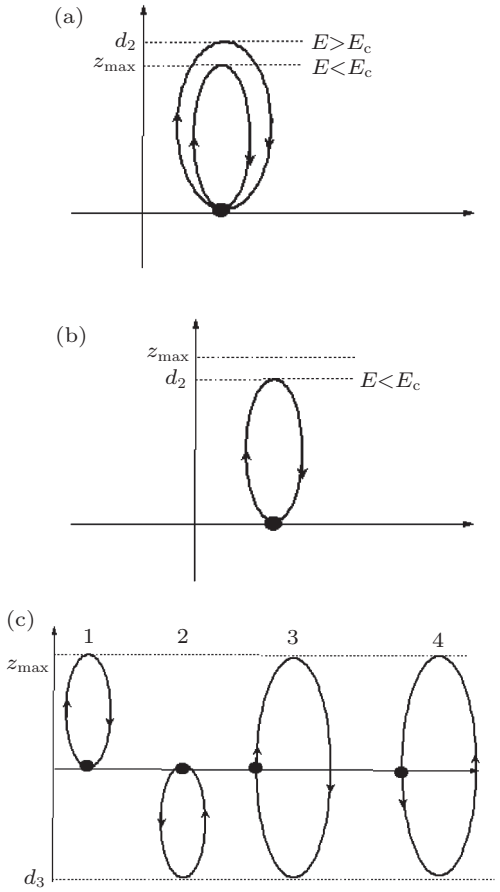



**Fig. 4.** Closed orbits for the detached electron between a metalic sphere surface and an elastic interface in the cases where (a) the elastic interface is located in the upper half space and $d_2 > z_{max}$, (b) the elastic interface is located in the upper half space and $d_2 < z_{max}$, and (c) the elastic interface is located in the lower half space.

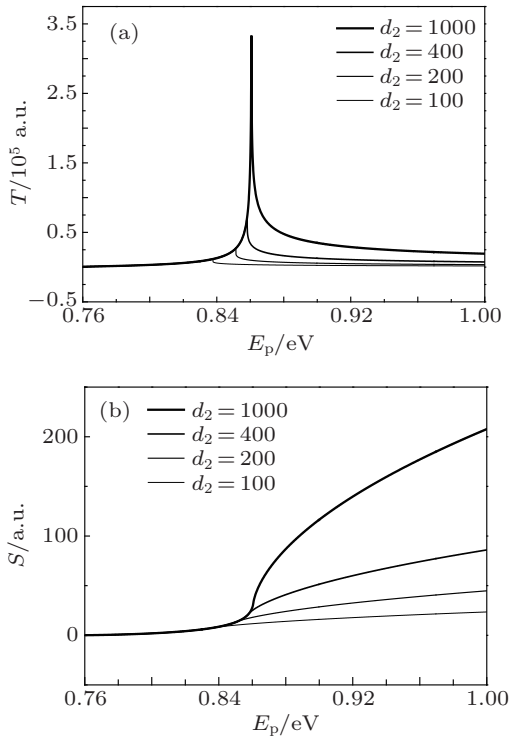



**Fig. 5.** Variations of period (a) and action (b) of the photo-detached electron with the distance between the elastic interface and $H^-$ ($E_p$ (eV)). The elastic interface is located in the upper half space.

