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ASSESSMENT OF PROTON-IMPACT EXCITATION RATE-COEFFICIENT DATA OF RELEVANCE TO THE SOHO MISSION

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Calculations of proton-impact fine-structure excitation of the Be- to Cl-like ions for elements from C to Ni are compiled and assessed, in line with the exercise recently carried out for electron-impact excitation data relevant to the analysis of experiments on the Solar and Heliospheric Observatory (SOHO) spacecraft and published in this journal [Vol. **57,** Nos. 1/2 (1994)]. References for individual transitions are presented in tabular form for each isoelectronic sequence considered, together with their estimated relative accuracy.

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INTRODUCTION

In the study of astrophysical and laboratory plasmas, it is important that accurate atomic data are available, e.g., to facilitate the analysis of emission lines in order to estimate plasma temperatures and densities. Excitation in plasmas is generally caused by both electrons and protons. Seaton [1] established that the proton cross sections will exceed the electron cross sections when the impact energy is in excess of the excitation energy, and it is for this reason that protons play an important role in fine-structure excitation in, for example, the solar corona. Hence accurate data are required for proton-induced fine-structure transitions,

$$\mathrm{H}^+ + X_J^{Z+} \rightarrow \mathrm{H}^+ + X_{J'}^{Z+}, \qquad (1)$$

where X^{Z+} denotes an ion with net charge Z.

Several theoretical models, both semiclassical and quantal, have been used in the study of such fine-structure transitions. In the case of semiclassical calculations, either first-order approximations or close-coupling approximations have been used. In the former, it is considered that, at low energies, collisions at all impact parameters are weak due to Coulomb repulsion between the colliding particles. In the semiclassical close-coupling approximations, the transition probabilities are determined by means of the numerical solution of coupled differential equations, thereby removing the need for first-order approximations and hence the uncertainty in the intermediate energy range. Quantal close-coupling calculations are potentially more accurate than, and hence provide insight into the reliability of, their semiclassical counterparts. The aim of this paper is to assess the different treatments and to compile a list of the available data together with their accuracy estimates, perhaps highlighting areas where accurate calculations may be required in the future. A similar exercise has been carried out previously for electron excitation data [2]. It is envisaged that this compilation of atomic data will be used to analyze spectra from the outer regions of the solar atmosphere obtained by the CDS (Coronal Diagnostic Spectrometer) and SUMER (Solar Ultraviolet Measurements of Emitted Radiation) experiments onboard the ESA/NASA Solar and Heliospheric Observatory (SOHO) spacecraft, launched in November 1995. The paper is not intended to serve as a review article of the various theoretical methods which have been developed, this having been more than adequately covered previously [3, 4]. However, details of individual treatments will be included, as required. Also, we should point out that throughout this review, when describing the formulation of the collision, we use the terms ''semiclassical'' and ''impact-parameter'' synonymously, meaning that the motion of the proton relative to the ion is described by a classical trajectory while the electronic states of the ion are treated quantally, even though this is not strictly the preferred usage of ''semiclassical'' in atomic physics.

The layout of the report is as follows. A separate

section is devoted to each of the isoelectronic sequences for which data are required by the CDS/SUMER experiments. Atoms and ions whose spectral lines lie in the wavelength range of CDS or SUMER, or both, can be found in the electron excitation data publication [2]. As in that publication, lines from ions heavier than nickel are not included here, due to their low solar abundances. For each transition, the various calculations are collated in tabular form. Regarding our assignment of uncertainty limits to the various calculations, we would caution that estimation of the accuracy of computations is notoriously difficult. Authors tend to give estimates that refer to numerical reliability, to sensitivity with respect to parameters within the framework of their model, and to sensitivity with respect to one aspect of their model compared with different models. There is no guarantee that a new model which more completely describes the physics will not give surprisingly different results. Also, in the present data tabulations, it is likely that the accuracy will be impact-energy (i.e., temperature) dependent, with greater accuracy pertaining in the low energy/temperature region of each calculation. We have adopted the approach of putting the data into bands of uncertainty: A $\leqslant$ 3%; B $\leqslant$ 10%; C $\leqslant$ 25%; D $\leqslant$ 50%; E $>$ 50%. In practice, we have not placed any data in band A or band E.

Beryllium-like Ions

Various calculations of proton-impact excitation cross sections and rate coefficients for positive ions in the beryllium isoelectronic sequence have been carried out for the $J = 0 \rightarrow 1$, $0 \rightarrow 2$, and $1 \rightarrow 2$ transitions between the levels of the $2s2p\,^3P^o$ and $2p^2\,^3P$ terms. The method of Landman and Brown [5] adapts the theory of semiclassical nuclear Coulomb excitation to the ionic problem. The symmetrized Schrödinger equation is integrated directly to give the differential cross section for $i \rightarrow f$ transitions $(d\sigma/d\omega)_{if}$ for deflection angles $\theta \leqslant \theta_0$, where θ_0 is the value for which the proton–ion distance of closest approach is equal to the ionic ''radius'' $\langle r \rangle_{2p}$. For collisions with $\theta > \theta_0$, corresponding to impact parameters less than b_0, the transition probability P_{if} is taken to be its value at b_0. Hence the total cross section is

$$\sigma_{if} = 2\pi \int_0^{\theta_0} \left(\frac{d\sigma}{d\omega}\right)_{if} \sin\theta \, d\theta + \frac{v_i}{v_f} P_{if}(b_0)\pi b_0^2, \quad (2)$$

where v_i (v_f) is the relative proton–ion speed when the ion is in state i (f). A significant feature in the method of Landman is the inclusion of intermediate coupling, rather than pure *LS*-coupling, in the description of the ionic states. In Ref. [5], rate coefficients are given for the fine-structure transitions among the levels of the $2s2p\,^3P^o$ term for selected ions between C III and Ca XVII. Rate coefficients are also calculated for the $2p^2\,^3P_J$ fine-structure transitions for C III, which are found, as expected, to be very similar to the corresponding $2s2p\,^3P^o$ rate coefficients.

Doyle et al. [6] have used the close-coupling impact-parameter method of Reid and Schwarz [7] to calculate proton excitation rate coefficients for fine-structure transitions in the $2s2p\,^3P^o$ and $2p^2\,^3P$ levels of the ions C III, O V, and Ne VII, using a form which ensures the interaction remains physically reasonable when the proton penetrates the ion's cloud and hence accounts for short-range interactions. They estimate that any error in the rate coefficients arises from the uncertainties in the cross sections due to this electron-cloud penetration, and hence the error in the rate coefficients for all transitions should be less than 1% for temperatures below 10^6 K, while for O V and Ne VII, at temperatures up to 10^7 K the error in the $J = 0 \rightarrow 2$ and $1 \rightarrow 2$ transitions is about 3%, rising to 10% for the $J = 0 \rightarrow 1$ transition.

The subsequent publication of Doyle [8] contains proton excitation cross sections and rate coefficients for the fine-structure transitions within the $2s2p\,^3P^o$ multiplet in the beryllium-like ions C III, N IV, O V, F VI, Ne VII, Mg IX, Si XI, S XIII, Ar XV, Ca XVII, and Fe XXIII, again using the semiclassical close-coupling method developed by Reid and Schwarz [7]. In the case of rate coefficients, the error estimates are in line with those of Doyle et al. [6], with an overall error of about 5% for all the transitions considered.

