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# CALCULATED ELECTRON EXCITATION CROSS SECTIONS FOR THE ALKALIS*

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Electron excitation cross sections for lithium, sodium, potassium, rubidium, and cesium have been calculated by means of the Born, Bethe, and Ochkur approximations. Herman-Skillman Hartree-Fock-Slater wavefunctions are used to describe the bound electrons.

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## CONTENTS



## INTRODUCTION

Numerical calculations have been carried out to evaluate the excitation cross sections for some of the alkali atoms by electrons. The cross sections have been evaluated in the Born, Bethe, and Ochkur approximations. They provide experimentalists with reliable high energy data which may be used for normalization purposes. The data should also prove useful in astrophysical calculations that often require cross sections which are better than order-of-magnitude estimates at intermediate and low energies.

The expression for the differential cross section is derived in numerous text books and is given by[1]

$$\frac{d\sigma}{dq} = \frac{1}{2\pi^2}\frac{q}{N\epsilon}|\langle\psi_f|T|\psi_i\rangle|^2. \tag{1}$$

We use atomic units ($E = k^2$, $I_H = 13.6$ eV); $\sigma$ is expressed in units of $\pi a_0^2$. The incoming and outgoing electrons have momenta $\mathbf{k}_i$ and $\mathbf{k}_f$ and $\mathbf{q} = \mathbf{k}_i - \mathbf{k}_f$. The energy of the incident electron is written as $E = k_i^2 = N\epsilon$, where $\epsilon$ is the energy required to excite the bound electron. The wavefunctions $\psi_i$ and $\psi_f$ describe the initial and final states of the system. The operator $T$ satisfies the operator equation $T = V + VG_0^+T$ where $V$ is the interaction potential and $G_0^+$ is the free-particle Green's operator corresponding to the outgoing waves. The limits for the momentum transfer are easily found to be

$$q_\pm = (N\epsilon)^{1/2}[1 \pm (1 - 1/N)^{1/2}]. \tag{2}$$

### *Born, Bethe, and Ochkur Approximations*

The first-order approximation for the T-operator is found by letting $T = V$. This gives the Born approximation.[1] Using this approximation, single-particle wavefunctions, and the coordinate representation we find

$$\langle\psi_f|T|\psi_i\rangle = \frac{4\pi}{q^2}\int d\mathbf{r}\phi_f^*(\mathbf{r})\, e^{i\mathbf{q}\cdot\mathbf{r}}\phi_i(\mathbf{r}) \tag{3}$$

where $\phi_i(\mathbf{r})$ and $\phi_f(\mathbf{r})$ are the initial and final state wavefunctions of the bound electron. These wavefunctions have the form

$$\phi(r) = R_{nl}(r)Y_{lm}(\Omega) = \frac{P_{nl}(r)}{r}Y_{lm}(\Omega) \tag{4}$$

where $P_{nl}(r)$ are the numerical Hartree-Fock-Slater (HFS) functions.[2] The excited-state wavefunctions were generated by a modified Herman-Skillman HFS program.

Averaging over initial and summing over final states we can write the Born approximation as

$$\frac{d\sigma_B}{dq} = \frac{8}{N\epsilon q^3(2l_i+1)} \times \sum_{m_i,m_f}\left|\int_0^\infty dr d\Omega P_{n_fl_f}(r)\,P_{n_il_i}(r)\,Y_{l_fm_f}(\Omega)e^{i\mathbf{q}\cdot\mathbf{r}}Y_{l_im_i}(\Omega)\right|^2. \tag{5}$$

Expanding $e^{i\mathbf{q}\cdot\mathbf{r}}$ in terms of spherical harmonics and carrying out the sums we find

$$\frac{d\sigma_B}{dq} = \frac{8(2l_f+1)}{N\epsilon q^3}\sum_{\substack{l=0\\ \Delta(l_il_fl)}}(2l+1)\begin{pmatrix} l_i & l & l_f\\ 0 & 0 & 0\end{pmatrix}^2 \times \left|\int_0^\infty dr P_{n_fl_f}(r) j_l(qr) P_{n_il_i}(r)\right|^2. \tag{6}$$

where $j_l(qr)$ is a spherical Bessel function and $\Delta(l_il_fl)$ means that $l_i$, $l_f$ and $l$ satisfy the triangle equality. The Born cross sections given in the accompanying tables were calculated from Eq. (6) with HFS numerical wavefunctions.[2]

The Bethe approximation may be derived by expanding $e^{i\mathbf{q}\cdot\mathbf{r}}$ in Eq. (3) and keeping the lowest-order nonzero term in the expansion, that is $|i\mathbf{q}\cdot\mathbf{r}| \ll 1$. The resulting expression is

$$\frac{d\sigma_\beta}{dq} = \frac{2(2l_f+1)}{N\pi\epsilon}q^{2s-3}\sum_{\substack{l=0\\ \Delta(l_il_fl)}}^{s}\left[\frac{(2l)!}{2^l(l!)^2}\right]^2\begin{pmatrix} l_i & l_f & l\\ 0 & 0 & 0\end{pmatrix}^2 \times \left|\int_0^\infty dr P_{n_fl_f}(r) r^s P_{n_il_i}(r)\right|^2, \tag{7}$$

where $s$ is the first nonzero term in the expansion. The upper limit of the momentum transfer ($q_+$) for the Bethe approximation was fixed by requiring $\sigma_\beta(N = 30) = \sigma_B(N = 30)$. At low energies the Bethe approximation can give negative cross sections because $q_+$ (Bethe) can become smaller than $q_-$, given by Eq. (2), for low energies. The cross sections have been set equal to zero for these energy values.

The Ochkur approximation[3] is a simplified way of including some exchange effects in the scattering amplitude. We have used the pure Ochkur approximation and have not included the corrections suggested by Rudge.[4] In this case

$$|f_O^\pm(\Omega)|^2 = \left(1 \pm \frac{2q^2}{k_i^2} + \frac{q^4}{k_i^4}\right)|f_B(q)|^2. \qquad (8)$$

Assuming a single active electron approximation we have

$$\frac{d\sigma_O}{dq} = \frac{1}{4}\frac{d\sigma_O^+}{dq} + \frac{3}{4}\frac{d\sigma_O^-}{dq}. \qquad (9)$$

The final expression for the differential cross section is

$$\frac{d\sigma_O}{dq} = \frac{8(2l_f+1)}{N\epsilon q^3}\sum_{\substack{l=0\\ \Delta(l_i l_f l)}} (2l+1)\begin{pmatrix} l_i & l & l_f \\ 0 & 0 & 0 \end{pmatrix}^2$$

$$\times\left(1 - \frac{q^2}{k_i^2} + \frac{q^4}{k_i^4}\right)\left|\int_0^\infty dr P_{n_f l_f}(r) j_l(qr) P_{n_i l_i}(r)\right|^2. \qquad (10)$$

The Bethe and Ochkur cross sections presented have been calculated from Eqs. (7) and (10), respectively.

## *Conclusions*

The Born calculations of both Vainshtein and ourselves are given for the resonance and lithium excitations.[7] The experimental data of Enemark and Gallagher have been included for the Na(3$s$–3$p$) excitation.[8] A comparison shows that in general the agreement is good. In the remainder of the tables only the Born data of Vainshtein are presented unless disagreement was found. This was found to be the case for Li(2$s$–3$s$), and $K$(4$s \rightarrow$ 4$d$, 4$s \rightarrow$ 5$d$, and 4$s$–6$d$) excitations. The last few Vainshtein values for the Li(2$s \rightarrow$ 3$s$) excitation cross section given by Moiseiwitsch and Smith seem too large by a factor of ten, perhaps because of a typographical error.

The discrepancies in the potassium cross sections are of a more serious nature. We are unable to explain them. Since all of our cross sections were calculated by generating the HFS wavefunctions and using these as input data for the Born computer program, an explanation probably would require a recalculation of Vainshtein's cross sections with his wavefunctions.

Recent theoretical calculations by McCavert and Rudge for low-energy electron excitation of Li, Na, and K give results which are more reliable than the present calculation for $N \lesssim 10$.[9] A four-state exchange close-coupling approximation by Moores and Norcross[10] for sodium gives excitation cross sections for $E_i \leq 5$ eV.

The relative merits and ranges of validity for the above approximations have been discussed by numerous authors[5] and are not repeated here. All of the above are "high-energy" approximations. However, the meaning of "high-energy" is not always clear. In general, we find that at approximately three threshold units of incident energy the Born approximation seems to be no more than half an order of magnitude above experimental data which are available in the literature for some of the excitations considered.[3,6,8] The Bethe and Ochkur approximations normally are smaller than the Born, but higher than experimental values in this energy range. At about fifty threshold units of incident energy the Born approximation seems to be valid. (However, many experimental cross sections have been normalized to Born approximations.) All three approximations approach the same values in this energy region. From the practical point of view an experimentalist should normalize to the Born approximation at the highest energy which is given reliably with his experimental apparatus. Preferably this would be at least fifty threshold units.