**Case 2 Elastic interface located in the lower half space**

As the elastic interface is located in the lower half space ($z < 0$), the detached electron motion is similar to that described in Case 1 and the closed orbits are still along the $z$ axis. However, the number of the closed orbits is increased. The closed orbits along the $+z$ axis and the $-z$ axis can both exist. If the detached electron goes up along the $+z$ direction, it will always feel a downward force caused by the metallic spherical surface, so it can be drawn back by the electrostatic potential of the metallic sphere to the origin. This orbit is the same as that in the case where only a metallic sphere surface exists. As the detached electron goes down along the $-z$ direction, after bouncing back by the interface, it returns to the origin and forms a closed orbit. In Fig. 2(b), we show a family of photo-detached electron trajectories near a metallic sphere surface when the elastic interface is perpendicular to the $-z$ axis. The closed orbits are marked by bold black lines in the figure. From this figure, we find four fundamental closed orbits. The four fundamental closed orbits are similar to the ones described in Ref. [42]. They are described as follows. (i) The electron goes up along the $+z$ direction, reaches its maximum and then bounces back by the electrostatic potential of the metallic sphere to the origin. We call this orbit the up orbit. (ii) The electron goes down along the $-z$ direction, reaches its minimum, after bouncing back by the lower elastic interface and finally returns to the origin. We call this orbit the down orbit. (iii) The electron first completes the up orbit and then passes through the origin, and continues to complete the down orbit. (iv) This orbit is similar to the one of the item (iii) above but in reverse sequence, the electron completes the down orbit first and then the up orbit. The above four fundamental closed orbits are shown in Fig. 4(c) for clarity.

The period of the above four closed orbits can be described by the following formula:

$$\begin{cases} T_1 = 2\int_0^{z_{\max}} \dfrac{1}{P_z} dz, \\ T_2 = 2\int_0^{-d_3} \dfrac{1}{-P_z} dz, \\ T_3 = T_4 = T_1 + T_2. \end{cases} \tag{8}$$

The actions of the above four closed orbits are described as

$$\begin{cases} S_1 = 2\int_0^{z_{\max}} P_z dz, \\ S_2 = 2\int_0^{-d_3} -P_z dz, \\ S_3 = S_4 = S_1 + S_2, \end{cases} \tag{9}$$

where $d_3$ is the distance between $H^-$ and the elastic interface.

For the current case, the Maslov indices of the above four closed orbits are $u_1 = 1$, $u_2 = 2$, $u_3 = u_4 = 3$.

## 3. Photodetachment cross section

For our system, the same procedure as that given in the derivation of the photodetachment cross section of $H^-$ near a metallic sphere can be used.[34] For simplicity, we only briefly summarize the results. According to the closed orbit theory, the photodetachment cross section of $H^-$ between an elastic interface and a metallic sphere can be divided into two parts:

$$\sigma\left(E_{\rm ph}\right) = \sigma_0\left(E_{\rm ph}\right) + \sigma^{\rm osc}\left(E_{\rm ph}\right), \tag{10}$$

where $\sigma_0\left(E_{\rm ph}\right)$ is the smooth background term of the photodetachment cross section of $H^-$ in free space[43] and expressed as

$$\sigma_0(E_{\rm ph}) = \frac{16\sqrt{2}B^2\pi^2(E_{\rm ph} - E_{\rm b})^{3/2}}{3cE_{\rm ph}^3}. \tag{11}$$

With $B$ being a normalization constant, i.e., $B = 0.31522$, $c$ is the speed of light with a value 137 a.u., $E_{\rm ph}$ is the photon energy, $E_{\rm ph} = E + E_{\rm b}$, with $E_{\rm b}$ being the binding energy of the detached electron which is approximately 0.754 eV.

$\sigma^{\rm osc}\left(E_{\rm ph}\right)$ is the oscillating term corresponding to the returning wave of the detached electron, which is given by Ref. [3] as follows:

$$\sigma^{\rm osc}\left(E_{\rm ph}\right) = \frac{8\pi^2B^2\sqrt{2(E_{\rm ph} - E_{\rm b})}}{cE_{\rm ph}^3} \times \sum h(j)\frac{1}{T_j}\sin\left(S_j - \mu_j\frac{\pi}{2}\right), \tag{12}$$

where the summation runs over all the detached electron closed orbits. $T_j$, $S_j$ and $\mu_j$ are the period, action and the Maslov index of the $j$-th closed orbit; $h(j)$ is the sign factor. For the up and down closed orbits, $h = -1$; while for the other closed orbits, $h = 1$. Since the detached electron closed orbits for the elastic interface in the upward half space and in the downward half space are different, therefore, we give the formulas for calculating the photodetachment cross sections according to the position of the elastic interface separately.

