Compilation of Low Energy Electron
Collision Cross Section Data
Part II
Line and Level Excitation

by
L. J. Kieffer

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University of Colorado
Boulder, Colorado
September 22, 1969
II. Line and Level Excitation (cont'd.)

$O_2$-----------------147

$N_2O$-----------------153

$CO_2$-----------------155

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I. INTRODUCTION

This is the second part of a comprehensive compilation of low energy electron collision cross section data. The compilation is limited to experimental measurements and includes data for all atomic species and those molecules which are important for aeronomy, astrophysics, and plasma physics. This choice makes the compilation of the data tractable and I believe useful. The data included were taken from literature published through December, 1968. However, reference to some materials is obtained through abstracting journals, so this compilation probably does not include all data published in the late fall of 1968.

Criteria for Data Selection

For the past several years the JILA Information Center has been engaged in a program of critically evaluating the reliability of low energy electron collision cross section data, resulting in publication of three critical reviews.* For the experimental data these reviews attempted to examine in detail the measurement techniques used to obtain the data and to point out, where possible, systematic errors which would cause the data to be in error. The vast majority of the data in the literature** which are not included in this compilation were rejected for one of two reasons. Either the data were not the result of an absolute measurement or were not normalized, or the experimental technique used was not in principle capable of measuring the cross section being compiled.

Among the techniques which in principle were capable of measuring cross sections it was concluded that all the measurements made so far were defective. This means that known sources of systematic error were not taken into account in the error analysis. There is great uncertainty in the absolute magnitude, as well as shape, of the cross sections presented. The best estimate of the range of

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uncertainties due to systematic errors is probably given by the differences between independent measurements. If this is so, it would indicate for the data presented in this part of the compilation a minimum uncertainty of 30-40 percent and a maximum uncertainty of an order of magnitude (i.e., a factor of 10). These estimates are applicable near the maximum of the cross sections. Note that the difference between independent measurements of excitation cross sections is considerably larger than the difference between independently measured ionization cross sections (Part I of this compilation, JILA Information Center Report No. 6).

Many of the systematic errors inherent in these measurement techniques which could lead to these large differences are discussed in detail in the review of Moiseiwitsch and Smith (see footnote on previous page for complete reference).

Almost all of the data included in this compilation were obtained by observing the light output in an atomic line or molecular rotational band at 90° to the direction of the electron beam. The total cross section for that emission can be computed from a knowledge of the solid angle subtended by the detector and the angular distribution of the emitted photons.

Since polarizations (i.e., angular distributions) are in most cases unmeasured and where they are measured there are large differences between independent measurements, the data where possible are given as total cross sections for line emission assuming no polarization and of course no correction for cascading. Specific notes to the graphs and tables explain what corrections have been applied to the data either by the authors or by us. In all cases, data from different authors displayed on the same graph are on a comparable basis.

The techniques for measuring excitation cross sections have so many potential and unexplored systematic errors that it was almost impossible to establish any objective criteria for selection of reliable data which could be applied. This is mainly due to lack of information supplied by authors. We have avoided rejecting older data even where several newer measurements agree with each other but not with older measurements (see page 145, N²⁺ 3914Å, 0,0 band). This agreement is possibly the "locking in" phenomenon. There appears to be, in this case, no objective reason for accepting the newer measurements.

Organization of the Compilation

All of the cross section data in this volume of the compilation are for electronic excitation. The data are organized by initial species in the following order: atoms, diatomic molecules, triatomic
molecules, etc. The atoms are ordered by the \( Z \) number of the nucleus, smallest \( Z \)'s first. For molecules, the \( Z \) number of the atom with the largest \( Z \) in the molecule is taken to characterize the molecule. The molecules are then ordered by these characteristic \( Z \)'s, smallest \( Z \) first. If necessary the second highest \( Z \) atom in the molecule is used in the same way to determine the order. If the line emitted is characteristic of the ionized species, the data are located following the neutral species.

If the initial state is a positive ion the data follow immediately after the neutral species and are indicated in the table of contents. Among the data for any particular initial species the level excitation (i.e., cross sections for exciting the species from one well-defined and specified initial electronic state to a defined and specified final state) precede the line excitation data. The line excitation data are ordered by the wave length emitted, shortest wave lengths first. In some cases cross sections have been measured for only one energy. Such data are collected in a single table for each initial species and placed after all of the graphical data for that initial species.