## *References*

1. Bransden, B. H., *Atomic Collision Theory*, Benjamin, New York (1970)

2. Herman, F., and S. Skillman, *Atomic Structure Calculations*, Prentice-Hall, Englewood Cliff, New Jersey (1963)

3. The Born, Bethe, and Ochkur approximations are discussed in a variety of texts, and papers found in the literature. A comprehensive review of calculations in these approximations is given by B. L. Moiseiwitsch and S. J. Smith, Rev. Mod. Phys. **40,** 238 (1968). S. T. Manson, Phys. Rev. A **6,** 1013 (1972) has used Herman-Skillman HFS wavefunctions and the Born approximation to calculate the L-shell ionization cross section for aluminum.

4. M. R. H. Rudge, Proc. Phys. Soc. **85,** 607 (1965). Rudge points out that the Ochkur approximation does not satisfy the variational principle and that at low energies the resulting cross sections should be used with caution.

5. See Refs. 1 and 3 and references therein.

6. We have included a limited amount of experimental data in this paper because of the large amount of

it available; e.g., L. J. Kieffer, JILA Inform..tion Center Report No. 7, University of Colorado, Boulder, Colorado, 1969. Additional experimental data since the date of publication of Kieffer's work are available in the literature.

7. The Vainshtein data (as revised by Prof. Vainshtein and Ref. 3, p. 339) presented in Moiseiwitsch and Smith, have been reproduced in our tables.

8. E. A. Enemark and A. Gallagher, Phys. Rev. A **6**, 192 (1972)

9. P. McCavert and M. R. H. Rudge, J. Phys. B **5**, 508 (1972)

10. D. L. Moores and D. W. Norcross, J. of Phys. B **5**, 1482 (1972)

## TABLES



### Explanation of Tables

The tables present cross sections $\sigma$, in units of $\pi a_0^2 = 0.880 \times 10^{-16}$ cm$^2$, for the transitions indicated.

| | |
|---|---|
| $2s$–$2p$, etc. | Transition |
| $\epsilon$ | Excitation energy of atom in rydbergs |
| N | $N\epsilon$ = energy of incident electron in rydbergs |
| BORN(V) | $\sigma_B$, Born cross section, as calculated by Vainshtein[7] |
| BORN | $\sigma_B$, Born cross section, calculated from Eq. (5) |
| BETHE | $\sigma_\beta$, Bethe cross section calculated from Eq. (7) |
| OCHKUR | $\sigma_O$, Ochkur cross section calculated from Eq. (10) |

TABLE 1: RESONANCE EXCITATION CROSS SECTIONS

LITHIUM

2s-2p $\epsilon$ = 0.136

| N | BORN(V) | BORN | OCHKUR | BETHE |
|---|---|---|---|---|
| 1.02 | 4.14(1) | 4.07(1) | 3.99(1) | 6.96(0) |
| 1.04 | 5.71(1) | 5.62(1) | 5.54(1) | 2.43(1) |
| 1.08 | 7.71(1) | 7.58(1) | 7.55(1) | 4.68(1) |
| 1.16 | 9.98(1) | 9.81(1) | 9.55(1) | 7.36(1) |
| 1.32 | 1.20(2) | 1.18(2) | 1.14(2) | 1.00(2) |
| 1.64 | 1.31(2) | 1.28(2) | 1.19(2) | 1.18(2) |
| 2.28 | 1.24(2) | 1.22(2) | 1.10(2) | 1.18(2) |
| 3.56 | 1.03(2) | 1.01(2) | 9.17(1) | 9.98(1) |
| 6.12 | 7.53(1) | 7.35(1) | 6.92(1) | 7.38(1) |
| 11.24 | 5.01(1) | 4.89(1) | 4.74(1) | 4.93(1) |
| 21.48 | 3.12(1) | 3.04(1) | 3.00(1) | 3.07(1) |
| 41.96 | 1.86(1) | 1.81(1) | 1.80(1) | 1.83(1) |
| 50.00 | | 1.57(1) | 1.57(1) | 1.59(1) |
| 75.00 | | 1.14(1) | 1.13(1) | 1.14(1) |
| 100.00 | | 8.97(0) | 8.94(0) | 9.04(0) |

SODIUM

3s-3p $\epsilon$ = 0.155

| N | BORN(V) | BORN | OCHKUR | BETHE | EXP* |
|---|---|---|---|---|---|
| 1.02 | 3.07(1) | 3.08(1) | 3.00(1) | 0.0 | 1.75(1) |
| 1.04 | 4.26(1) | 4.27(1) | 4.14(1) | 0.0 | 1.81(1) |
| 1.08 | 5.78(1) | 5.79(1) | 5.62(1) | 0.0 | 1.94(1) |
| 1.16 | 7.56(1) | 7.58(1) | 7.06(1) | 2.50(1) | 2.20(1) |
| 1.32 | 9.32(1) | 9.32(1) | 8.45(1) | 5.87(1) | 2.72(1) |
| 1.64 | 1.04(2) | 1.04(2) | 9.14(J) | 8.56(1) | 3.30(1) |
| 2.28 | 1.03(2) | 1.03(2) | 9.04(1) | 9.56(1) | 3.52(1) |
| 3.56 | 8.84(1) | 8.85(1) | 8.07(1) | 8.66(1) | 3.65(1) |
| 6.12 | 6.66(1) | 6.66(1) | 6.33(1) | 6.67(1) | 3.56(1) |
| 11.24 | 4.54(1) | 4.53(1) | 4.42(1) | 4.57(1) | 3.15(1) |
| 21.48 | 2.87(1) | 2.87(1) | 2.84(1) | 2.90(1) | 2.42(1) |
| 41.96 | 1.73(1) | 1.73(1) | 1.72(1) | 1.75(1) | 1.66(1) |
| 50.00 | | 1.51(1) | 1.50(1) | 1.52(1) | 1.50(1) |
| 75.00 | | 1.09(1) | 1.09(1) | 1.11(1) | 1.11(1) |
| 100.00 | | 8.68(0) | 8.66(0) | 8.75(0) | 8.70(0) |

*Interpolated from Enemark and Gallagher. See ref. 8.

POTASSIUM

4s-4p $\epsilon$ = 0.119

| N | BORN(V) | BORN | OCHKUR | BETHE |
|---|---|---|---|---|
| 1.02 | 5.47(1) | 5.51(1) | 5.36(1) | 0.0 |
| 1.04 | 7.57(1) | 7.65(1) | 7.39(1) | 0.0 |
| 1.08 | 1.03(2) | 1.04(2) | 1.00(2) | 0.0 |
| 1.16 | 1.35(2) | 1.37(2) | 1.26(2) | 2.77(1) |
| 1.32 | 1.66(2) | 1.69(2) | 1.51(2) | 9.58(1) |
| 1.64 | 1.87(2) | 1.91(2) | 1.65(2) | 1.52(2) |
| 2.28 | 1.86(2) | 1.91(2) | 1.67(2) | 1.75(2) |
| 3.56 | 1.59(2) | 1.66(2) | 1.51(2) | 1.62(2) |
| 6.12 | 1.20(2) | 1.26(2) | 1.20(2) | 1.26(2) |
| 11.24 | 8.21(1) | 8.60(1) | 8.41(1) | 8.67(1) |
| 21.48 | 5.20(1) | 5.47(1) | 5.41(1) | 5.52(1) |
| 41.96 | 3.14(1) | 3.31(1) | 3.29(1) | 3.34(1) |
| 50.00 | | 2.89(1) | 2.88(1) | 2.92(1) |
| 75.00 | | 2.10(1) | 2.09(1) | 2.12(1) |
| 100.00 | | 1.66(1) | 1.66(1) | 1.68(1) |

RUBIDIUM

5s-5p $\epsilon$ = 0.116

| N | BORN(V) | BORN | OCHKUR | BETHE |
|---|---|---|---|---|
| 1.02 | 5.85(1) | 5.66(1) | 5.47(1) | 0.0 |
| 1.04 | 8.11(1) | 7.86(1) | 7.54(1) | 0.0 |
| 1.08 | 1.10(2) | 1.07(2) | 1.02( | 0.0 |
| 1.16 | 1.46(2) | 1.42(2) | 1.29(2) | 1.11(0) |
| 1.32 | 1.80(2) | 1.78(2) | 1.55(2) | 8.33(1) |
| 1.64 | 2.03(2) | 2.04(2) | 1.73(2) | 1.53(2) |
| 2.28 | 2.02(2) | 2.07(2) | 1.80(2) | 1.86(2) |
| 3.56 | 1.76(2) | 1.82(2) | 1.66(2) | 1.76(2) |
| 6.12 | 1.33(2) | 1.39(2) | 1.33(2) | 1.39(2) |
| 11.24 | 9.13(1) | 9.60(1) | 9.39(1) | 9.67(1) |
| 21.48 | 5.80(1) | 6.13(1) | 6.07(1) | 6.19(1) |
| 41.96 | 3.51(1) | 3.72(1) | 3.71(1) | 3.76(1) |
| 50.00 | | 3.25(1) | 3.24(1) | 3.29(1) |
| 75.00 | | 2.37(1) | 2.36(1) | 2.39(1) |
| 100.00 | | 1.88(1) | 1.88(1) | 1.90(1) |