Malinovsky [9] has applied the method of Sahal-Bréchot [10] to O V. This method is based on the first-order semiclassical perturbation theory with the cutoff of Seaton [2], with a modification made to the cutoff procedure by comparing the cross sections calculated by this method with the exact ones calculated by Masnou-Seeuws and McCarroll [11] using a semiclassical close-coupling treatment. Malinovsky has estimated an accuracy of 20% in the results for O V, although it is considered that, while adequate for the $J = 0 \rightarrow 2$ and $1 \rightarrow 2$ transitions, the method of Sahal-Bréchot is inappropriate for the $J = 0 \rightarrow 1$ transition, where a close-coupling approximation is required. Similarly, first-order semiclassical theory has been used by Bhatia et al. [12] and Feldman et al. [13], who have used the method of Kastner [14] (see the following section) to calculate excitation rate coefficients for Ti XIX, Cr XXI, Fe XXIII, and Ni XXV.

Boron-like Ions

Bahcall and Wolf [15] carried out the first semiclassical close-coupling calculation for several ions in the solar corona, including the calculation of rate coefficients for the fine-structure transition $2s^2 2p\,^2P^o_{1/2\rightarrow 3/2}$ in the boron-like ions C II and N III. Due to the computing power then available, the integration of the close-coupling equa-

tions was performed only at several proton energies for each ion; the remaining values were obtained by means of a curve-fitting routine, which, while perhaps suitable at intermediate energies, is considered inappropriate at high energies.

The first-order semiclassical calculation of Bely and Faucher [16], based on the semiclassical approach of Alder et al. [17], has produced proton-impact excitation rate coefficients for 15 ions in the boron isoelectronic sequence for which the error estimate starts at about 50% for the first ions in the sequence and improves for more highly charged ions. On comparison with the results of Bahcall and Wolf [15] for C II, Bely and Faucher find their own results to be about 30% higher. This is thought to be due to a difference in the values of $\langle r^2 \rangle$ used in the Bahcall–Wolf method, where $\langle r^2 \rangle$ is the mean-square radius of the ion's $2p$ electron.

First-order impact-parameter calculations have also been carried out by Flower and Nussbaumer [18] for O IV, by Nussbaumer and Storey [19] for N III, and by Hayes and Nussbaumer [20] for C II. All these calculations, based on the semiclassical perturbation approximation of Sahal-Bréchot [21], have produced proton collision rate coefficients for transitions among the levels of both the $2s^2 2p\ ^2P^o$ and $2s2p^2\ ^4P$ terms of the respective ions. Similarly, Kastner [14] has developed a comparatively simple first-order impact-parameter approximation to calculate excitation rate coefficients for the $2s^2 2p\ ^2P^o_{1/2\rightarrow 3/2}$ transition in Fe XXII. This technique, subsequently corrected and extended by Kastner and Bhatia [22], has been used by Bhatia et al. [12] to calculate excitation rate coefficients for transitions within the $2s^2 2p\ ^2P^o$, $2s2p^2\ ^4P$, $2s2p^2\ ^2P$ and $2p^3\ ^2P^o$ terms of Ti XVIII, and by Feldman et al. [13] for the $2s^2 2p\ ^2P^o$ and $2s2p^2\ ^4P$ terms of Cr XX and Ni XXIV.

A quantal approach to proton-induced fine-structure transitions has been taken by Heil et al. [23], who have calculated excitation rate coefficients for the $2s^2 2p\ ^2P^o$ term of O IV by adapting the quasimolecular approach of Mies [24] to Coulomb scattering. The $^2\Pi$ and $^2\Sigma$ states of the OH^{4+} molecule formed by the approach of the proton and O^{3+} are represented by self-consistent-field wave functions, which includes the effects of polarization and hence produces accurate close-coupling solutions.

The work of Foster et al. [25–27] has produced cross sections and excitation rate coefficients for fine-structure transitions within both the ground $2s^2 2p\ ^2P^o$ and the metastable $2s2p^2\ ^4P$ terms for a complete range of astrophysical and laboratory ions in the boron-like sequence [27]. Both calculations involve the close-coupling impact-parameter method of Reid and Schwarz [7], modified to include higher lying levels by means of a polarization potential. In the former case [25, 27], the $2s2p^2\ ^2S$, P, D terms were included, while in the latter [26, 27], the $2p^3\ ^4S^o$ term was included. They have found the inclusion of the polarization term to have a marked effect on the calculation, in that for low ionized species the polarization term reduces the cross sections, whereas for more highly charged ions, the result is an increase in the calculated cross sections.

Carbon-like Ions

In the case of carbon-like ions, semiclassical close-coupling calculations have been carried out for N II by Bahcall and Wolf [15], as described in the previous section, and by Masnou-Seeuws and McCarroll [11], who have calculated proton collisional cross sections for the $J = 0 \rightarrow 1$, $J = 0 \rightarrow 2$, and $J = 1 \rightarrow 2$ transitions in the $2s^2 2p^2\ ^3P$ ground term in the ions N II, O III, and Si IX. The latter authors adopt a quasimolecular formulation of the collision, with the fine-structure transitions caused by the difference between the adiabatic potentials $W_\Pi(R)$ and $W_\Sigma(R)$. They estimate an accuracy of 1% in the computed cross sections, although it should be noted that due to a sign error in their calculations, significant errors have since been detected.

Faucher et al. [28] have calculated proton excitation rate coefficients and cross sections for five ions in the carbon isoselectronic sequence using both the semiclassical method of Masnou-Seeuws and McCarroll [11] and also the quantal approach of Faucher [29] (see section on silicon-like ions). It should be noted that since the quantal calculation is computationally very costly, only a few energies are considered for each ion. Excellent agreement is found between the semiclassical and quantal close-coupling treatments. Similarly, Faucher [30] also has used the quantal method of Faucher [29] to calculate both cross sections and rate coefficients for the carbon-like ions Ca XV and Fe XXI.

A number of first-order semiclassical calculations have also been made. Mason [31] has used the method of Bely and Faucher [16] for fine-structure transitions in Ca XV (see section on boron-like ions). Her results are in good agreement with those of Faucher [30]. Kastner [14] and Kastner and Bhatia [22] have used their first-order impact-parameter treatment to calculate excitation rate coefficients for the transition $2s^2 2p^2\ ^3P_{0\rightarrow 2}$ in both Ca XV and Fe XXI. In addition, Kastner [14] has compared the calculated cross sections for the $^3P_{1\rightarrow 2}$ transition in N II with those of Masnou-Seeuws and McCarroll [11]. It is found, however, that as in the case of the aluminum-like ion Fe XIV, there is an unrealistic cusp in the Kastner results of the first-order approximation where the low- and high-energy results connect. In line with the boron-like ions, this first-order method has been subsequently adopted by Bhatia et al. [12] for the $2s^2 2p^2\ ^3P$ and

$2s2p^3\,^3P^o$ terms of Ti XVII, and by Feldman et al. [13] for the $2s^22p^2\,^3P$ term of both Cr XIX and Ni XXIII.

Nitrogen-like Ions

The work of Bhatia and co-workers [12, 13, 32] has produced proton excitation rate coefficients for transitions within the $2s^22p^3\,^2D^o$ or $2s^22p^3\,^2P^o$ term for several nitrogen-like ions. Bhatia et al. [12] and Feldman et al. [13] have used the method of Kastner and Bhatia [22] in the calculation for the ions Ti XVI, Cr XVIII, and Ni XXII, whereas Bhatia and Mason [32] have used the semiclassical first-order method of Bely and Faucher [16] for fine-structure transitions in Fe XX.

Oxygen-like Ions

Landman [33] has calculated proton-impact excitation cross sections and rate coefficients for transitions between the fine-structure levels of the $2s^22p^4\,^3P$ ground term for ions F II through S IX in the oxygen isoelectronic sequence. This semiclassical close-coupling method, based on the earlier calculations of Landman [34–36] and Landman and Brown [5], involves the direct integration of the symmetrized Schrödinger equation (see Eq. (2)) and again includes the effects of intermediate, rather than pure *LS*, coupling.