1) Figure Labels

In order to present the data in as compact a form as possible and still indicate exactly what the process being measured is, a set of labels has been devised. These labels appear in the upper right corner of the figures. The impacting electron energy is given on the abscissa in electron volts. The cross section [indicated by the Greek lower case sigma (\( \sigma \))] for the process per atom or molecule of the original species is given on the ordinate in \( \text{cm}^2 \) units.

Since the laboratory conditions almost never allow a theoretically precise statement of the exact initial and final states of the systems, the labels were chosen to reflect this uncertainty. For atoms and atomic ions the presumption is that the system initially is in its ground electronic state. For sources of ions and atoms such as discharges, high temperature ovens, and charge exchange cells, positive evidence that the target was in its ground electronic state was used as a criterion for selecting the data. For molecules, the initial condition is presumed to be that of a gas in equilibrium at room temperature, except where noted otherwise.

The most common label is:

\[ \text{X 3546A (} ^2 \text{P} \rightarrow ^1 \text{S}) \]

Here and in the following discussion X indicates the species, which may be an atom, molecule, or a positive atomic or molecular ion. In this
example, X is the radiating species. The wavelength of the radiation in angstrom units follows the species. If the classification of the levels involved in the transition is known it is indicated in parentheses following the wavelength. In some cases where unresolved multipliers are involved, only the principal quantum numbers for the levels are indicated.

The second label used is:

\[ X(S_{1/2}) \]

This label indicates that the cross section for direct excitation to the level indicated in parentheses of species X from its ground state, unless otherwise indicated, has been measured.

2) Figure Captions

The figure caption contains abbreviated information about the data sources. The experiment is identified by the name of the first author, followed by a number in parentheses which refers to the bibliographic section where the full citation may be found. When necessary, the caption also contains specific notes about how the data were handled.

3) Bibliographic Sections

Following the figures is the bibliography, a listing of all publications from which data were taken. This list is ordered by the citation numbers which appear in the figure captions as mentioned above.

The last section of the report is an author index which lists all of the authors, not just first ones. Each author’s name is followed by the citation numbers of all his publications from which data were obtained.

General Remarks about the Compilation and Presentation of the Data

Almost all of the data included in this compilation were given in the original literature in graphical form. In the early stages of our compiling activities, attempts were made to obtain tabular data from the authors. If digital data were made available to us they were used, but in general, the effort to obtain digital data from authors was so inefficient that it was abandoned. In most cases blown up photographs of the graphs are made and the data are digitized using a Gerber Digital Data Reduction System which is connected to an IBM card punch. The least count of the Gerber Reader is 0.1 percent of full scale. This uncertainty becomes significant only when the cross sections plotted are less than 10 percent of full scale. Given our estimates of the
accuracy of the original data (see first part of the Introduction), these errors would appear in general to be relatively insignificant. Data which were read from tables or appeared as points on graphs are reproduced as points. Data which appeared in the original publication as a continuous line in a graph are reproduced here as a continuous line.

Where possible we checked the wave length and classification of the lines quoted by the authors. We have corrected any discrepancies between wave length and/or classification using C. R. Harrison, M.I.T. Wavelength Tables, M.I.T. Press, Cambridge, Mass., C. E. Moore, Atomic Energy Levels, Volume I, Circular of the National Bureau of Standards 467, 1949, or A. R. Striganov and N. S. Sventitskii, Tables of Spectral Lines of Neutral and Ionized Atoms, IFI/Plenum, New York, 1968. In most cases the wave length is given only to the nearest angstrom. This is consistent with the resolution used in these experiments. In the case of excitation of molecular rotation bands none of the experiments attempted to resolve the rotational lines. The wave length quoted in these cases is for the band head.

Graphical display of the data is used for several reasons. In cases where there are several measurements it emphasizes the disagreements and acts as a warning for the user. The precision of these data far exceeds their accuracy. A tabular compilation would, I think, tend to convince the user that the second and third figures given were significant, which they are not, as there is great uncertainty about the second figure. We realize that the method of presentation makes using large amounts of these data somewhat difficult, but at present the advantages seem to outweigh the disadvantages. However in the future when the accuracy warrants it, no doubt we shall use tabular presentation.