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TABLE 1: RESONANCE EXCITATION CROSS SECTION (cont'd)

CESIUM

6s-6p

$\epsilon$ = 0.104

| N | BORN(V) | BORN | OCHKUR | BETHE |
|---|---|---|---|---|
| 1.02 | 7.50(1) | 7.06(1) | 6.81(1) | 0.0 |
| 1.04 | 1.04(2) | 9.82(1) | 9.38(1) | 0. |
| 1.08 | 1.41(2) | 1.35(2) | 1.27(2) | 0. |
| 1.16 | 1.86(2) | 1.79(2) | 1.60(2) | 0.0 |
| 1.32 | 2.30(2) | 2.26(2) | 1.95(2) | 8.78(1) |
| 1.64 | 2.60(2) | 2.62(2) | 2.21(2) | 1.88(2) |
| 2.28 | 2.60(2) | 2.69(2) | 2.34(2) | 2.39(2) |
| 3.56 | 2.26(2) | 2.39(2) | 2.19(2) | 2.31(2) |
| 6.12 | 1.72(2) | 1.85(2) | 1.77(2) | 1.84(2) |
| 11.24 | 1.17(2) | 1.28(2) | 1.25(2) | 1.29(2) |
| 21.48 | 7.46(1) | 8.21(1) | 8.14(1) | 8.29(1) |
| 41.96 | 4.52(1) | 5.00(1) | 4.98(1) | 5.05(1) |
| 50.00 | | 4.37(1) | 4.36(1) | 4.42(1) |
| 75.00 | | 3.18(1) | 3.18(1) | 3.22(1) |
| 100.00 | | 2.53(1) | 2.52(1) | 2.56(1) |

TABLE 2. LITHIUM ELECTRON EXCITATION CROSS SECTIONS

| | 2s-3p $\epsilon$ = 0.282 | | | | 2s-4p $\epsilon$ = 0.332 | | | |
|---|---|---|---|---|---|---|---|---|
| N | BORN(V) | BORN | BETHE | OCHKUR | BORN(V) | BORN | BETHE | OCHKUR |
| 1.02 | 9.67(-1) | 9.74(-1) | 2.76(-0) | 9.72(-1) | 2.24(-1) | 2.27(-1) | 3.24(-1) | 2.28(-1) |
| 1.04 | 1.30(0) | 1.32(0) | 2.72(-0) | 1.34(-1) | 3.01(-1) | 3.05(-1) | 3.30(-1) | 3.14(-1) |
| 1.08 | 1.68(0) | 1.70(0) | 2.64(-0) | 1.79(-0) | 3.84(-1) | 3.90(-1) | 3.35(-1) | 4.16(-1) |
| 1.16 | 2.01(0) | 2.03(0) | 2.48(-0) | 2.15(-0) | 4.49(-1) | 4.56(-1) | 3.33(-1) | 4.95(-1) |
| 1.32 | 2.11(0) | 2.15(0) | 2.21(-0) | 2.29(-0) | 4.67(-1) | 4.67(-1) | 3.18(-1) | 5.10(-1) |
| 1.64 | 1.87(0) | 1.92(0) | 1.80(-0) | 1.90(-0) | 3.91(-1) | 4.02(-1) | 2.82(-1) | 4.04(-1) |
| 2.28 | 1.39(0) | 1.43(0) | 1.33(-0) | 1.27(-0) | 2.84(-1) | 2.93(-1) | 2.26(-1) | 2.56(-1) |
| 3.56 | 8.91(-1) | 9.22(-1) | 8.71(-1) | 7.34(-1) | 1.84(-1) | 1.89(-1) | 1.62(-1) | 1.56(-1) |
| 6.12 | 5.20(-1) | 5.37(-1) | 5.19(-1) | 4.66(-1) | 1.13(-1) | 1.13(-1) | 1.05(-1) | 9.76(-2) |
| 11.24 | 2.88(-1) | 2.94(-1) | 2.90(-1) | 2.69(-1) | 6.67(-2) | 6.55(-2) | 6.39(-1) | 5.99(-2) |
| 21.48 | 1.55(-1) | 1.56(-1) | 1.56(-1) | 1.49(-1) | 3.85(-2) | 3.69(-2) | 3.69(-2) | 3.53(-2) |
| 41.96 | 8.23(-2) | 8.16(-2) | 8.19(-2) | 7.95(-2) | 2.19(-2) | 2.05(-2) | 2.07(-2) | 2.00(-2) |
| 50.00 | | 6.88(-2) | 6.92(-2) | 6.74(-2) | | 1.76(-2) | 1.78(-2) | 1.72(-2) |
| 75.00 | | 4.65(-2) | 4.68(-2) | 4.59(-2) | | 1.23(-2) | 1.25(-2) | 1.21(-2) |
| 100.00 | | 3.52(-2) | 3.55(-2) | 3.49(-2) | | 9.52(-3) | 9.66(-3) | 9.44(-3) |

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TABLE 2: LITHIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

| | 2s-5p | | | | 2s-3s | | | |
|---|---|---|---|---|---|---|---|---|
| | ε = 0.356 | | | | ε = 0.248 | | | |
| N | BORN(V) | BORN | BETHE | OCHKUR | BORN(V) | BORN | BETHE | OCHKUR |
| 1.02 | 8.95(-2) | 9.07(-2) | 7.90(-2) | 9.12(-2) | 1.21(0) | 1.23(-0) | 1.03(0) | 1.20(-0) |
| 1.04 | 1.20(-1) | 1.21(-1) | 8.43(-2) | 1.26(-1) | 1.66(0) | 1.68(-0) | 1.83(0) | 1.64(-0) |
| 1.08 | 1.52(-1) | 1.54(-1) | 9.03(-2) | 1.66(-1) | 2.21(0) | 2.24(-0) | 2.72(0) | 2.17(-0) |
| 1.16 | 1.76(-1) | 1.79(-1) | 9.58(-2) | 1.97(-1) | 2.79(0) | 2.83(-0) | 3.55(0) | 2.62(-0) |
| 1.32 | 1.77(-1) | 1.82(-1) | 9.81(-2) | 2.00(-1) | 3.25(0) | 3.27(-0) | 4.04(0) | 2.91(-0) |
| 1.64 | 1.50(-1) | 1.55(-1) | 9.35(-2) | 1.56(-1) | 3.33(0) | 3.32(-0) | 3.94(0) | 2.83(-0) |
| 2.28 | 1.09(-1) | 1.12(-1) | 8.00(-2) | 9.78(-2) | 2.90(0) | 2.88(-0) | 3.23(0) | 2.45(-0) |
| 3.56 | 7.21(-2) | 7.32(-2) | 6.09(-2) | 6.02(-2) | 2.12(0) | 2.10(-0) | 2.25(0) | 1.86(-0) |
| 6.12 | 4.54(-2) | 4.51(-2) | 4.15(-2) | 3.89(-2) | 1.34(0) | 1.33(-0) | 1.37(0) | 1.23(-0) |
| 11.24 | 2.78(-2) | 2.69(-2) | 2.62(-2) | 2.47(-2) | 7.68(0) | 7.55(-1) | 7.66(-1) | 7.24(-1) |
| 21.48 | 1.65(-2) | 1.56(-2) | 1.56(-2) | 1.50(-2) | 4.12(0) | 4.05(-1) | 4.06(-1) | 3.96(-1) |
| 41.96 | 9.63)-3) | 8.89(-3) | 8.99(-3) | 8.71(-3) | 2.14(0) | 2.10(-1) | 2.10(-1) | 2.08(-1) |
| 50.00 | | 7.66(-3) | 7.76(-3) | 7.53(-3) | | 1.77(-1) | 1.76(-1) | 1.75(-1) |
| 75.00 | | 5.43(-3) | 5.51(-3) | 5.37(-3) | | 1.18(-1) | 1.18(-1) | 1.17(-1) |
| 100.00 | | 4.24(-3) | 4.31(-3) | 4.21(-3) | | 8.88(-1) | 8.83(-2) | 8.83(-2) |