A number of first-order impact-parameter calculations have also been carried out for oxygen-like ions. As described previously, Kastner [14] and Kastner and Bhatia [22] have calculated excitation rate coefficients for the $2s^22p^4\,^3P_{2\to0}$ transition in Ca XIII, with an estimated error in the region of 50%. This method has also been used by Bhatia et al. [12] for Ti XV and by Feldman et al. [13] for the ions Cr XVII, Fe XIX, and Ni XXI.

Fluorine-like Ions

Several semiclassical calculations, both first-order and close-coupling, have been performed for ions in the fluorine isoelectronic sequence. In the case of first-order impact-parameter calculations, the method of Bely and Faucher [16] has produced excitation rate coefficients for 15 fluorine-like ions, in line with their work on boron-like ions, and again with an error estimate in the region of 50%. In addition, Kastner [14] and Kastner and Bhatia [22] have produced rate coefficients for the $2s^22p^5\,^2P^o_{3/2\to1/2}$ transition in Fe XVIII, and their method has been used by Feldman et al. [13] and Bhatia et al. [12] for calculations involving the fluorine-like ions Ti XIV, Cr XVI, Fe XVIII, and Ni XX.

The close-coupling impact-parameter method of Reid and Schwarz [7] has been used by several authors to calculate both proton collisional excitation cross sections and rate coefficients for the $2s^22p^5\,^2P^o_{3/2\to1/2}$ transition in fluorine-like ions. Keenan and Reid [37, 38] and Keenan et al. [39] have all based their calculations on this method, where they have aimed for an accuracy of 10% and so do not consider aspects such as polarization effects, symmetrization of coupled equations, or departures from *LS*-coupling. They find significant differences with several first-order calculations. For instance, in the case of Fe XVIII [37], their results are a factor of 2.5 smaller than those of Kastner and Bhatia [22], whereas for Ti XIV [38, 39], their results are a factor of five smaller at low temperatures and up to 60% smaller at high temperatures than those of Bely and Faucher [16].

Keenan and Reid [40] have also developed this method to incorporate symmetrization with respect to channel velocities for the $2s^22p^5\,^2P^o_{3/2\to1/2}$ transition in both Fe XVIII and Ni XX. In a further development, Foster et al. [41, 42] have improved the accuracy of the calculations by considering both symmetrization and polarization effects, whereby they have included the $2s2p^6\,^2S$ state by means of a polarization potential. The inclusion of such factors has resulted in a difference of 60% in the cross sections with those of Keenan and Reid [40].

Neon-like Ions

Proton collisional excitation cross sections and rate coefficients have been calculated by Landman [43] for transitions among the $2p^53s\ ^3P^o_J$ levels in the neon-like ions Na II through Ni XIX. As in the earlier work for the beryllium and oxygen isoelectronic sequences [5, 33], the calculations are performed using symmetrized semiclassical Coulomb excitation theory and by the direct integration of the truncated Schrödinger equation for electric quadrupole excitation.

Magnesium-like Ions

Two calculations have been carried out for fine-structure transitions in magnesium-like ions. Landman and Brown [5] have calculated proton-impact excitation cross sections and rate coefficients for transitions between the $3s3p\ ^3P^o_J$ fine-structure levels in a number of astrophysically important ions, namely Si III, S V, Ar VII, Ca IX, and Fe XV. Again, they have followed the semiclassical close-coupling treatment of Landman [34–36] as described previously for the beryllium-like sequence. In addition, Kastner [14] has used first-order semiclassical theory to calculate rate coefficients for $3s3p\ ^3P^o_{1\to2}$ excitation in Fe XV.

Aluminum-like Ions

Bahcall and Wolf [15] carried out the first close-coupling calculation (see section on boron-like ions) for several ions in the solar corona, including the calculation

of rate coefficients for the fine-structure transition $3s^2 3p\ ^2P^o_{1/2\to 3/2}$ in the aluminum-like ions Si II and S IV. Reid and Schwarz [7] have also used semiclassical close-coupling theory to calculate cross sections for the $J = 1/2 \to 3/2$ transition in the ground term of S IV, by solving the fully coupled impact-parameter equations, using a Coulomb trajectory for $\mathbf{R}(t)$, the proton–ion separation. Their method has formed the basis of further close-coupling approximations (see, for example, sections on boron-like and fluorine-like ions).

In contrast, Bely and Faucher [16] have used first-order semiclassical theory to calculate proton-impact excitation rate coefficients for 15 ions in the aluminum isoelectronic sequence. As in their calculations for the boron-like and fluorine-like ions, they again estimate an error in the region of 50% for the first ions in the sequence, but find the accuracy improving for more highly charged ions. On comparison with the results of Bahcall and Wolf [15] for Si II and S IV, they find agreement to within a few percent although they also find that the high energy velocity dependence predicted [15] by the (1968) close-coupling method is incorrect, a view upheld by Reid and Schwarz [7].

There have been several different calculations performed for the coronal ion Fe XIV, the first of these being the early calculation of Seaton [2], who developed an approximation based on first-order semiclassical theory, with an adaptation to allow for strong collisions. His results have been found to compare well with many subsequent calculations, and indeed the method is widely regarded as giving the correct insight into the proton–ion collision process. The subsequent treatment of Sahal-Bréchot [10] is based on the Seaton method, modified so that the cutoff is determined by comparing the cross sections with those of Masnou-Seeuws and McCarroll [11], who used semiclassical close-coupling theory to calculate cross sections for Fe XIV with an error estimate of less than 1%. Similarly, Kastner [14] and Kastner and Bhatia [22] have also used first-order semiclassical theory to calculate excitation rate coefficients for the $3s^2 3p\ ^2P^o_{1/2\to 3/2}$ transition in Fe XIV, although it should be noted that due to the absence of an approximation for intermediate energies, their cross sections have an unrealistic cusp where the high- and low-energy results merge.

Landman [34, 35] has also calculated rate coefficients for the same fine-structure transition, using a semiclassical impact-parameter treatment analogous to that of Masnou-Seeuws and McCarroll [11] and extending the analysis to include the entire ground configuration in intermediate coupling. The results for Fe XIV compare reasonably well with those of Masnou-Seeuws and McCarroll [11].

The close-coupling quantal calculation of Heil et al. [44], following on the work of Heil et al. [23] for boron-like O IV, is probably the most accurate for Fe XIV to date. They follow the quasi-molecular treatment of Mies [24] and adapt the method to allow for the Coulomb nature of the proton–ion collision. Hence by evaluating the $^2\Pi$ and $^2\Sigma$ adiabatic potentials of the colliding system, they model the interaction accurately by not only expressing the short-range term accurately, but also including the polarization term for the long-range interaction as well as the quadrupole term.

Silicon-like Ions

A number of calculations for proton-impact fine-structure transitions for ions in the silicon isoelectronic sequence have been carried out, most notably for Fe XIII.

Bahcall and Wolf [15] have carried out semiclassical close-coupling calculations for the fine-structure transitions $3s^2 3p^2\ ^3P_{J\to J'}$ in the silicon-like ion S III. As with the aluminum-like ions described previously, however, their results have been largely superseded.

Cross sections and rate coefficients have been obtained by several treatments for fine-structure transitions in the $3s^2 3p^2\ ^3P$ levels of the silicon-like Fe XIII coronal ion. Using semiclassical close-coupling theory, Masnou-Seeuws and McCarroll [11] have calculated cross sections for the fine-structure transitions $^3P_{0\to 1}$, $^3P_{0\to 2}$, and $^3P_{1\to 2}$ in Fe XIII with an estimated accuracy of better than 1%. Flower and Pineau des Forêts [45] adopted these results and, together with further values at higher incident proton energies, obtained the corresponding excitation rate coefficients. Landman [34, 35] has calculated rate coefficients for the same fine-structure transitions, using the same method as for the aluminum-like Fe XIV ion. The values obtained are somewhat smaller than those from the purely *LS*-coupled treatment of Masnou-Seeuws and McCarroll, particularly in the $^3P_{0\to 1}$ transition, where the difference is about a factor of 2.5. It should be noted, however, that this method does not allow for penetration of the ion cloud by the proton in the scattering process.