**Case i Elastic interface located in the upper half space**

Under this conditon, there is only one closed orbit, which is along the $+z$ axis, thus the oscillating term in the photodetachment cross section can be described as follows:

$$\sigma^{\rm osc}(E) = \frac{8\pi^2B^2\sqrt{2E}}{c(E_{\rm b} + E)^3T}\cos(S). \tag{13}$$

Therefore, the total photodetachment cross section can be formulated as follows:

$$\sigma\left(E_{\rm ph}\right) = \sigma_0\left(E\right) + \frac{8\pi^2B^2\sqrt{2(E_{\rm ph} - E_{\rm b})}}{cE_{\rm ph}^3T}\cos(S). \tag{14}$$

The values of period $T$ and action $S$ of the closed orbit are given by Eqs. (6a), (6b), and (7a), (7b) respectively.

**Case ii Elastic interface located in the lower half space**

As the elastic interface is located in the lower half space, there are four fundamental closed orbits along the $z$ axis; therefore, the total photodetachment cross section can be described as follows:

$$\sigma\left(E_{\rm ph}\right) = \sigma_0\left(E\right) + \frac{8\pi^2 B^2\sqrt{2(E_{\rm ph}-E_{\rm b})}}{cE_{\rm ph}^3} \times \sum_{j=1}^{4} h(j)\frac{1}{T_j}\sin\left(S_j - \mu_j\frac{\pi}{2}\right). \quad (15)$$

The values of period $T_j$, action $S_j$ and the Maslov index $\mu_j$ of each closed orbit are given by Eqs. (6a), (6b) and (7a), (7b), respectively.

## 4. Results and discussion

Firstly, we calculate the photodetachment cross section of $H^-$ with the elastic interface located in the upper half space. In our calculations, the distance between $H^-$ and the metalic sphere surface is fixed, $d = 50$ a.u. The radius of the metallic sphere is $R = 500$ a.u. Using Eq. (14), we calculate the photodetachment cross sections of $H^-$ for different values of the distance between the elastic interface and $H^-$. The results are given in Fig. 6. The dashed line denotes the cross section of $H^-$ near a metallic sphere without the elastic interface, which is given for comparison. Figure 6(a) shows the variation of cross section with the distance between the elastic interface and $H^-$ ($E_{\rm p}$ (eV)) for the case of the distance between the elastic interface and $H^-$ $d_2 = 10000$ a.u. Under this condition, the cross section is similar to that in the case without the elastic interface, and the influence of the elastic interface can be neglected. As the distance between the elastic interface and $H^-$ decreases, the difference in cross section between with and without the elastic interface becomes apparent. Figure 6(b) shows the case of the distance between the elastic interface and $H^-$ $d_2 = 2000$ a.u. We find that when the energy of the electron is less than 0.86 eV, which is just the critical energy, the oscillation existing in the cross section with the elastic interface is just like that in the case without the elastic interface. However, when the energy of the electron is greater than 0.86 eV, there are some differences between them. The oscillation existing in the cross section with the elastic interface becomes obvious. As the distance $d_2$ further decreases, the oscillation of the cross section of our system becomes much more complex. But the influence of the elastic interface on the cross section is restricted only in the energy region $E > E_{\rm c}$, which can be seen from Figs. 6(b)–6(c). The reason can be interpreted as follows. From Fig. 3, we find that the maximum height that the electron can reach along the $+z$ axis is $z_m = 500$ a.u. as the energy of the detached electron $E$ is in the range $0 < E < E_{\rm c}$. In Figs. 6(a)–6(c), the distances between the elastic interface and $H^-$ are all larger than $z_{\rm max}$; therefore, the electrons are turned back by the electrostatic potential rather than the elastic interface, thus the influence of the elastic interface can be neglected as the energy $E$ is in the range $0 < E < E_{\rm c}$. When the distance between the elastic interface and $H^-$ is smaller than $z_{\rm max}$, the electron can reach the elastic interface before it turned back to the origin, even in the energy range $0 < E < E_{\rm c}$, therefore, the influence of the elastic interface becomes significant as the distance between the elastic interface and $H^-$ $d_2 < z_{\rm max}$, which can be seen from Figs. 6(d)–6(f). From Figs. 6(d)–6(f), we also find that with the decrease of the ion-interface distance, the oscillation amplitude increases obviously. The reasons are as follows. Becauses of $d_2 < z_{\rm max}$, when the detached electrons leave the origin and moves along the $+z$ axis, some electrons will be bounced back by the elastic interface before their momenta reach zero. Since the elastic interface prevents the detached electron from moving further, the period of the closed orbit becomes shorter. The shorter the period of the closed orbit, the larger the ocillating amplitude becomes.