| | 2s-4s | | | | 2s-5s | | | |
|---|---|---|---|---|---|---|---|---|
| | ε = 0.320 | | | | ε = 0.350 | | | |
| N | BORN(V) | BORN | BETHE | OCHKUR | BORN(V) | BORN | BETHE | OCHKUR |
| 1.02 | 2.13(-1) | 2.17(-1) | 4.43(-1) | 2.11(-1) | 7.81(-2) | 7.89(-2) | 1.83(-1) | 7.65(-2) |
| 1.04 | 2.91(-1) | 2.96(-1) | 5.31(-1) | 2.86(-1) | 1.07(-1) | 1.08(-1) | 2.10(-1) | 1.04(-1) |
| 1.08 | 3.86(-1) | 3.91(-1) | 6.24(-1) | 3.76(-1) | 1.41(-1) | 1.42(-1) | 2.36(-1) | 1.36(-1) |
| 1.16 | 4.84(-1) | 4.88(-1) | 7.00(-1) | 4.47(-1) | 1.76(-1) | 1.76(-1) | 2.59(-1) | 1.60(-1) |
| 1.32 | 5.55(-1) | 5.56(-1) | 7.24(-1) | 4.86(-1) | 2.01(-1) | 2.00(-1) | 2.62(-1) | 1.73(-1) |
| 1.64 | 5.58(-1) | 5.56(-1) | 6.64(-1) | 4.64(-1) | 2.00(-1) | 1.98(-1) | 2.37(-1) | 1.65(-1) |
| 2.28 | 4.76(-1) | 4.71(-1) | 5.25(-1) | 3.96(-1) | 1.60(-1) | 1.67(-1) | 1.85(-1) | 1.40(-1) |
| 3.56 | 3.42(-1) | 3.37(-1) | 3.57(-1) | 2.97(-1) | 1.21(-1) | 1.18(-1) | 1.25(-1) | 1.04(-1) |
| 6.12 | 2.13(-1) | 2.09(-1) | 2.15(-1) | 1.93(-1) | 7.50(-2) | 7.32(-2) | 7.52(-2) | 6.76(-2) |
| 11.24 | 1.20(-1) | 1.18(-1) | 1.19(-1) | 1.13(-1) | 4.23(-2) | 4.12(-2) | 4.17(-2) | 3.94(-2) |
| 21.48 | 6.43(-2) | 6.30(-2) | 6.31(-2) | 6.15(-2) | 2.25(-2) | 2.19(-2) | 2.20(-2) | 2.14(-2) |
| 41.96 | 3.32(-2) | 3.25(-2) | 3.25(-2) | 3.22(-2) | 1.16(-2) | 1.13(-2) | 1.13(-2) | 1.12(-2) |
| 50.00 | | 2.74(-2) | 2.73(-2) | 2.71(-2) | | 9.53(-3) | 9.50(-2) | 9.43(-3) |
| 75.00 | | 1.83(-2) | 1.82(-2) | 1.82(-2) | | 6.37(-3) | 6.34(-3) | 6.32(-3) |
| 100.00 | | 1.37(-2) | 1.37(-2) | 1.37(-2) | | 4.78(-3) | 4.76(-3) | 4.76(-3) |

See page 164 for Explanation of Tables

TABLE 2: LITHIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

| | 2s-3d $\epsilon$ = 0.286 | | | | 2s-4d $\epsilon$ = 0.334 | | | |
|---|---|---|---|---|---|---|---|---|
| N | BORN(V) | BORN | BETHE | OCHKUR | BORN(V) | BORN | BETHE | OCHKUR |
| 1.02 | 1.38(0) | 1.31(-0) | 0.0 | 1.26(-0) | 4.09(-1) | 3.91(-1) | 0.0 | 3.79(-1) |
| 1.04 | 1.90(0) | 1.80(-0) | 0.0 | 1.73(-0) | 5.62(-1) | 5.36(-1) | 0.0 | 5.16(-1) |
| 1.08 | 2.56(0) | 2.43(-0) | 0.0 | 2.31(-0) | 7.56(-1) | 7.15(-1) | 0.0 | 6.83(-1) |
| 1.16 | 3.31(0) | 3.13(-0) | 0.0 | 2.83(-0) | 9.53(-1) | 9.07(-1) | 2.60(-1) | 8.25(-1) |
| 1.32 | 3.96(0) | 3.73(-0) | 9.82(-1) | 3.24(-0) | 1.11(0) | 1.06(-0) | 7.26(-1) | 9.22(-1) |
| 1.64 | 4.19(0) | 3.94(-0) | 2.81(-1) | 3.32(-0) | 1.14(0) | 1.08(-0) | 9.54(-1) | 9.10(-1) |
| 2.28 | 3.77(0) | 3.52(-0) | 3.18(-0) | 3.01(-0) | 9.86(-1) | 9.35(-1) | 9.00(-1) | 7.94(-1) |
| 3.56 | 2.82(0) | 2.63(-0) | 2.56(-0) | 2.35(-0) | 7.16(-1) | 6.79(-1) | 6.72(-1) | 6.02(-1) |
| 6.12 | 1.81(0) | 1.69(-0) | 1.67(-0) | 1.58(-0) | 4.50(-1) | 4.26(-1) | 4.25(-1) | 3.96(-1) |
| 11.24 | 1.04(0) | 9.70(-1) | 9.69(-1) | 9.35(-1) | 2.56(-1) | 2.42(-1) | 2.42(-1) | 2.32(-1) |
| 21.48 | 5.62(-1) | 5.23(-1) | 5.23(-1) | 5.13(-1) | 1.37(-1) | 1.30(-1) | 1.30(-1) | 1.26(-1) |
| 41.96 | 2.92(-1) | 2.72(-1) | 2.72(-1) | 2.69(-1) | 7.08(-2) | 6.71(-2) | 6.71(-2) | 6.63(-2) |
| 50.00 | | 2.29(-1) | 2.29(-1) | 2.27(-1) | | 5.64(-2) | 5.64(-2) | 5.59(-2) |
| 75.00 | | 1.53(-1) | 1.53(-1) | 1.52(-1) | | 3.77(-2) | 3.77(-2) | 3.75(-2) |
| 100.00 | | 1.51(-1) | 1.15(-1) | 1.15(-1) | | 2.83(-2) | 2.84(-2) | 2.82(-2) |

2s-5d

$\epsilon$ = 0.356

| N | BORN(V) | BORN | BETHE | OCHKUR |
|---|---|---|---|---|
| 1.02 | 1.79(-1) | 1.71(-1) | 0.0 | 1.66(-1) |
| 1.04 | 2.45(-1) | 2.35(-1) | 0.0 | 2.26(-1) |
| 1.08 | 3.26(-1) | 3.12(-1) | 2.23(-2) | 2.98(-1) |
| 1.16 | 4.10(-1) | 3.93(-1) | 2.14(-1) | 3.58(-1) |
| 1.32 | 4.73(-1) | 4.52(-1) | 3.65(-1) | 3.95(-1) |
| 1.64 | 4.78(-1) | 4.57(-1) | 4.25(-1) | 3.84(-1) |
| 2.28 | 4.08(-1) | 3.90(-1) | 3.82(-1) | 3.30(-1) |
| 3.56 | 2.93(-1) | 2.80(-1) | 2.78(-1) | 2.47(-1) |
| 6.12 | 1.82(-1) | 1.74(-1) | 1.74(-1) | 1.61(-1) |
| 11.24 | 1.03(-1) | 9.85(-2) | 9.85(-2) | 9.43(-2) |
| 21.48 | 5.50(-2) | 5.26(-2) | 5.26(-2) | 5.14(-2) |
| 41.96 | 2.85(-2) | 2.72(-2) | 2.72(-2) | 2.69(-2) |
| 50.00 | | 2.29(-2) | 2.29(-2) | 2.26(-2) |
| 75.00 | | 1.53(-2) | 1.53(-2) | 1.52(-2) |
| 100.00 | | 1.15(-2) | 1.15(-2) | 1.14(-2) |