Sahal-Bréchot [10] has also applied her first-order semiclassical method for aluminum-like Fe XIV to the Fe XIII ion. The results obtained show reasonable agreement with the close-coupling results of Masnou-Seeuws and McCarroll [11], although it is thought that the $3s^2 3p^2\ ^3P_{0\to 1}$ cross section is poorly represented by the first-order method. Kastner [14] and Kastner and Bhatia [22] have also calculated rate coefficients for the $3s^2 3p^2\ ^3P_{0\to 2}$ transition in Fe XIII using first-order semiclassical theory, with an estimated error of about 50%.

A quantal approach to the close-coupling method has been taken by Faucher [29]. He calculated proton-impact excitation cross sections for the $3s^2 3p^2\ ^3P_{0\to 1}$, $^3P_{0\to 2}$, and $^3P_{1\to 2}$ transitions in Fe XIII by adapting the electron–

ion quantum collision theory of Bely et al. [46] to the proton–ion case. While such quantal calculations can model the short-range interaction more accurately, the price to be paid is a computationally more costly method. Indeed, the accuracy of the method of Faucher [29] was affected by the available computational power, with the coupled equations being solved for only some values of angular momentum l and interpolated for other l-values. In a subsequent publication, Faucher [30] has applied this quantal approach to the case of the Ni XV ion. As in the case of Fe XIII, the discrepancy between the semiclassical and quantal results for the $^3P_{0\to2}$ transition, for instance, is due to collisional coupling.

Phosphorus-like Ions

Landman [36] has calculated proton collisional excitation cross sections at solar coronal energies for the $3s^2 3p^3\,{}^2P^o$ fine-structure transitions in Fe XII, again applying the semiclassical excitation method of Landman [34, 35], whereby the symmetrized Schrödinger equation is integrated directly (see section on beryllium-like ions). Corresponding proton-impact excitation rate coefficients are also presented.

Sulfur-like Ions

As in the case of the oxygen isoelectronic sequence, cross sections and rate coefficients have been calculated by Landman [33] for transitions between the fine-structure levels of the $3s^2 3p^4\,{}^3P$ ground term for the sulfur-like ions Cl II through Ni XIII, again by applying his semiclassical impact-parameter method [5, 34–36].

For Fe XI, Bhatia and Doschek [47] have calculated rate coefficients for transitions between levels of the ground configuration, including excitation within the $3s^2 3p^4\,{}^3P$ ground term, using the formulation of Kastner and Bhatia [22] (see section on boron-like ions).

Chlorine-like Ions

Bely and Faucher [16] have used first-order semiclassical time-dependent perturbation theory, as discussed previously for the boron, fluorine, and aluminum isoelectronic sequences, to calculate fine-structure proton excitation rate coefficients for the $3s^2 3p^5\,{}^2P^o$ term of the chlorine-like ions Ar II through Ni XII. As before, they estimate their rate coefficients to be accurate to within 50% for the first ions in the isoelectronic sequence, this error estimate improving for the more highly charged ions.

In the case of the Fe X ion, Kastner [14], Kastner and Bhatia [22], and Bhatia and Doschek [48] have calculated proton excitation rate coefficients for the $3s^2 3p^5\,{}^2P^o_{3/2\to1/2}$ transition, again using first-order semiclassical collision theory. On comparison with the results of Bely and Faucher [16], Kastner [14] finds his calculated results to be on the whole lower than those earlier values.

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EXPLANATION OF TABLES

Data are listed in Tables I–XIII for ions that are isoelectronic with Be, B, C, N, O, F, Ne, Mg, Al, Si, P, S and Cl, respectively.

TABLES I–XIII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Beryllium-like to Chlorine-like Ions of Elements from Carbon to Nickel

All transitions for which data are available are listed in order of ion and transition.

ION	The ion, in spectroscopic notation
TRANSITION	The configuration and transition studied
log T RANGE	The range of the logarithm of the temperature (in kelvin) at which data on excitation rate coefficients are available
CS	Data are available on cross sections only
METHOD	The method of calculation
SC-1	Semiclassical first-order approximation
SC-CC	Semiclassical close-coupling calculation
Q	Close-coupling quantal calculation
ACC	Estimated accuracy of calculation
A	$\leqslant$3%
B	$\leqslant$10%
C	$\leqslant$25%
D	$\leqslant$50%
E	$>$50%
REF	The reference for the calculation (see Introduction)

TABLE I. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Beryllium-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.2 – 5.4	SC-CC	C	5
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.0 – 6.0	SC-CC	C	6
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.5 – 5.1	SC-CC	C	8
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.2 – 5.4	SC-CC	C	5
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.0 – 6.0	SC-CC	C	6
C III	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.5 – 5.1	SC-CC	C	8
C III	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.2 – 5.4	SC-CC	C	5
C III	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.0 – 6.0	SC-CC	C	6
C III	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.5 – 5.1	SC-CC	C	8
C III	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_1$	4.2 – 5.4	SC-CC	C	5
C III	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_1$	4.0 – 6.0	SC-CC	C	6
C III	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	4.2 – 5.4	SC-CC	C	5
C III	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	4.0 – 6.0	SC-CC	C	6
C III	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	4.2 – 5.4	SC-CC	C	5
C III	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	4.0 – 6.0	SC-CC	C	6
N IV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.6 – 5.7	SC-CC	C	5
N IV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.9 – 5.4	SC-CC	C	8
N IV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.6 – 5.7	SC-CC	C	5
N IV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.9 – 5.4	SC-CC	C	8
N IV	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.6 – 5.7	SC-CC	C	5
N IV	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.9 – 5.4	SC-CC	C	8
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.0 – 6.0	SC-1	D	9
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	4.9 – 6.0	SC-CC	C	5
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.0 – 7.0	SC-CC	C	6
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.1 – 5.6	SC-CC	C	8
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.0 – 6.0	SC-1	D	9
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	4.9 – 6.0	SC-CC	C	5
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.0 – 7.0	SC-CC	C	6
O V	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.1 – 5.6	SC-CC	C	8
O V	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.0 – 6.0	SC-1	D	9
O V	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	4.9 – 6.0	SC-CC	C	5
O V	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.0 – 7.0	SC-CC	C	6
O V	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.1 – 5.6	SC-CC	C	8
O V	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_1$	5.0 – 6.0	SC-1	D	9
O V	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_1$	5.0 – 7.0	SC-CC	C	6
O V	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	5.0 – 6.0	SC-1	D	9
O V	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	5.0 – 7.0	SC-CC	C	6
O V	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	5.0 – 6.0	SC-1	D	9
O V	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	5.0 – 7.0	SC-CC	C	6

