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Short Communication

Importance of atomic physics in verification of experimental results and diagnostics of solar and astrophysical observations

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Abstract

Accurate results are needed to confirm the experimental results of various atomic processes and analyze the solar and astrophysical observations of intensities of emission lines to infer plasma parameters like electron density, electron temperature and element abundance. A number of theories have been developed over the years to calculate phase shifts when electrons and positrons are scattered from targets. We discuss in this article the recent hybrid theory which has been applied to scattering processes, resonances and photoabsorption process, which is a bound-free transition.

Introduction

During the last six decades, a number of satellites were launched to study the Sun and other astrophysical objects. A large number of observations were made to record the intensities of various lines from solar flares. From these observations, various elements, their excited states and their abundance can be determined. However, this kind of diagnostic is possible only if atomic physics is sufficiently developed. There are various approaches employed to study the scattering of electrons and positrons from targets, and excitation of various levels. Very important and versatile computer codes like Superstructure, Distorted wave approximation and R-matrix approach were developed at the University College London and Queen's University in Belfast [1]. All this was possible because of the discovery of the electron by J. J. Thompson in 1897 and the discovery of the atomic nucleus by E. Rutherford in 1911 by bombarding alpha particles on atoms. In 1912, Bohr proposed a model of the hydrogen atom. Without these important developments, the above-mentioned computer codes, useful for the study of many-electron systems, could not have been developed.

Results

For understanding, it is necessary to study simple systems like electron-hydrogen or positron-hydrogen. The earliest calculation is the exchange approximation calculation by Morse and Allis [2] carried out in 1933, assuming that the nucleus is of infinite mass and is fixed. Using a simple target like a hydrogen atom, it is possible to judge the accuracy of any approximation to calculate the scattering phase shifts and cross sections because the target wave function s known exactly. I have developed a theory called the hybrid theory [3]. In this theory, short-range and long-range correlations are included, exact polarizability is obtained in this formalism and the proposed theory is variationally correct. This implies that the calculated phase shifts have lower bounds, i.e., they are always below the exact phase shifts. The hybrid theory is a modification of the theory of Temkin called the method of polarized orbitals [4]. In Table 1, we give the phase shifts calculated in the above-mentioned theories.

$^{a}k=0$ results represent the scattering lengths.

The scattering length a, mentioned in the above table, is defined as

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$$\lim(k \to 0)k \cot \eta = -1 / a. \quad (1)$$

It was suggested by Wildt [5] that the opacity (loss of or absorption of photons) in the atmosphere of the Sun is due to the photodetachment of negative ion

$$h\nu + H^{-} \to e + H. \quad (2)$$

The cross sections, calculated in the length form and in the dipole approximation [6], are given in Table 2.

Cross sections for the photoionization of He, calculated using the hybrid theory, agreed with those obtained using the *R*-matrix theory [7] and the experimental results [8]. These results are shown in Table 3. A detailed account of photoabsorption is given in [9].

Excitation cross sections by electron impact [10] and positron impact [11] have been carried out because the initial wave function can be obtained accurately using the hybrid theory [5]. Parameters of Feshbach resonances or doubly excited states have also been calculated by determining phase shifts in the resonance region using the hybrid theory [12], and then using the well-known Breit-Wigner, relating the calculated phase shifts to the resonance parameters. In the projection operator formalism, the interaction of the discrete state with the continuum state has to be calculated separately. In the calculation mentioned above, it is automatically included. The opacity of the Sun and of the interstellar medium have been studied using hybrid theory by including not only the photodetachment cross sections of H^- and Ps^- but also free-free transitions of electrons and positrons in H and Ps. It is known that positron processes take place in the Sun [13]. In addition to the photoabsorption of H^- indicated in Eq. (2), we indicate below processes involving photodetachment of Ps^- and free-free transitions of electrons and positrons with hydrogen

$$h\nu + e^{-} + H \to e^{-} + H \quad (3)$$

$$h\nu + Ps^{-} \to e^{-} + Ps \quad (4)$$

$$h\nu + e^{+} + H \to e^{+} + H \quad (5)$$

Bound-free and free-free cross sections to determine the opacity of the Sun are given in [14].

Table 1: Electron-hydrogen singlet and triplet phase shifts (radians) for S-wave scattering.

k	PO	Hybrid theory	PO	Hybrid theory
	Singlet		Triplet	
[a]0	5.8	6.00092	1.9	1.900
0.1	2.553	2.55372	2.949	2.93856
0.2	2.144	2.06699	2.732	2.71751
0.3	1.750	1.69853	2.519	2.49987
0.4	1.469	1.41561	2.320	2.29465
0.5	1.251	1.20112	2.133	2.10544
0.6		1.04110		1.93322
0.7	0.930	0.93094	1.815	1.77998
0.8	0.853	0.88768	1.682	1.64425

Table 2: Photodetachment cross section (Mb) of H^-.

k	Cross section	k	Cross section
0.1	15.3024	0.5	16.0858
0.2	38.5443	0.6	10.7410
0.3	36.2318	0.7	7.4862
0.4	24.4774	0.8	5.6512

Table 3: Photoionization cross sections (Mb) of He.

K	Hybrid theory [5]	R-Matrix [7]	Experiment [8]
0.1	7.3300	7.295	7.44
0.2	7.1544	7.115	7.13
0.3	6.8716	6.838	6.83
0.4	6.4951	6.474	6.46
0.5	6.0461	6.006	6.02
0.6	5.5825	5.535	5.95
0.7	5.0120	4.995	5.04
0.8	5.4740	4.482	4.51
1.0	3.4654	3.476	3.48
1.1	3.0206	3.023	3.00
1.3	2.2561	2.271	2.19
1.2	1.9821	1.943	1.89

Conclusion

In this short article, we have indicated that there are various formulations to calculate scattering and photoionization cross sections. The results obtained using the hybrid theory agree well with those obtained using the close-coupling and R-matrix formulations, which are known to give accurate results for atomic and molecular processes. The photoabsorption cross-sections obtained agree not only with other theoretical results but also with the experimental results. Some of the results using the hybrid theory have been used to study the opacity of the Sun. Detailed discussions can be found in references [1,9].

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