Finally, a word about the preparation of the figures. Once the digital data are obtained, they are permanently stored on magnetic tapes. The figures are then photocomposed from these tapes on a DD280 Cathode Ray Tube at the ESSA Boulder Laboratories computing facility. Because the CRT is a very high speed device, there is the possibility of plotting error. The errors due to digitizing and plotting amount to less than 0.5 percent near the peak values and are somewhat larger where the cross section is small (< 10 percent of the peak). However, handling this volume of data entirely by computer, from input to final display, minimizes the possibility of transcribing errors, thus by-passing one of the most difficult problems in preserving the integrity of the data.
II. LINE AND LEVEL EXCITATION DATA
+ Slebbings (1932); □ Hills (2021).
See Footnote 1.

+ Long (19927); △ Fite (19326).
See Footnote 2.
See Footnote 3.

See Footnote 4.
Δ Moussa (1929)

See Footnote 6.

- Zapesochnyi (1995); Δ Moussa (1929).

See Footnote 6.
- Zapesochnyi (1995); Δ Mousso (2929).

See Footnote 6.
He 3614A (5 P→2 S)

- Zapesochnyi (1895); A Moussa (1929).

See Footnote 6.

He 3634A (8 D→2 P)

1 Zapesochnyi (1895); 2 Jobe (1938).

See Footnote 7.
He 3705A (7'S\rightarrow 2P)

1 Jobe (2838); 2 Zapesochnyi (1895).

See Footnote 7.

He 3733A (7'S\rightarrow 2P)

1 Zapesochnyi (1895); 2 Jobe (2838).

See Footnote 7.
He 3820 A (6D+2P)

1 Jabe (2838); 2 Zapesochnyi (1895); □ Miller (1455).

See Footnote 9.

He 3868 A (6S+2P)

1 Zapesochnyi (1895); 2 Jabe (2838).

See Footnote 7.
He 3889A (3\(^P\)→2\(^S\))

Electron Energy (eV)

- Zapesochnyi(1895); O Lees(56); □ Miller(1955);
□ Moussa(2929).

See Footnote 8.

He 3926A (8\(^D\)→2\(^P\))

Electron Energy (eV)

1 Zapesochnyi(1895); 2 Jobe(2898).

See Footnote 7.
1 Zapesochnyi (1895); 2 Jobe (2838).

See Footnote 7.

- Zapesochnyi (1895); Ø Miller (1455); Δ Moussa (2929).

See Footnote 8.
1 Zapeschnyi (1895); 2 Jobe (2838).

See Footnote 7.
He 4026A (5°D→2°P)

1 Zapesochnyi(1895); 2 Jobe(2838); 3 Yakhontova(1325);
Δ Miller(1455).

See Footnote 9.

He 4121A (5°S→2°P)

1 Zapesochnyi(1895); 2 Jobe(2838); 3 Yakhontova(1323);
Δ Lees(56); Δ Miller(1455); Δ Moussa(2929).

See Footnotes 8 and 9.
1 Zapesochnyi(1895); 2 Jobe(2838); 3 Yakhontova(1323); 
\( \square \) Miller(1455); \( \triangle \) Moussa(2929).

See Footnotes 8 and 9.

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1 Jobe(2838); 2 Zapesochnyi(1895); \( \phi \) Lees(56);
\( \square \) Miller(1455); \( \triangle \) Moussa(2929).

See Footnotes 8 and 9.
He 4388\( ^{A} \) (5\(^{D}\)\( ^{2} \)P)

1 Zapesochnyi(1895); 2 Jobe(2838); 3 Yakhontova(1523); 
4 Miller(1455); 5 Moussa(2929).
See Footnotes 8 and 9.

He 4438\( ^{A} \) (5\(^{S}\)\( ^{2} \)P)

1 Zapesochnyi(1895); 2 Jobe(2838); 3 Yakhontova(1523); 
4 Lees(56); 5 Miller(1455); 6 Moussa(2929).
See Footnotes 8 and 9.
He 4472A \((4^1\text{D} \rightarrow 2^1\text{P})\)

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<th>Energy (eV)</th>
<th>Cross Section ((10^{-12}\text{cm}^2))</th>
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<td>(10^2)</td>
<td></td>
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<tr>
<td>(10^3)</td>
<td></td>
</tr>
</tbody>
</table>

1 Jobe(2838); 2 Zapesochnyi(1895); 3 Yakhontova(1323)
- Miller(1455); 6 Moussa(2929).

See Footnotes 8 and 9.