TABLE I. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Beryllium-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
F VI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.2 – 5.7	SC-CC	C	8
F VI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.2 – 5.7	SC-CC	C	8
F VI	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.2 – 5.7	SC-CC	C	8
Ne VII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.2 – 7.0	SC-CC	C	6
Ne VII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.5 – 5.9	SC-CC	C	8
Ne VII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.2 – 7.0	SC-CC	C	6
Ne VII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.5 – 5.9	SC-CC	C	8
Ne VII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.2 – 7.0	SC-CC	C	6
Ne VII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.5 – 5.9	SC-CC	C	8
Ne VII	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_1$	5.2 – 7.0	SC-CC	C	6
Ne VII	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	5.2 – 7.0	SC-CC	C	6
Ne VII	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	5.2 – 7.0	SC-CC	C	6
Mg IX	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.6 – 6.6	SC-CC	C	5
Mg IX	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.8 – 6.2	SC-CC	C	8
Mg IX	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.6 – 6.6	SC-CC	C	5
Mg IX	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.8 – 6.2	SC-CC	C	8
Mg IX	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.6 – 6.6	SC-CC	C	5
Mg IX	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.8 – 6.2	SC-CC	C	8
Si XI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	5.9 – 6.9	SC-CC	C	5
Si XI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.0 – 6.4	SC-CC	C	8
Si XI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	5.9 – 6.9	SC-CC	C	5
Si XI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.0 – 6.4	SC-CC	C	8
Si XI	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	5.9 – 6.9	SC-CC	C	5
Si XI	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.0 – 6.4	SC-CC	C	8
S XIII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.2 – 6.6	SC-CC	C	8
S XIII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.2 – 6.6	SC-CC	C	8
S XIII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.2 – 6.6	SC-CC	C	8
Ar XV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.4 – 6.8	SC-CC	C	8
Ar XV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.4 – 6.8	SC-CC	C	8
Ar XV	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.4 – 6.8	SC-CC	C	8
Ca XVII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.3 – 7.3	SC-CC	C	5
Ca XVII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.5 – 6.9	SC-CC	C	8
Ca XVII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.3 – 7.3	SC-CC	C	5
Ca XVII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.5 – 6.9	SC-CC	C	8
Ca XVII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.3 – 7.3	SC-CC	C	5
Ca XVII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.5 – 6.9	SC-CC	C	8
Ti XIX	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.93	SC-1	D	12
Ti XIX	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.93	SC-1	D	12
Ti XIX	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	6.93	SC-1	D	12
Ti XIX	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	6.93	SC-1	D	12

TABLE I. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Beryllium-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Cr XXI	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	7.04	SC-1	D	13
Cr XXI	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	7.04	SC-1	D	13
Cr XXI	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	7.04	SC-1	D	13
Cr XXI	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	7.04	SC-1	D	13
Fe XXIII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_1$	6.9 – 7.3	SC-CC	C	8
Fe XXIII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	7.15	SC-1	D	13
Fe XXIII	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	6.9 – 7.3	SC-CC	C	8
Fe XXIII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	7.15	SC-1	D	13
Fe XXIII	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	6.9 – 7.3	SC-CC	C	8
Fe XXIII	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	7.15	SC-1	D	13
Fe XXIII	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	7.15	SC-1	D	13
Ni XXV	$2s\,2p\ ^3P^o_0 \rightarrow 2s\,2p\ ^3P^o_2$	7.25	SC-1	D	13
Ni XXV	$2s\,2p\ ^3P^o_1 \rightarrow 2s\,2p\ ^3P^o_2$	7.25	SC-1	D	13
Ni XXV	$2p^2\ ^3P_0 \rightarrow 2p^2\ ^3P_2$	7.25	SC-1	D	13
Ni XXV	$2p^2\ ^3P_1 \rightarrow 2p^2\ ^3P_2$	7.25	SC-1	D	13

TABLE II. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Boron-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
C II	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.0 – 6.0	SC-CC	D	15
C II	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.2 – 5.5	SC-1	D	16
C II	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	3.3 – 4.8	SC-1	D	20
C II	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	3.0 – 5.7	SC-CC	B	27
C II	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	3.3 – 4.8	SC-1	D	20
C II	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	3.0 – 5.6	SC-CC	B	26,27
C II	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.3 – 4.8	SC-1	D	20
C II	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.0 – 5.6	SC-CC	B	26,27
C II	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.3 – 4.8	SC-1	D	20
C II	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.0 – 5.6	SC-CC	B	26,27
N III	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.0 – 6.0	SC-CC	D	15
N III	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.4 – 5.7	SC-1	D	16
N III	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.0 – 5.0	SC-CC	C	19
N III	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	3.6 – 6.3	SC-CC	B	25,27
N III	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	3.3 – 5.0	SC-CC	B	26,27
N III	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.3 – 5.0	SC-CC	B	26,27
N III	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.3 – 5.0	SC-CC	B	26,27
O IV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.7 – 6.0	SC-1	D	16
O IV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.7 – 5.4	SC-1	D	18
O IV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	CS	Q	B	23
O IV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.0 – 6.8	SC-CC	B	25,27
O IV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.7 – 5.4	SC-1	D	18
O IV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	3.6 – 5.5	SC-CC	B	26,27
O IV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.7 – 5.4	SC-1	D	18
O IV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.6 – 5.5	SC-CC	B	26,27
O IV	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.7 – 5.4	SC-1	D	18
O IV	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	3.6 – 5.5	SC-CC	B	26,27
F V	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.9 – 6.2	SC-1	D	16
Ne VI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.0 – 6.3	SC-1	D	16
Ne VI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.5 – 7.0	SC-CC	B	27
Ne VI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.0 – 6.0	SC-CC	B	27
Ne VI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.0 – 6.0	SC-CC	B	27
Ne VI	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.0 – 6.0	SC-CC	B	27
Na VII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.1 – 6.4	SC-1	D	16
Mg VIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.2 – 6.5	SC-1	D	16
Mg VIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.9 – 7.5	SC-CC	B	27
Mg VIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.5 – 6.4	SC-CC	B	27
Mg VIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.5 – 6.4	SC-CC	B	27
Mg VIII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.5 – 6.4	SC-CC	B	27

TABLE II. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Boron-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Al IX	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.2 – 6.5	SC-1	D	16
Al IX	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	4.9 – 7.6	SC-CC	B	27
Al IX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.6 – 6.5	SC-CC	B	27
Al IX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.6 – 6.5	SC-CC	B	27
Al IX	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.6 – 6.5	SC-CC	B	27
Si X	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.3 – 6.6	SC-1	D	16
Si X	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.0 – 7.7	SC-CC	B	27
Si X	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.7 – 6.7	SC-CC	B	27
Si X	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.7 – 6.7	SC-CC	B	27
Si X	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.7 – 6.7	SC-CC	B	27
P XI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.4 – 6.7	SC-1	D	16
S XII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.5 – 6.8	SC-1	D	16
S XII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.3 – 7.9	SC-CC	B	27
S XII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	4.9 – 6.9	SC-CC	B	27
S XII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.9 – 6.9	SC-CC	B	27
S XII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	4.9 – 6.9	SC-CC	B	27
Cl XIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.5 – 6.8	SC-1	D	16
Ar XIV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.6 – 6.9	SC-1	D	16
Ar XIV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.5 – 8.0	SC-CC	B	27
Ar XIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.2 – 7.2	SC-CC	B	27
Ar XIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.2 – 7.2	SC-CC	B	27
Ar XIV	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.2 – 7.2	SC-CC	B	27
K XV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.6 – 6.9	SC-1	D	16
Ca XVI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.7 – 7.0	SC-1	D	16
Ca XVI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.6 – 8.2	SC-CC	B	27
Ca XVI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.4 – 7.3	SC-CC	B	27
Ca XVI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.4 – 7.3	SC-CC	B	27
Ca XVI	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.4 – 7.3	SC-CC	B	27
Ti XVIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.81	SC-1	D	12
Ti XVIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.8 – 8.3	SC-CC	B	27
Ti XVIII	$2s\,2p^2\ ^2P_{1/2} \rightarrow 2s\,2p^2\ ^2P_{3/2}$	6.81	SC-1	D	12
Ti XVIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	6.81	SC-1	D	12
Ti XVIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.5 – 7.5	SC-CC	B	27
Ti XVIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	6.81	SC-1	D	12
Ti XVIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.5 – 7.5	SC-CC	B	27
Ti XVIII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	6.81	SC-1	D	12
Ti XVIII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.5 – 7.5	SC-CC	B	27
Ti XVIII	$2p^3\ ^2P^o_{1/2} \rightarrow 2p^3\ ^2P^o_{3/2}$	6.81	SC-1	D	12