See page 164 for Explanation of Tables

TABLE 3: SODIUM ELECTRON EXCITATION CROSS SECTIONS

| | 3s-4p | | | 3s-5p | | | 3s-6p | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.276 | | | ε = 0.320 | | | ε = 0.34 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 1.43(0) | 6.61(-0) | 1.40(-1) | 3.85(-1) | 1.66(-0) | 3.75(-1) | 1.64(-1) | 6.77(-1) | 1.59(-1) |
| 1.04 | 1.95(0) | 6.56(-0) | 1.91(-0) | 5.23(-1) | 1.64(-0) | 5.11(-1) | 2.22(-1) | 6.66(-1) | 2.16(-1) |
| 1.08 | 2.58(0) | 6.42(-0) | 2.53(-0) | 6.83(-1) | 1.59(-0) | 6.68(-1) | 2.89(-1) | 6.44(-1) | 2.82(-1) |
| 1.16 | 3.20(0) | 6.10(-0) | 3.03(-0) | 8.37(-1) | 1.49(-0) | 7.88(-1) | 3.51(-1) | 6.30(-1) | 3.30(-1) |
| 1.32 | 3.63(0) | 5.52(-0) | 3.28(-0) | 9.25(-1) | 1.33(-0) | 8.32(-1) | 3.84(-1) | 5.34(-1) | 3.44(-1) |
| 1.64 | 3.60(0) | 4.60(-0) | 3.06(-0) | 8.90(-1) | 1.09(-0) | 7.46(-1) | 3.65(-1) | 4.35(-1) | 3.04(-1) |
| 2.28 | 3.06(0) | 3.45(-0) | 2.53(-0) | 7.30(-1) | 7.97(-1) | 5.92(-1) | 2.96(-1) | 3.17(-1) | 2.37(-1) |
| 3.56 | 2.22(0) | 2.32(-0) | 1.88(-0) | 5.13(-1) | 5.22(-1) | 4.26(-1) | 2.05(-1) | 2.06(-1) | 1.68(-1) |
| 6.12 | 1.42(0) | 1.42(0) | 1.26(-0) | 3.18(-1) | 3.11(-1) | 2.75(-1) | 1.26(-1) | 1.22(-1) | 1.08(-1) |
| 11.24 | 8.39(-1) | 8.10(-1) | 7.62(-1) | 1.82(-1) | 1.73(-1) | 1.63(-1) | 7.10(-2) | 6.73(-1) | 6.30(-2) |
| 21.48 | 4.68(-1) | 4.45(-1) | 4.32(-1) | 9.91(-2) | 9.30(-2) | 9.00(-2) | 3.83(-2) | 3.58(-2) | 3.47(-2) |
| 41.96 | 2.54(-1) | 2.39(-1) | 2.36(-1) | 5.25(-2) | 4.88(-2) | 4.81(-2) | 2.01(-2) | 1.86(-2) | 1.84(-2) |
| 50.00 | | 2.03(-1) | 2.01(-1) | | 4.12(-2) | 4.07(-2) | | 1.57(-2) | 1.55(-2) |
| 75.00 | | 1.39(-1) | 1.38(-1) | | 2.79(-2) | 2.77(-2) | | 1.06(-2) | 1.05(-2) |
| 100.00 | | 1.06(-1) | 1.06(-1) | | 2.11(-2) | 2.10(-2) | | 7.98(-3) | 7.95(-3) |

| | 3s-7p | | | 3s-4s | | | 3s-5s | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.352 | | | ε = 0.234 | | | ε = 0.302 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 8.65(-2) | 3.47(-1) | 8.38(-2) | 1.27(0) | 6.92(-1) | 1.32(-0) | 2.25(-1) | 4.60(-1) | 2.32(-1) |
| 1.04 | 1.17(-1) | 3.41(-1) | 1.14(-1) | 1.75(0) | 1.70(0) | 1.81(-0) | 3.08(-1) | 5.70(-1) | 3.14(-1) |
| 1.08 | 1.52(-1) | 3.30(-1) | 1.48(-1) | 2.33(0) | 2.83(0) | 2.39(-0) | 4.09(-1) | 6.89(-1) | 4.12(-1) |
| 1.16 | 1.84(-1) | 3.08(-1) | 1.73(-1) | 2.96(0) | 3.89(0) | 2.89(-0) | 5.15(-1) | 7.89(-1) | 4.90(-1) |
| 1.32 | 2.01(-1) | 2.73(-1) | 1.78(-1) | 3.47(0) | 4.57(0) | 3.23(-0) | 5.96(-1) | 8.29(-1) | 5.37(-1) |
| 1.64 | 1.90(-1) | 2.21(-1) | 1.57(-1) | 3.58(0) | 4.54(0) | 3.19(-0) | 6.06(-1) | 7.67(-1) | 5.24(-1) |
| 2.28 | 1.53(-1) | 1.61(-1) | 1.21(-1) | 3.15(0) | 3.76(0) | 2.82(-0) | 5.21(-1) | 6.10(-1) | 4.58(-1) |
| 3.56 | 1.06(-1) | 1.04(-1) | 8.54(-2) | 2.32(0) | 2.63(0) | 2.17(-0) | 3.76(-1) | 4.17(-1) | 3.46(-1) |
| 6.12 | 6.47(-2) | 6.13(-2) | 5.43(-2) | 1.47(0) | 1.61(0) | 1.44(-0) | 2.35(-1) | 2.52(-1) | 2.27(-1) |
| 11.24 | 3.65(-2) | 3.38(-2) | 3.17(-2) | 8.43(-1) | 9.00(-1) | 8.51(-1) | 1.33(-1) | 1.40(-1) | 1.32(-1) |
| 21.48 | 1.96(-2) | 1.79(-2) | 1.73(-2) | 4.53(-1) | 4.78(-1) | 4.66(-1) | 7.11(-2) | 7.40(-2) | 7.21(-2) |
| 41.96 | 1.03(-2) | 9.30(-3) | 9.16(-3) | 2.35(-1) | 2.46(-1) | 2.44(-1) | 3.68(-2) | 3.81(-2) | 3.77(-2) |
| 50.00 | | 7.83(-3) | 7.73(-3) | | 2.07(-1) | 2.07(-1) | | 3.20(-2) | 3.18(-2) |
| 75.00 | | 5.26(-3) | 5.22(-3) | | 1.38(-1) | 1.38(-1) | | 2.14(-2) | 2.13(-2) |
| 100.00 | | 3.97(-3) | 3.95(-3) | | 1.04(-1) | 1.04(-1) | | 1.60(-2) | 1.60(-2) |

See page 164 for Explanation of Tables

TABLE 3: SODIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

| | 3s-6s | | | 3s-7s | | | 3s-3d | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\epsilon$ = 0.332 | | | $\epsilon$ = 0.346 | | | $\epsilon$ = 0.266 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 8.02(-2) | 1.96(-1) | 8.40(-2) | 3.94(-2) | 1.00(-1) | 4.07(-2) | 1.94(0) | 0.0 | 1.80(-0) |
| 1.04 | 1.10(-1) | 2.30(-1) | 1.14(-1) | 5.40(-2) | 1.16(-1) | 5.50(-2) | 2.67(0) | 0.0 | 2.46(-0) |
| 1.08 | 1.46(-1) | 2.65(-1) | 1.48(-1) | 7.16(-2) | 1.31(-1) | 7.17(-2) | 3.60(0) | 0.0 | 3.28(-0) |
| 1.16 | 1.83(-1) | 2.94(-1) | 1.76(-1) | 8.99(-2) | 1.44(-1) | 8.46(-2) | 4.62(0) | 0.0 | 4.02(-0) |
| 1.32 | 2.11(-1) | 3.01(-1) | 1.91(-1) | 1.03(-1) | 1.46(-1) | 9.19(-2) | 5.49(0) | 0.0 | 4.60(-0) |
| 1.64 | 2.14(-1) | 2.73(-1) | 1.86(-1) | 1.04(-1) | 1.32(-1) | 8.93(-2) | 5.76(0) | 4.00(-0) | 4.70(-0) |
| 2.28 | 1.83(-1) | 2.15(-1) | 1.62(-1) | 8.87(-2) | 1.03(-1) | 7.75(-2) | 5.13(0) | 4.50(-0) | 4.25(-0) |
| 3.56 | 1.31(-1) | 1.46(-1) | 1.22(-1) | 6.34(-2) | 6.96(-2) | 5.81(-2) | 3.82(0) | 3.60(-0) | 3.31(-0) |
| 6.12 | 8.17(-2) | 8.79(-2) | 7.92(-2) | 3.94(-2) | 4.18(-2) | 3.77(-2) | 2.44(0) | 2.36(-0) | 2.22(-0) |
| 11.24 | 4.61(-2) | 4.88(-2) | 4.62(-2) | 2.22(-2) | 2.32(-2) | 2.20(-2) | 1.40(0) | 1.36(-0) | 1.31(-0) |
| 21.48 | 2.46(-2) | 2.58(-2) | 2.53(-2) | 1.18(-2) | 1.23(-2) | 1.19(-2) | 7.56(-1) | 7.35(-1) | 7.21(-1) |
| 41.96 | 1.27(-2) | 1.33(-2) | 1.31(-2) | 6.11(-3) | 6.30(-3) | 6.24(-3) | 3.93(-1) | 3.82(-1) | 3.78(-1) |
| 50.00 | | 1.11(-2) | 1.11(-2) | | 5.29(-3) | 5.25(-3) | | 3.22(-1) | 3.19(-1) |
| 75.00 | | 7.43(-3) | 7.41(-3) | | 3.53(-3) | 3.52(-3) | | 2.15(-1) | 2.14(-1) |
| 100.00 | | 5.58(-3) | 5.58(-3) | | 2.65(-3) | 2.65(-3) | | 1.62(-1) | 1.61(-1) |