He 4713A \((4^3\text{S} \rightarrow 2^3\text{P})\)

<table>
<thead>
<tr>
<th>Energy (eV)</th>
<th>Cross Section ((10^{-12}\text{cm}^2))</th>
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</thead>
<tbody>
<tr>
<td>(10^1)</td>
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<td>(10^2)</td>
<td></td>
</tr>
<tr>
<td>(10^3)</td>
<td></td>
</tr>
</tbody>
</table>

1 Yakhontova(1323); 2 Zapesochnyi(1895); 6 Lees(56)
- Miller(1455); 6 Moussa(2929).

See Footnote 8.
He 4922A (4' D+2' P)

CROSS SECTION (10^-19 cm^2)

10^11 10^12 10^13 10^14

ELECTRON ENERGY (eV)

1 Zapesochnyi(1895); 2 Yakhontova(1928); □ Miller(1955); 
□ Moussa(2929).

See Footnote 8.

He 5016A (3' P+2' S)

CROSS SECTION (10^-19 cm^2)

10^11 10^12 10^13 10^14

ELECTRON ENERGY (eV)

- Zapesochnyi(1895); □ Moussa(2929); □ Miller(1955).

See Footnote 8.
He 5048A (4'S→2'P)

Electron Energy (eV)

1 Zapesochnyi (1895); 2 Jobe (2838); 3 Yakhontova (1323);
4 Miller (1455); 5 Moussa (2929).

See Footnotes 8 and 9.

He 5876A (3'D→2'P)

Electron Energy (eV)

1 Yakhontova (1323); 2 Zapesochnyi (1895); 3 Jobe (2838);
4 Miller (1455); 5 Moussa (2929).

See Footnotes 8 and 9.

19
He 6678A (3’D-2’P)

1 Zapernchnyj (1995); 2 Jobe (2838); □ Miller (1455);
△ Moussa (2929).

See Footnotes 8 and 9.

He 7066A (3’S-2’P)

1 Zapernchnyj (1995); 2 Jobe (2838); □ Miller (1455);
△ Moussa (2929).

See Footnotes 8 and 9.
He 7281A (3'5\rightarrow2'P)

CROSS SECTION (10^{-16}cm^2)

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}

ELECTRON ENERGY (eV)

1 Zapesochnyi(1895); 2 Jobe(2838); 3 Miller(1455); 4 Moussa(2929).

See Footnotes 8 and 9.

He 10,829/10,830A (2 P\rightarrow2 S)

CROSS SECTION (10^{-16}cm^2)

3.0 2.0 1.0

ELECTRON ENERGY (eV)

0 50 100 150 200

1 Zapesochnyi(1895); 2 Jobe(2838).

See Footnote 7.
He 20,584A (2'P=2'S)

CROSS SECTION (10^{-2}cm^2)

0 0.5 1.0

0 100 200 300 400

ELECTRON ENERGY (eV)

- Jobe (2858)

See Footnote 7.

He^+ 2568A (3^2P=1^2S)

CROSS SECTION (10^{-2}cm^2)

0 1.0 2.0 3.0

0 10^2 10^3

ELECTRON ENERGY (eV)

X Moussa (3541)
He\(^+\) 303A (2\(^P\)\(^+\)1\(^S\))

Cross section (10^\text{-}\text{cm}^2) vs. Electron energy (eV)

X Moussa (3541)

He\(^+\) 1215A (4\(^S\))

Cross section (10^\text{-}\text{cm}^2) vs. Electron energy (eV)

X Moussa (3541)
- Anderson (1942)

- Anderson (1942)
- Anderson (1942)

- St John (1942); + Zapesochnyi (1895); X Moussa (3541);
  • Hughes (787); © Weaver (2639).
0, 0 Dance (1903)