TABLE II. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Boron-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Cr XX	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.95	SC-1	D	13
Cr XX	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	5.9 – 8.5	SC-CC	B	27
Cr XX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	6.95	SC-1	D	13
Cr XX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.7 – 7.6	SC-CC	B	27
Cr XX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\ 2p^2\ ^2P_{5/2}$	6.95	SC-1	D	13
Cr XX	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.7 – 7.6	SC-CC	B	27
Cr XX	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	6.95	SC-1	D	13
Cr XX	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.7 – 7.6	SC-CC	B	27
Mn XXI	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.0 – 8.6	SC-CC	B	27
Mn XXI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.8 – 7.7	SC-CC	B	27
Mn XXI	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.7	SC-CC	B	27
Mn XXI	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.7	SC-CC	B	27
Fe XXII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.3 – 7.0	SC-1	D	14
Fe XXII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.0 – 8.8	SC-CC	B	27
Fe XXII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.8 – 7.8	SC-CC	B	27
Fe XXII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.8	SC-CC	B	27
Fe XXII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.8	SC-CC	B	27
Co XXIII	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.2 – 8.8	SC-CC	B	27
Co XXIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.8 – 7.8	SC-CC	B	27
Co XXIII	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.8	SC-CC	B	27
Co XXIII	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.8 – 7.8	SC-CC	B	27
Ni XXIV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	7.2	SC-1	D	13
Ni XXIV	$2s^2\,2p\ ^2P^o_{1/2} \rightarrow 2s^2\,2p\ ^2P^o_{3/2}$	6.2 – 8.8	SC-CC	B	27
Ni XXIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	7.2	SC-1	D	13
Ni XXIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{3/2}$	5.9 – 7.9	SC-CC	B	27
Ni XXIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	7.2	SC-1	D	13
Ni XXIV	$2s\,2p^2\ ^4P_{1/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.9 – 7.9	SC-CC	B	27
Ni XXIV	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	7.2	SC-1	D	13
Ni XXIV	$2s\,2p^2\ ^4P_{3/2} \rightarrow 2s\,2p^2\ ^4P_{5/2}$	5.9 – 7.9	SC-CC	B	27

TABLE III. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Carbon-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	4.0 – 6.0	SC-CC	D	15
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	CS	SC-CC	C	11
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	3.6 – 5.3	SC/Q	C	28
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.0 – 6.0	SC-CC	D	15
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
N II	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	3.6 – 5.3	SC/Q	C	28
N II	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.0 – 6.0	SC-CC	D	15
N II	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
N II	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-1	D	14
N II	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	3.6 – 5.3	SC/Q	C	28
O III	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	CS	SC-CC	C	11
O III	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	4.0 – 5.6	SC/Q	C	28
O III	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
O III	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.0 – 5.6	SC/Q	C	28
O III	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
O III	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.0 – 5.6	SC/Q	C	28
Ne V	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	4.4 – 6.0	SC/Q	C	28
Ne V	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.4 – 6.0	SC/Q	C	28
Ne V	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.4 – 6.0	SC/Q	C	28
Na VI	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	4.7 – 6.3	SC/Q	C	28
Na VI	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.7 – 6.3	SC/Q	C	28
Na VI	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.7 – 6.3	SC/Q	C	28
Mg VII	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	4.9 – 6.5	SC/Q	C	28
Mg VII	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.9 – 6.5	SC/Q	C	28
Mg VII	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	4.9 – 6.5	SC/Q	C	28
Si IX	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	CS	SC-CC	C	11
Si IX	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
Si IX	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	CS	SC-CC	C	11
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	6.0 – 7.0	SC-1	D	31
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_1$	6.2 – 6.7	Q	C	30
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.0 – 7.0	SC-1	D	31
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.2 – 6.7	Q	C	30
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.1 – 6.4	SC-1	D	14
Ca XV	$2s^2\,2p^2\ ^3P_0 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.2 – 6.7	SC-1	D	22
Ca XV	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.0 – 7.0	SC-1	D	31
Ca XV	$2s^2\,2p^2\ ^3P_1 \rightarrow 2s^2\,2p^2\ ^3P_2$	6.0 – 6.6	Q	C	30

TABLE III. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Carbon-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Ti XVII	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.81	SC-1	D	12
Ti XVII	$2s^2\,2p^2\ {}^3P_1 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.81	SC-1	D	12
Ti XVII	$2s\,2p^3\ {}^3P^o_0 \rightarrow 2s\,2p^3\ {}^3P^o_2$	6.81	SC-1	D	12
Ti XVII	$2s\,2p^3\ {}^3P^o_1 \rightarrow 2s\,2p^3\ {}^3P^o_2$	6.81	SC-1	D	12
Cr XIX	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.95	SC-1	D	13
Cr XIX	$2s^2\,2p^2\ {}^3P_1 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.95	SC-1	D	13
Fe XXI	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_1$	6.8 – 7.1	Q	C	30
Fe XXI	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.8 – 7.1	Q	C	30
Fe XXI	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.4 – 7.1	SC-1	D	14
Fe XXI	$2s^2\,2p^2\ {}^3P_1 \rightarrow 2s^2\,2p^2\ {}^3P_2$	6.8 – 7.1	Q	C	30
Ni XXIII	$2s^2\,2p^2\ {}^3P_0 \rightarrow 2s^2\,2p^2\ {}^3P_2$	7.08	SC-1	D	13
Ni XXIII	$2s^2\,2p^2\ {}^3P_1 \rightarrow 2s^2\,2p^2\ {}^3P_2$	7.08	SC-1	D	13

TABLE IV. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Nitrogen-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Ti XVI	$2s^2\,2p^3\ {}^2D^o_{3/2} \rightarrow 2s^2\,2p^3\ {}^2D^o_{5/2}$	6.7	SC-1	D	12
Cr XVIII	$2s^2\,2p^3\ {}^2D^o_{3/2} \rightarrow 2s^2\,2p^3\ {}^2D^o_{5/2}$	6.8	SC-1	D	13
Fe XX	$2s^2\,2p^3\ {}^2D^o_{3/2} \rightarrow 2s^2\,2p^3\ {}^2D^o_{5/2}$	6.8 – 7.2	SC-1	D	32
Fe XX	$2s^2\,2p^3\ {}^2P^o_{1/2} \rightarrow 2s^2\,2p^3\ {}^2P^o_{3/2}$	6.8 – 7.2	SC-1	D	32
Ni XXII	$2s^2\,2p^3\ {}^2D^o_{3/2} \rightarrow 2s^2\,2p^3\ {}^2D^o_{5/2}$	7.0	SC-1	D	13

TABLE V. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Oxygen-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
F II	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	4.0 – 4.9	SC-CC	C	33
F II	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.0 – 4.9	SC-CC	C	33
F II	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.0 – 4.9	SC-CC	C	33
Ne III	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	4.5 – 5.4	SC-CC	C	33
Ne III	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.5 – 5.4	SC-CC	C	33
Ne III	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.5 – 5.4	SC-CC	C	33
Na IV	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	4.8 – 5.6	SC-CC	C	33
Na IV	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.8 – 5.6	SC-CC	C	33
Na IV	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	4.8 – 5.6	SC-CC	C	33
Mg V	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	5.0 – 5.8	SC-CC	C	33
Mg V	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.0 – 5.8	SC-CC	C	33
Mg V	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.0 – 5.8	SC-CC	C	33
Al VI	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	5.2 – 6.0	SC-CC	C	33
Al VI	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.2 – 6.0	SC-CC	C	33
Al VI	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.2 – 6.0	SC-CC	C	33
Si VII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	5.4 – 6.1	SC-CC	C	33
Si VII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.4 – 6.1	SC-CC	C	33
Si VII	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.4 – 6.1	SC-CC	C	33
P VIII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	5.5 – 6.3	SC-CC	C	33
P VIII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.5 – 6.3	SC-CC	C	33
P VIII	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.5 – 6.3	SC-CC	C	33
S IX	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	5.7 – 6.4	SC-CC	C	33
S IX	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.7 – 6.4	SC-CC	C	33
S IX	$2s^2\,2p^4\,{}^3P_1 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.7 – 6.4	SC-CC	C	33
Ca XIII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	5.7 – 6.4	SC-1	D	14
Ca XIII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	6.0 – 6.6	SC-1	D	22
Ti XV	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	6.6	SC-1	D	12
Ti XV	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	6.6	SC-1	D	12
Cr XVII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	6.8	SC-1	D	13
Cr XVII	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	6.8	SC-1	D	13
Fe XIX	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	6.95	SC-1	D	13
Fe XIX	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	6.95	SC-1	D	13
Ni XXI	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_1$	7.0	SC-1	D	13
Ni XXI	$2s^2\,2p^4\,{}^3P_2 \rightarrow 2s^2\,2p^4\,{}^3P_0$	7.0	SC-1	D	13