| | 3s-4d | | | 3s-5d | | | 3s-6d | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\epsilon$ = 0.314 | | | $\epsilon$ = 0.338 | | | $\epsilon$ = 0.350 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 5.45(-1) | 0.0 | 5.11(-1) | 2.34(-1) | 0.0 | 2.19(-1) | 1.22(-1) | 0.0 | 1.16(-1) |
| 1.04 | 7.46(-1) | 0.0 | 6.96(-1) | 3.19(-1) | 0.0 | 2.98(-1) | 1.67(-1) | 3.28(-2) | 1.57(-1) |
| 1.08 | 9.92(-1) | 0.0 | 9.16(-1) | 4.22(-1) | 1.53(-1) | 3.92(-1) | 2.20(-1) | 1.26(-1) | 2.06(-1) |
| 1.16 | 1.25(0) | 5.30(-1) | 1.11(-0) | 5.28(-1) | 3.60(-1) | 4.69(-1) | 2.75(-1) | 2.18(-1) | 2.46(-1) |
| 1.32 | 1.44(0) | 1.06(-0) | 1.23(-0) | 6.02(-1) | 5.15(-1) | 5.14(-1) | 3.11(-1) | 2.83(-1) | 2.67(-1) |
| 1.64 | 1.46(0) | 1.30(-0) | 1.20(-0) | 6.00(-1) | 5.62(-1) | 4.94(-1) | 3.07(-1) | 2.96(-1) | 2.54(-1) |
| 2.28 | 1.25(0) | 1.20(-0) | 1.04(-0) | 5.05(-1) | 4.90(-1) | 4.89(-1) | 2.57(-1) | 2.52(-1) | 2.14(-1) |
| 3.56 | 9.01(-1) | 8.77(-1) | 7.82(-1) | 3.59(-1) | 3.52(-1) | 3.11(-1) | 1.81(-1) | 1.79(-1) | 1.57(-1) |
| 6.12 | 5.62(-1) | 5.51(-1) | 5.12(-1) | 2.22(-1) | 2.18(-1) | 2.02(-1) | 1.12(-1) | 1.10(-1) | 1.02(-1) |
| 11.24 | 3.18(-1) | 3.13(-1) | 3.00(-1) | 1.25(-1) | 1.23(-1) | 1.18(-1) | 6.27(-1) | 6.20(-2) | 5.93(-2) |
| 21.48 | 1.70(-1) | 1.67(-1) | 1.63(-1) | 6.65(-2) | 6.56(-2) | 6.40(-2) | 3.33(-2) | 3.30(-2) | 3.22(-2) |
| 41.96 | 8.79(-2) | 8.65(-2) | 8.55(-2) | 3.44(-2) | 3.39(-2) | 3.35(-2) | 1.72(-2) | 1.71(-2) | 1.68(-2) |
| 50.00 | | 7.27(-2) | 7.20(-2) | | 2.85(-2) | 2.82(-2) | | 1.43(-2) | 1.42(-2) |
| 75.00 | | 4.86(-2) | 4.83(-2) | | 1.90(-2) | 1.89(-2) | | 9.58(-3) | 9.51(-3) |
| 100.00 | | 3.65(-2) | 3.63(-2) | | 1.43(-2) | 1.42(-2) | | 7.19(-3) | 7.15(-3) |

See page 164 for Explanation of Tables

TABLE 3: SODIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

3s-7d

ε = 0.358

| N | BORN(V) | BETHE | OCHKUR |
|---|---|---|---|
| 1.02 | 7.31(-2) | 0.0 | 6.89(-2) |
| 1.04 | 9.97(-2) | 3.86(-2) | 9.35(-2) |
| 1.08 | 1.31(-1) | 8.92(-2) | 1.23(-1) |
| 1.16 | 1.63(-1) | 1.38(-1) | 1.46(-1) |
| 1.32 | 1.84(-1) | 1.72(-1) | 1.58(-1) |
| 1.64 | 1.81(-1) | 1.75(-1) | 1.49(-1) |
| 2.28 | 1.50(-1) | 1.48(-1) | 1.25(-1) |
| 3.56 | 1.06(-1) | 1.05(-1) | 9.16(-2) |
| 6.12 | 6.48(-2) | 6.42(-2) | 5.91(-2) |
| 11.24 | 3.64(-2) | 3.60(-2) | 3.44(-2) |
| 21.48 | 1.94(-2) | 1.92(-2) | 1.87(-2) |
| 41.96 | 9.97(-3) | 9.88(-3) | 9.76(-3) |
| 50.00 | | 8.31(-3) | 8.22(-3) |
| 75.00 | | 5.55(-3) | 5.51(-3) |
| 100.00 | | 4.17(-3) | 4.14(-3) |

TABLE 4: POTASSIUM ELECTRON EXCITATION CROSS SECTIONS

| | 4s-5p ε = 0.226 | | | 4s-6p ε = 0.264 | | | 4s-7p ε = 0.284 | | |
|---|---|---|---|---|---|---|---|---|---|
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 2.24(0) | 1.13(+1) | 2.19(0) | 5.92(-1) | 2.72(0) | 5.78(-1) | 2.51(-1) | 1.09(0) | 2.44(-1) |
| 1.04 | 3.06(0) | 1.12(+1) | 2.98(0) | 8.05(-1) | 2.67(0) | 7.81(-1) | 3.40(-1) | 1.07(0) | 3.30(-1) |
| 1.08 | 4.03(0) | 1.09(+1) | 3.90(0) | 1.06(0) | 2.59(0) | 1.01(0) | 4.44(-1) | 1.04(0) | 4.26(-1) |
| 1.16 | 5.01(0) | 1.03(+1) | 4.63(0) | 1.29(0) | 2.42(0) | 1.18(0) | 5.42(-1) | 9.68(-1) | 4.92(-1) |
| 1.32 | 5.69(0) | 9.20(0) | 5.00(0) | 1.44(0) | 2.14(0) | 1.24(0) | 5.99(-1) | 8.55(-1) | 5.11(-1) |
| 1.64 | 5.57(0) | 7.60(0) | 4.74(0) | 1.40(0) | 1.74(0) | 1.14(0) | 5.76(-1) | 6.92(-1) | 4.62(-1) |
| 2.28 | 4.84(0) | 5.63(0) | 4.02(0) | 1.16(0) | 1.27(0) | 9.30(-1) | 4.70(-1) | 5.01(-1) | 3.72(-1) |
| 3.56 | 3.32(0) | 3.73(0) | 3.02(0) | 8.21(-1) | 8.24(-1) | 6.74(-1) | 3.28(-1) | 3.24(-1) | 2.67(-1) |
| 6.12 | 2.25(0) | 2.25(0) | 2.00(0) | 5.11(-1) | 4.86(-1) | 4.33(-1) | 2.02(-1) | 1.90(-1) | 1.70(-1) |
| 11.24 | 1.32(0) | 1.27(0) | 1.20(0) | 2.92(-1) | 2.70(-1) | 2.53(-1) | 1.14(-1) | 1.04(-1) | 9.82(-2) |
| 21.48 | 7.34(-1) | 6.90(-1) | 6.71(-1) | 1.59(-1) | 1.43(-1) | 1.39(-1) | 6.17(-2) | 5.51(-2) | 5.35(-2) |
| 41.96 | 3.97(-1) | 3.66(-1) | 3.62(-1) | 8.44(-2) | 7.43(-2) | 7.34(-2) | 3.24(-2) | 2.85(-2) | 2.81(-2) |
| 50.00 | | 3.10(-1) | 3.07(-1) | | 6.26(-2) | 6.20(-2) | | 2.40(-2) | 2.37(-2) |
| 75.00 | | 2.11(-1) | 2.10(-1) | | 4.22(-2) | 4.19(-2) | | 1.61(-2) | 1.60(-2) |
| 100.00 | | 1.61(-1) | 1.60(-1) | | 3.18(-2) | 3.17(-2) | | 1.21(-2) | 1.21(-2) |