Next, by using Eq. (15), we calculate the photodetachment cross section of $H^-$ with the elastic interface that is located in the lower half space, the elastic interface is located at $z = -d_3$. The results are shown in Fig. 7. In our calculations, the distance between $H^-$ and the metalic sphere surface is $d = 200$ a.u. and the radius of the sphere surface is $R = 500$ a.u. The dashed line represents the cross section of $H^-$ near a metallic sphere without the elastic interface. Figure 7(a) shows the cross section with the distance between the elastic interface and $H^-$ $d_3 = 180$ a.u. From this figure, we find that the difference in oscillation of cross section between the cases with and without the elastic interface becomes apparent. With the decrease of the distance between the elastic interface and the $H^-$, the oscillating amplitude becomes increased greatly, as we can see from Figs. 7(a)–7(d) clearly. The reasons are as follows. When the detached electron moves along the $-z$ axis, it will hit the elastic interface and reflect back to the origin. Although the elastic interface has no influence on the up orbit, it will affect the down orbit all the time. As the distance between the elastic interface and $H^-$ becomes shorter, the period of the down orbit also becomes shorter, so do the third and the fourth closed orbits. According to the closed orbit theory, the oscillation of the cross section is caused by the interference between the returning waves and the outgoing waves. The shorter the period of the closed orbit, the more the returning waves return back to the origin. Therefore, their contribution to the cross section becomes significant. Besides, by comparing Fig. 6 and Fig. 7, we find that the influence of the elastic interface becomes much more significant when it is located in the lower half space rather than in the upper half space.