TABLE VI. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Fluorine-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Ne II	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	4.4 – 5.7	SC-1	D	16
Ne II	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	3.7 – 5.3	SC-CC	B	42
Na III	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	4.7 – 6.0	SC-1	D	16
Mg IV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	4.9 – 6.2	SC-1	D	16
Mg IV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	4.8 – 5.8	SC-CC	C	38
Al V	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.0 – 6.3	SC-1	D	16
Si VI	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.1 – 6.4	SC-1	D	16
P VII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.2 – 6.5	SC-1	D	16
S VIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.3 – 6.6	SC-1	D	16
S VIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.4 – 6.3	SC-CC	C	38
S VIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.0 – 6.8	SC-CC	B	42
Cl IX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.4 – 6.7	SC-1	D	16
Cl IX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.5 – 6.5	SC-CC	C	38
Ar X	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.5 – 6.8	SC-1	D	16
K XI	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.5 – 6.8	SC-1	D	16
Ca XII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.6 – 6.9	SC-1	D	16
Sc XIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.6 – 6.9	SC-1	D	16
Ti XIV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.7 – 7.0	SC-1	D	16
Ti XIV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.6	SC-1	D	12
Ti XIV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.0 – 6.9	SC-CC	C	38
Ti XIV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.0 – 7.0	SC-CC	C	39
Ti XIV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.0 – 7.3	SC-CC	B	42
V XV	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.7 – 7.0	SC-1	D	16
Cr XVI	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	5.8 – 7.1	SC-1	D	16
Cr XVI	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.78	SC-1	D	13
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.1 – 7.0	SC-1	D	14
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.0 – 6.6	SC-1	D	22
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.9	SC-1	D	13
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.0 – 7.6	SC-CC	C	37
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.2 – 7.6	SC-CC	C	40
Fe XVIII	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.2 – 7.6	SC-CC	B	41
Ni XX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	7.0	SC-1	D	13
Ni XX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.3 – 7.7	SC-CC	B	42
Ni XX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.3 – 7.3	SC-CC	C	38
Ni XX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.5 – 7.5	SC-CC	C	39
Ni XX	$2s^2\,2p^5\ ^2P^o_{3/2} \rightarrow 2s^2\,2p^5\ ^2P^o_{1/2}$	6.5 – 7.5	SC-CC	C	40

TABLE VII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Neon-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Na II	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	3.8 – 5.0	SC-CC	C	43
Na II	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	3.8 – 5.0	SC-CC	C	43
Na II	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	3.8 – 5.0	SC-CC	C	43
Mg III	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	4.2 – 5.4	SC-CC	C	43
Mg III	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.2 – 5.4	SC-CC	C	43
Mg III	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.2 – 5.4	SC-CC	C	43
Al IV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	4.5 – 5.7	SC-CC	C	43
Al IV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.5 – 5.7	SC-CC	C	43
Al IV	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.5 – 5.7	SC-CC	C	43
Si V	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	4.7 – 5.9	SC-CC	C	43
Si V	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.7 – 5.9	SC-CC	C	43
Si V	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.7 – 5.9	SC-CC	C	43
P VI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	4.9 – 6.1	SC-CC	C	43
P VI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.9 – 6.1	SC-CC	C	43
P VI	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	4.9 – 6.1	SC-CC	C	43
S VII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.1 – 6.2	SC-CC	C	43
S VII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.1 – 6.2	SC-CC	C	43
S VII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.1 – 6.2	SC-CC	C	43
Cl VIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.2 – 6.3	SC-CC	C	43
Cl VIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.2 – 6.3	SC-CC	C	43
Cl VIII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.2 – 6.3	SC-CC	C	43
Ar IX	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.4 – 6.4	SC-CC	C	43
Ar IX	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.4 – 6.4	SC-CC	C	43
Ar IX	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.4 – 6.4	SC-CC	C	43
K X	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.5 – 6.6	SC-CC	C	43
K X	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.5 – 6.6	SC-CC	C	43
K X	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.5 – 6.6	SC-CC	C	43
Ca XI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.6 – 6.6	SC-CC	C	43
Ca XI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.6 – 6.6	SC-CC	C	43
Ca XI	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.6 – 6.6	SC-CC	C	43
Sc XII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.7 – 6.7	SC-CC	C	43
Sc XII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.7 – 6.7	SC-CC	C	43
Sc XII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.7 – 6.7	SC-CC	C	43
Ti XIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.7 – 6.7	SC-CC	C	43
Ti XIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.7 – 6.7	SC-CC	C	43
Ti XIII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.7 – 6.7	SC-CC	C	43
V XIV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.8 – 6.8	SC-CC	C	43
V XIV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.8 – 6.8	SC-CC	C	43
V XIV	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.8 – 6.8	SC-CC	C	43

TABLE VII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Neon-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Cr XV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	5.9 – 6.9	SC-CC	C	43
Cr XV	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.9 – 6.9	SC-CC	C	43
Cr XV	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	5.9 – 6.9	SC-CC	C	43
Mn XVI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	6.0 – 7.0	SC-CC	C	43
Mn XVI	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.0 – 7.0	SC-CC	C	43
Mn XVI	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.0 – 7.0	SC-CC	C	43
Fe XVII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	6.1 – 7.1	SC-CC	C	43
Fe XVII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.1 – 7.1	SC-CC	C	43
Fe XVII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.1 – 7.1	SC-CC	C	43
Co XVIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	6.2 – 7.2	SC-CC	C	43
Co XVIII	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.2 – 7.2	SC-CC	C	43
Co XVIII	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.2 – 7.2	SC-CC	C	43
Ni XIX	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_1$	6.3 – 7.3	SC-CC	C	43
Ni XIX	$2p^5\,3s\,{}^3P^o_2 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.3 – 7.3	SC-CC	C	43
Ni XIX	$2p^5\,3s\,{}^3P^o_1 \rightarrow 2p^5\,3s\,{}^3P^o_0$	6.3 – 7.3	SC-CC	C	43

TABLE VIII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Magnesium-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Si III	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_1$	4.0 – 5.2	SC-CC	C	5
Si III	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_2$	4.0 – 5.2	SC-CC	C	5
Si III	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	4.0 – 5.2	SC-CC	C	5
S V	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_1$	4.6 – 5.6	SC-CC	C	5
S V	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_2$	4.6 – 5.6	SC-CC	C	5
S V	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	4.6 – 5.6	SC-CC	C	5
Ar VII	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_1$	5.0 – 6.1	SC-CC	C	5
Ar VII	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_2$	5.0 – 6.1	SC-CC	C	5
Ar VII	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	5.0 – 6.1	SC-CC	C	5
Ca IX	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_1$	5.3 – 6.3	SC-CC	C	5
Ca IX	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_2$	5.3 – 6.3	SC-CC	C	5
Ca IX	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	5.3 – 6.3	SC-CC	C	5
Fe XV	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_1$	6.0 – 7.0	SC-CC	C	5
Fe XV	$3s\,3p\,{}^3P^o_0 \rightarrow 3s\,3p\,{}^3P^o_2$	6.0 – 7.0	SC-CC	C	5
Fe XV	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	5.7 – 6.2	SC-1	D	14
Fe XV	$3s\,3p\,{}^3P^o_1 \rightarrow 3s\,3p\,{}^3P^o_2$	6.0 – 7.0	SC-CC	C	5