See page 164 for Explanation of Tables

TABLE 4: POTASSIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

| | 4s-5s | | | 4s-6s | | | 4s-7s | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.192 | | | ε = 0.250 | | | ε = 0.276 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 1.66(0) | 0.0 | 1.91(0) | 2.90(-1) | 5.38(-1) | 3.24(-1) | 1.01(-1) | 2.58(-1) | 1.17(-1) |
| 1.04 | 2.29(0) | 9.14(-1) | 2.60(0) | 4.00(-1) | 7.56(-1) | 4.39(-1) | 1.39(-1) | 3.25(-1) | 1.57(-1) |
| 1.08 | 3.09(0) | 3.22(0) | 3.45(0) | 5.38(-1) | 9.95(-1) | 5.77(-1) | 1.87(-1) | 3.96(-1) | 2.06(-1) |
| 1.16 | 3.96(0) | 5.48(0) | 4.19(0) | 6.93(-1) | 1.21(0) | 6.94(-1) | 2.41(-1) | 4.57(-1) | 2.47(-1) |
| 1.32 | 4.77(0) | 7.08(0) | 4.79(0) | 8.24(-1) | 1.32(0) | 7.89(-1) | 2.88(-1) | 4.82(-1) | 2.81(-1) |
| 1.64 | 5.06(0) | 7.38(0) | 5.00(0) | 8.66(-1) | 1.26(0) | 8.20(-1) | 3.02(-1) | 4.48(-1) | 2.92(-1) |
| 2.28 | 4.38(0) | 6.28(0) | 4.66(0) | 7.53(-1) | 1.01(0) | 7.52(-1) | 2.67(-1) | 3.57(-1) | 2.66(-1) |
| 3.56 | 3.42(0) | 4.46(0) | 3.69(0) | 5.60(-1) | 6.98(-1) | 5.82(-1) | 1.94(-1) | 2.44(-1) | 2.04(-1) |
| 6.12 | 2.19(0) | 2.75(0) | 2.47(0) | 3.53(-1) | 4.24(-1) | 3.83(-1) | 1.22(-1) | 1.48(-1) | 1.34(-1) |
| 11.24 | 1.26(0) | 1.55(0) | 1.47(0) | 2.01(-1) | 2.36(-1) | 2.25(-1) | 6.90(-2) | 8.21(-2) | 7.01(-2) |
| 21.48 | 6.80(-1) | 8.22(0) | 8.04(-1) | 1.08(-1) | 1.25(-1) | 1.22(-1) | 3.59(-2) | 4.34(-2) | 4.25(-2) |
| 41.96 | 3.53(-1) | 4.24(-1) | 4.22(-1) | 5.57(-2) | 6.45(-2) | 6.40(-2) | 1.91(-2) | 2.24(-2) | 2.22(-2) |
| 50.00 | | 3.57(-1) | 3.55(-1) | | 5.42(-2) | 5.39(-2) | | 1.88(-2) | 1.87(-2) |
| 75.00 | | 2.38(-1) | 2.38(-1) | | 3.62(-2) | 3.62(-2) | | 1.25(-2) | 1.25(-2) |
| 100.00 | | 1.70(-1) | 1.80(-1) | | 2.72(-2) | 2.72(-2) | | 9.41(-3) | 9.42(-3) |

| | 4s-3d | | | 4s-4d | | | 4s-5d | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.196 | | | ε = 0.250 | | | ε = 0.276 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 7.64(0) | 1.77(+1) | 8.27(0) | 1.36(0) | 0.0 | 5.91(-1) | 4.27(-1) | 0.0 | 5.25(-2) |
| 1.04 | 1.04(1) | 9.86(+1) | 1.14(-1) | 1.84(0) | 0.0 | 8.38(-1) | 5.75(-1) | 0.0 | 8.48(-2) |
| 1.08 | 1.38(1) | 7.84(-1) | 1.53(+1) | 2.39(0) | 1.99(-1) | 1.15(0) | 7.39(-1) | 0.0 | 1.40(-1) |
| 1.16 | 1.74(1) | 8.50(0) | 1.87(+1) | 2.88(0) | 5.12(-1) | 1.46(0) | 8.76(-1) | 0.0 | 2.18(-1) |
| 1.32 | 1.98(1) | 1.59(+1) | 2.10(+1) | 3.11(0) | 7.49(-1) | 1.64(0) | 9.17(-1) | 0.0 | 3.10(-1) |
| 1.64 | 1.97(1) | 1.91(+1) | 1.99(+1) | 2.87(0) | 8.25(-1) | 1.37(0) | 8.12(-1) | 0.0 | 3.22(-1) |
| 2.28 | 1.67(1) | 1.73(+1) | 1.60(+1) | 2.23(0) | 7.22(-1) | 8.45(-1) | 6.07(-1) | 1.52(-1) | 2.47(-1) |
| 3.56 | 1.20(1) | 1.27(+1) | 1.14(+1) | 1.49(0) | 5.20(-1) | 4.65(-1) | 3.93(-1) | 1.68(-1) | 1.70(-1) |
| 6.12 | 7.46(0) | 7.98(0) | 7.31(0) | 8.86(-1) | 3.23(-1) | 2.75(-1) | 2.30(-1) | 1.23(-1) | 1.15(-1) |
| 11.24 | 4.23(0) | 4.52(0) | 4.29(0) | 4.88(-1) | 1.82(-1) | 1.63(-1) | 1.25(-1) | 7.47(-2) | 7.06(-2) |
| 21.48 | 2.26(0) | 2.42(0) | 2.35(0) | 2.57(-1) | 9.70(-2) | 2.08(-2) | 6.65(-1) | 4.12(-2) | 3.98(-2) |
| 41.96 | 1.17(0) | 1.25(0) | 1.23(0) | 1.32(-1) | 5.01(-2) | 4.83(-2) | 3.35(-2) | 2.17(-2) | 2.13(-2) |
| 50.00 | | 1.05(0) | 1.04(0) | | 4.21(-2) | 4.08(-2) | | 1.83(-2) | 1.80(-2) |
| 75.00 | | 7.03(-1) | 6.96(-1) | | 2.82(-2) | 2.76(-2) | | 1.23(-2) | 1.21(-2) |
| 100.00 | | 5.28(-1) | 5.24(-1) | | 2.12(-2) | 2.08(-2) | | 9.25(-3) | 9.17(-3) |

See page 164 for Explanation of Tables

TABLE 4: POTASSIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

4s-6d

$\varepsilon$ = 0.288

| N | BORN(V) | BETHE | OCHKUR |
|---|---|---|---|
| 1.02 | 2.08(-1) | 0.0 | 8.01(-3) |
| 1.04 | 2.80(-1) | 0.0 | 1.72(-2) |
| 1.08 | 3.59(-1) | 0.0 | 3.76(-2) |
| 1.16 | 4.23(-1) | 0.0 | 7.39(-2) |
| 1.32 | 4.39(-1) | 0.0 | 1.28(-1) |
| 1.64 | 3.86(-1) | 1.18(-2) | 1.56(-1) |
| 2.28 | 2.87(-1) | 1.01(-1) | 1.40(-1) |
| 3.56 | 1.86(-1) | 1.06(-1) | 1.06(-1) |
| 6.12 | 1.08(-1) | 7.65(-2) | 7.28(-2) |
| 11.24 | 5.89(-2) | 4.62(-2) | 4.45(-2) |
| 21.48 | 3.08(-2) | 2.55(-2) | 2.49(-2) |
| 41.96 | 1.58(-2) | 1.34(-2) | 1.32(-2) |
| 50.00 | | 1.13(-2) | 1.11(-2) |
| 75.00 | | 7.56(-3) | 7.51(-3) |
| 100.00 | | 5.69(-3) | 5.66(-3) |

TABLE 5: RUBIDIUM ELECTRON EXCITATION CROSS SECTIONS

| | 5s-6p | | | 5s-7p | | | 5s-8p | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\varepsilon$ = 0.216 | | | $\varepsilon$ = 0.254 | | | $\varepsilon$ = 0.272 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 2.47(0) | 1.32(+1) | 2.36(0) | 6.48(-1) | 3.29(0) | 6.29(-1) | 2.79(-1) | 1.35(0) | 2.68(-1) |
| 1.04 | 3.37(0) | 1.31(+1) | 3.20(0) | 8.84(-1) | 3.25(0) | 8.48(-1) | 3.80(-1) | 1.33(0) | 3.60(-1) |
| 1.08 | 4.47(0) | 1.28(+1) | 4.20(0) | 1.17(0) | 3.15(0) | 1.10(0) | 5.01(-1) | 1.28(0) | 4.65(-1) |
| 1.16 | 5.62(0) | 1.21(+1) | 5.01(0) | 1.46(0) | 2.96(0) | 1.29(0) | 6.23(-1) | 1.20(0) | 5.42(-1) |
| 1.32 | 6.47(0) | 1.10(+1) | 5.51(0) | 1.67(0) | 2.64(0) | 1.39(0) | 7.08(-1) | 1.07(0) | 5.76(-1) |
| 1.64 | 6.68(0) | 9.15(0) | 5.43(0) | 1.68(0) | 2.16(0) | 1.33(0) | 7.06(-1) | 8.70(-1) | 5.46(-1) |
| 2.28 | 5.73(0) | 6.86(0) | 4.81(0) | 1.44(0) | 1.59(0) | 1.14(0) | 6.00(-1) | 6.35(-1) | 4.61(-1) |
| 3.56 | 4.26(0) | 4.60(0) | 3.72(0) | 1.05(0) | 1.04(0) | 8.50(-1) | 4.33(-1) | 4.13(-1) | 3.39(-1) |
| 6.12 | 2.77(0) | 2.81(0) | 2.51(0) | 6.76(-1) | 6.21(-1) | 5.55(-1) | 2.75(-1) | 2.45(-1) | 2.19(-1) |
| 11.24 | 1.65(0) | 1.60(0) | 1.52(0) | 3.98(-1) | 3.47(-1) | 3.28(-1) | 1.50(-1) | 1.36(-1) | 1.28(-1) |
| 21.48 | 9.29(-1) | 8.83(-1) | 8.60(-1) | 2.22(-1) | 1.87(-1) | 1.82(-1) | 8.86(-2) | 7.25(-2) | 7.06(-2) |
| 41.96 | 5.08(-1) | 4.74(-1) | 4.69(-1) | 1.20(-1) | 9.81(-2) | 9.70(-2) | 4.47(-2) | 3.78(-2) | 3.74(-2) |
| 50.00 | | 4.02(-1) | 3.99(-1) | | 8.29(-2) | 8.22(-2) | | 3.19(-2) | 3.16(-2) |
| 75.00 | | 2.75(-1) | 2.74(-1) | | 5.61(-2) | 5.59(-2) | | 2.15(-2) | 2.14(-2) |
| 100.00 | | 2.10(-1) | 2.10(-1) | | 4.25(-2) | 4.25(-2) | | 1.63(-2) | 1.62(-2) |