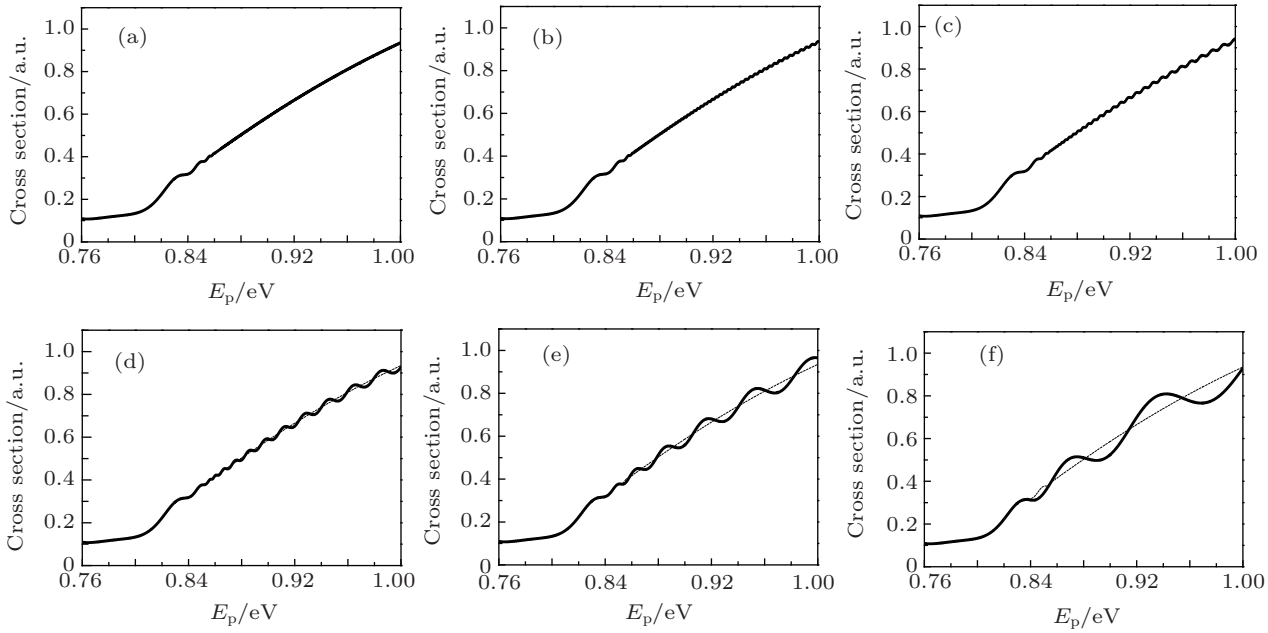



**Fig. 6.** Photodetachment cross section of $H^-$ between a metalic sphere surface and an elastic interface. The elastic interface is located in the upper half space. The radius of the sphere is $R = 500$ a.u. and the ion-sphere surface distance is $d = 50$ a.u. The darker solid line represents the photodetachment cross section of our system, while the dashed line denotes the cross section near a metallic sphere surface without the elastic interface. The distances between the ion and the elastic interface are (a) $d_2 = 10000$ a.u., (b) $d_2 = 2000$ a.u., (c) $d_2 = 1000$ a.u., (d) $d_2 = 400$ a.u., (e) $d_2 = 200$ a.u., and (f) $d_2 = 100$ a.u.

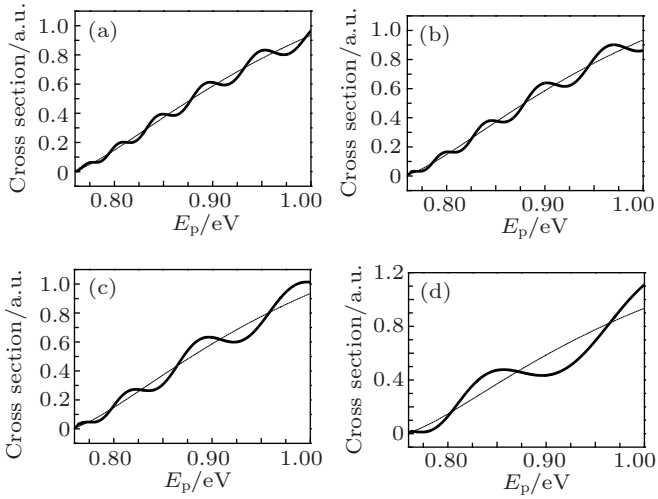



**Fig. 7.** Photodetachment cross section of $H^-$ between a metalic sphere surface and an elastic interface, with the elastic interface located in the lower half space. The radius of the sphere is $R = 500$ a.u. and the ion-sphere surface distance is $d = 200$ a.u. The darker solid line represents the photodetachment cross section of our system, while the dashed line denotes the cross section near a metallic sphere surface without the elastic interface. The distances between the ion and the elastic interface are (a) $d_3 = 180$ a.u., (b) $d_3 = 150$ a.u., (c) $d_3 = 100$ a.u., (d) $d_3 = 50$ a.u.

## 5. Conclusion

Based on the closed orbit theory, we studied the influence of an elastic interface on the photodetachment of $H^-$ near a metallic sphere surface. It is found that the photodetachment cross section of $H^-$ varies with the distance between the elastic interface and $H^-$. With the decrease of the distance between the elastic interface and $H^-$, the oscillating amplitude of the cross section becomes strengthened. However, the mechanisms for strengthening the oscillations are different for the elastic interface located in different spaces. When the elastic interface is located in the upper half space ($z > 0$), the interface can strengthen the oscillations by extending the detached electron energy range and shortening the period and the action of the closed orbit. When the elastic interface is located in the lower half space ($z < 0$), the interface can strengthen the oscillations by increasing the total number of closed orbits. Besides, our study suggests that the influence of the elastic interface becomes much more significant when it is located in the lower half space rather than in the upper half space. We hope that our work is conducive to the understanding of the photodetachment process of negative ions near interfaces, cavities and ion traps.

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