TABLE IX. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Aluminum-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Si II	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.0 – 6.0	SC-CC	D	15
Si II	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.0 – 5.3	SC-1	D	16
P III	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.4 – 5.7	SC-1	D	16
S IV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.0 – 6.0	SC-CC	D	15
S IV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	CS	SC-CC	C	7
S IV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.5 – 5.8	SC-1	D	16
Cl V	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.7 – 6.0	SC-1	D	16
Ar VI	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.8 – 6.1	SC-1	D	16
K VII	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	4.9 – 6.2	SC-1	D	16
Ca VIII	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.0 – 6.3	SC-1	D	16
Sc IX	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.1 – 6.4	SC-1	D	16
Ti X	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.2 – 6.5	SC-1	D	16
V XI	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.2 – 6.5	SC-1	D	16
Cr XII	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.3 – 6.6	SC-1	D	16
Mn XIII	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.3 – 6.6	SC-1	D	16
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	CS	SC-1	D	2
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.4 – 6.7	SC-1	D	16
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	CS	SC-CC	C	11
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	6.0 – 6.5	SC-CC	C	34,35
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	6.0 – 6.5	SC-1	D	10
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.0 – 6.0	SC-1	D	14
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	6.0 – 6.6	SC-1	D	22
Fe XIV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	6.0 – 6.5	Q	B	44
Co XV	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.4 – 6.7	SC-1	D	16
Ni XVI	$3s^2\,3p\,^2P^o_{1/2} \rightarrow 3s^2\,3p\,^2P^o_{3/2}$	5.5 – 6.8	SC-1	D	16

TABLE X. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Silicon-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
S III	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	4.0 – 6.0	SC-CC	D	15
S III	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	4.0 – 6.0	SC-CC	D	15
S III	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	4.0 – 6.0	SC-CC	D	15
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	CS	SC-CC	C	11
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	6.0 – 6.5	SC-CC	C	34,35
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	5.7 – 6.5	SC-CC	C	45
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	6.0 – 6.5	SC-1	D	10
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	CS	Q	C	29
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	CS	SC-CC	C	11
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	6.0 – 6.5	SC-CC	C	34,35
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	5.7 – 6.5	SC-CC	C	45
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	6.0 – 6.5	SC-1	D	10
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	CS	Q	C	29
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	5.7 – 6.2	SC-1	D	14
Fe XIII	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	6.0 – 6.6	SC-1	D	22
Fe XIII	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	CS	SC-CC	C	11
Fe XIII	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	6.0 – 6.5	SC-CC	C	34,35
Fe XIII	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	5.7 – 6.5	SC-CC	C	45
Fe XIII	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	6.0 – 6.5	SC-1	D	10
Fe XIII	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	CS	Q	C	29
Ni XV	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_1$	5.7 – 6.6	Q	C	30
Ni XV	$3s^2\,3p^2\,{}^3P_0 \rightarrow 3s^2\,3p^2\,{}^3P_2$	5.7 – 6.6	Q	C	30
Ni XV	$3s^2\,3p^2\,{}^3P_1 \rightarrow 3s^2\,3p^2\,{}^3P_2$	5.7 – 6.6	Q	C	30

TABLE XI. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Phosphorus-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Fe XII	$3s^2\,3p^3\,{}^2P^o_{1/2} \rightarrow 3s^2\,3p^3\,{}^2P^o_{3/2}$	6.0 – 6.4	SC-CC	C	36

TABLE XII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Sulfur-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	log T RANGE	METHOD	ACC	REF
Cl II	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	4.0 – 4.8	SC-CC	C	33
Cl II	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.0 – 4.8	SC-CC	C	33
Cl II	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.0 – 4.8	SC-CC	C	33
Ar III	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	4.3 – 5.1	SC-CC	C	33
Ar III	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.3 – 5.1	SC-CC	C	33
Ar III	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.3 – 5.1	SC-CC	C	33
K IV	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	4.6 – 5.4	SC-CC	C	33
K IV	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.6 – 5.4	SC-CC	C	33
K IV	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.6 – 5.4	SC-CC	C	33
Ca V	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	4.8 – 5.6	SC-CC	C	33
Ca V	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.8 – 5.6	SC-CC	C	33
Ca V	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.8 – 5.6	SC-CC	C	33
Sc VI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	4.9 – 5.8	SC-CC	C	33
Sc VI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.9 – 5.8	SC-CC	C	33
Sc VI	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	4.9 – 5.8	SC-CC	C	33
Ti VII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.0 – 5.9	SC-CC	C	33
Ti VII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.0 – 5.9	SC-CC	C	33
Ti VII	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.0 – 5.9	SC-CC	C	33
V VIII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.2 – 6.1	SC-CC	C	33
V VIII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.2 – 6.1	SC-CC	C	33
V VIII	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.2 – 6.1	SC-CC	C	33
Cr IX	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.4 – 6.2	SC-CC	C	33
Cr IX	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.4 – 6.2	SC-CC	C	33
Cr IX	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.4 – 6.2	SC-CC	C	33
Mn X	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.5 – 6.3	SC-CC	C	33
Mn X	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.5 – 6.3	SC-CC	C	33
Mn X	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.5 – 6.3	SC-CC	C	33
Fe XI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.6 – 6.4	SC-CC	C	33
Fe XI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	6.1	SC-1	D	47
Fe XI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.6 – 6.4	SC-CC	C	33
Fe XI	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	6.1	SC-1	D	47
Fe XI	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.6 – 6.4	SC-CC	C	33
Co XII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.7 – 6.4	SC-CC	C	33
Co XII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.7 – 6.4	SC-CC	C	33
Co XII	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.7 – 6.4	SC-CC	C	33
Ni XIII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_1$	5.9 – 6.5	SC-CC	C	33
Ni XIII	$3s^2\,3p^4\ ^3P_2 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.9 – 6.5	SC-CC	C	33
Ni XIII	$3s^2\,3p^4\ ^3P_1 \rightarrow 3s^2\,3p^4\ ^3P_0$	5.9 – 6.5	SC-CC	C	33

TABLE XIII. Characterizations and Accuracy Estimates for Available Data on Proton-Impact Excitation of Chlorine-like Ions

See page 187 for Explanation of Tables

ION	TRANSITION	$\log T$ RANGE	METHOD	ACC	REF
Ar II	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	4.2 – 5.5	SC-1	D	16
K III	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	4.4 – 5.7	SC-1	D	16
Ca IV	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	4.5 – 5.8	SC-1	D	16
Sc V	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	4.7 – 6.0	SC-1	D	16
Ti VI	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	4.9 – 6.2	SC-1	D	16
V VII	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.0 – 6.3	SC-1	D	16
Cr VIII	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.1 – 6.4	SC-1	D	16
Mn IX	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.2 – 6.5	SC-1	D	16
Fe X	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.2 – 6.5	SC-1	D	16
Fe X	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.0 – 6.0	SC-1	D	14
Fe X	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	6.0 – 6.6	SC-1	D	22
Fe X	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	6.0	SC-1	D	48
Co XI	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.3 – 6.6	SC-1	D	16
Ni XII	$3s^2\,3p^5\ {}^2P^o_{3/2} \rightarrow 3s^2\,3p^5\ {}^2P^o_{1/2}$	5.3 – 6.6	SC-1	D	16