See page 164 for Explanation of Tables

TABLE 5: RUBIDIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

| | 5s-6s | | | 5s-7s | | | 5s-8s | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.183 | | | ε = 0.240 | | | ε = 0.264 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 1.80(-1) | 0.0 | 2.00(0) | 2.78(-1) | 4.80(-1) | 3.35(-1) | 1.06(-1) | 2.54(-1) | 1.20(-1) |
| 1.04 | 2.51(0) | 0.0 | 2.72(0) | 3.85(-1) | 1.48(-1) | 4.54(-1) | 1.47(-1) | 3.36(-1) | 1.62(-1) |
| 1.08 | 3.38(0) | 2.78(0) | 3.62(0) | 5.22(-1) | 1.04(0) | 6.01(-1) | 1.99(-1) | 4.25(-1) | 2.14(-1) |
| 1.16 | 4.38(0) | 5.62(0) | 4.43(0) | 6.81(-1) | 1.31(0) | 7.31(-1) | 2.58(-1) | 5.03(-1) | 2.60(-1) |
| 1.32 | 5.27(0) | 7.71(0) | 5.15(0) | 8.25(-1) | 1.47(0) | 8.50(-1) | 3.12(-1) | 5.40(-1) | 3.03(-1) |
| 1.64 | 5.64(0) | 8.27(0) | 5.52(0) | 8.81(-1) | 1.42(0) | 9.11(-1) | 3.31(-1) | 5.07(-1) | 3.25(-1) |
| 2.28 | 5.10(0) | 7.14(0) | 5.27(0) | 7.88(-1) | 1.15(0) | 8.52(-1) | 2.92(-1) | 4.07(-1) | 3.02(-1) |
| 3.56 | 3.84(0) | 5.10(0) | 4.22(0) | 5.83(-1) | 7.99(-1) | 6.65(-1) | 2.14(-1) | 2.79(-1) | 2.34(-1) |
| 6.12 | 2.47(0) | 3.16(0) | 2.84(0) | 3.69(-1) | 4.86(-1) | 4.40(-1) | 1.35(-1) | 1.69(-1) | 1.54(-1) |
| 11.24 | 1.42(0) | 1.78(0) | 1.69(0) | 2.10(-1) | 2.71(-1) | 2.58(-1) | 7.67(-2) | 9.42(-2) | 8.98(-2) |
| 21.48 | 7.66(-1) | 9.47(-1) | 9.26(-1) | 1.13(-1) | 1.44(-1) | 1.41(-1) | 4.10(-2) | 4.99(-2) | 4.88(-2) |
| 41.96 | 3.98(-1) | 4.89(-1) | 4.86(-1) | 5.85(-2) | 7.42(-2) | 7.36(-2) | 2.12(-2) | 2.57(-2) | 2.55(-2) |
| 50.00 | | 4.11(-1) | 4.10(-1) | | 6.23(-2) | 6.20(-2) | | 2.16(-2) | 2.15(-2) |
| 75.00 | | 2.75(-1) | 2.75(-1) | | 4.16(-2) | 4.16(-2) | | 1.44(-2) | 1.44(-2) |
| 100.00 | | 2.06(-1) | 2.07(-1) | | 3.12(-2) | 3.13(-2) | | 1.08(-2) | 1.08(-2) |

| | 5s-4d | | | 5s-5d | | | 5s-6d | | |
|---|---|---|---|---|---|---|---|---|---|
| | ε = 0.176 | | | ε = 0.234 | | | ε = 0.262 | | |
| N | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR | BORN(V) | BETHE | OCHKUR |
| 1.02 | 1.04(+1) | 0.0 | 1.15(+1) | 1.24(0) | 0.0 | 8.25(-1) | 3.38(-1) | 0.0 | 1.32(-1) |
| 1.04 | 1.43(+1) | 0.0 | 1.59(+1) | 1.67(0) | 1.43(-1) | 1.16(0) | 4.65(-1) | 0.0 | 1.96(-1) |
| 1.08 | 1.88(+1) | 1.61(0) | 2.13(+1) | 2.15(0) | 4.94(-1) | 1.58(0) | 5.83(-1) | 0.0 | 2.85(-1) |
| 1.16 | 2.35(+1) | 1.35(+1) | 2.61(+1) | 2.58(0) | 8.38(-1) | 1.96(0) | 6.89(-1) | 0.0 | 3.86(-1) |
| 1.32 | 2.66(+1) | 2.28(+1) | 2.92(+1) | 2.71(0) | 1.08(0) | 2.13(0) | 7.11(-1) | 0.0 | 4.63(-1) |
| 1.64 | 2.62(+1)) | 2.65(+1) | 2.74(+1) | 2.42(0) | 1.13(0) | 1.73(0) | 6.18(-1) | 5.08(-2) | 4.08(-1) |
| 2.28 | 2.18(+1) | 2.38(+1) | 2.18(+1) | 1.81(0) | 9.59(-1) | 1.05(0) | 4.62(-1) | 1.84(-1) | 2.74(-1) |
| 3.56 | 1.54(+1) | 1.73(+1) | 1.54(+1) | 1.17(0) | 6.80(-1) | 5.94(-1) | 2.91(-1) | 1.84(-1) | 1.77(-1) |
| 6.12 | 9.52(0) | 1.08(+1) | 9.90(0) | 6.84(-1) | 4.19(-1) | 3.58(-1) | 1.79(-1) | 1.30(-1) | 1.18(-1) |
| 11.24 | 5.36(0) | 6.12(0) | 5.80(0) | 3.72(-1) | 2.36(-1) | 2.11(-1) | 9.29(-2) | 7.82(-2) | 7.26(-2) |
| 21.48 | 2.86(0) | 3.27(0) | 3.17(0) | 1.95(-1) | 1.25(-1) | 1.18(-1) | 4.88(-2) | 4.30(-2) | 4.11(-2) |
| 41.96 | 1.48(0) | 1.69(0) | 1.66(0) | 9.98(-2) | 6.47(-2) | 6.25(-2) | 2.50(-2) | 2.25(-2) | 2.20(-2) |
| 50.00 | | 1.42(0) | 1.40(0) | | 5.44(-2) | 5.28(-2) | | 1.90(-2) | 1.86(-2) |
| 75.00 | | 9.51(-1) | 9.42(-1) | | 3.63(-2) | 3.56(-2) | | 1.27(-2) | 1.26(-2) |
| 100.00 | | 7.14(-1) | 7.09(-1) | | 2.73(-2) | 2.69(-2) | | 9.59(-3) | 9.49(-3) |

See page 164 for Explanation of Tables

TABLE 5: RUBIDIUM ELECTRON EXCITATION CROSS SECTIONS (cont'd)

5s-7d

$\epsilon$ = 0.276

| N | BORN(V) | BETHE | OCHKUR |
|---|---|---|---|
| 1.02 | 1.23(-1) | 0.0 | 3.74(-2) |
| 1.04 | 1.66(-1) | 0.0 | 5.87(-2) |
| 1.08 | 2.12(-1) | 0.0 | 9.28(-2) |
| 1.16 | 2.61(-1) | 0.0 | 1.38(-1) |
| 1.32 | 2.60(-1) | 0.0 | 1.82(-1) |
| 1.64 | 2.27(-1) | 7.54(-3) | 1.77(-1) |
| 2.28 | 1.38(-1) | 9.14(-2) | 1.33(-1) |
| 3.56 | 1.10(-1) | 9.68(-2) | 9.50(-2) |
| 6.12 | 6.68(-2) | 7.01(-2) | 6.51(-2) |
| 11.24 | 3.66(-2) | 4.24(-2) | 4.01(-2) |
| 21.48 | 1.93(-2) | 2.34(-2) | 2.26(-2) |
| 41.96 | 9.97(-3) | 1.23(-2) | 1.21(-2) |
| 50.00 | | 1.04(-2) | 1.02(-2) |
| 75.00 | | 6.95(-3) | 6.87(-3) |
| 100.00 | | 5.23(-3) | 5.19(-3) |

See page 164 for Explanation of Tables