See Footnote 5.
Effective Excitation Cross Sections of the 
S, P, and D Levels of Lithium 

Aleksakhin (3063)

<table>
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<tr>
<th>Level</th>
<th>E (eV)</th>
<th>( \sigma ) (10^{-18} \text{ cm}^2)</th>
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<tr>
<td>3S</td>
<td>5.9</td>
<td>40.0</td>
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<td>4S</td>
<td>6.3</td>
<td>17.0</td>
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<td>5S</td>
<td>7.3</td>
<td>3.9</td>
</tr>
<tr>
<td>6S</td>
<td>7.8</td>
<td>0.9</td>
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<tr>
<td>3P</td>
<td>7.7</td>
<td>0.3</td>
</tr>
<tr>
<td>3D</td>
<td>7.7</td>
<td>120.</td>
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<tr>
<td>4D</td>
<td>8.9</td>
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<td>6D</td>
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<td>3.1</td>
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*Cross sections were measured at the maximum.*
+ Feltson (2725)
CROSS SECTION (10^-2 cm²)

ELECTRON ENERGY (eV)

+ Feltson (2725)

CROSS SECTION (10^-2 cm²)

ELECTRON ENERGY (eV)

+ Feltson (2725)
CROSS SECTION (10⁻²⁰CM²)

ELECTRON ENERGY (eV)

+ Feltson (2725)
+ Fellsan (2725)

+ Fellsan (2725)
+ Feltisan (2725)

+ Feltisan (2725)
+ Feltsan (2725)
CROSS SECTION (10^{-14} m^2)

ELECTRON ENERGY (eV)

+ Feltson (2725)

CROSS SECTION (10^{-14} m^2)

ELECTRON ENERGY (eV)

+ Feltson (2725)
Ne 6552A

CROSS SECTION (10^-16cm^2)

ELECTRON ENERGY (eV)

+ Feltson (2725)

Ne 6596A

CROSS SECTION (10^-16cm^2)

ELECTRON ENERGY (eV)

+ Feltson (2725)
+ Feltson (2725)

+ Feltson (2725)
+ Feltson (2725)

+ Feltson (2725)
Ne 8654/8647/8655A

CROSS SECTION (10^{-16}m^{2})

ELECTRON ENERGY (eV)

+ Feltsan (2725)

Ne 8780/8783A

CROSS SECTION (10^{-16}m^{2})

ELECTRON ENERGY (eV)

+ Feltsan (2725)
Effective Line Excitation Cross Sections of Neon
Feltsan (2725)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>E (eV)</th>
<th>$\sigma$ ($10^{-18} \text{ cm}^2$)</th>
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<tbody>
<tr>
<td>4708</td>
<td>30</td>
<td>1.0</td>
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<tr>
<td>4752/4750</td>
<td>31</td>
<td>2.01</td>
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<td>4827.3/4827.5</td>
<td>105</td>
<td>2.4</td>
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<td>4837</td>
<td>30</td>
<td>2.6</td>
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<td>5080/5078</td>
<td>30</td>
<td>3.93</td>
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<td>5341/5343</td>
<td>94</td>
<td>5.0</td>
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*Cross sections were measured at the maximum.
No 5169/5154A (6S+3P)

GROSS SECTION (10^{-18}cm^2)

[Graph of electron energy vs. cross section]

- Zapesochnyi (1965)

No 5683/5689A (4D+3P)

GROSS SECTION (10^{-18}cm^2)

[Graph of electron energy vs. cross section]

- Zapesochnyi (1965)

No 5935/5803A (5P+3P)

GROSS SECTION (10^{-18}cm^2)

[Graph of electron energy vs. cross section]

- Zapesochnyi (1965); Christoph (1991)

No 6154/6161A (5S+3P)

GROSS SECTION (10^{-18}cm^2)

[Graph of electron energy vs. cross section]

- Zapesochnyi (1965)

57
<table>
<thead>
<tr>
<th>Wavelength (Å)</th>
<th>Transition</th>
<th>E (eV)</th>
<th>$d^2$</th>
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<tbody>
<tr>
<td>4190/4191</td>
<td>$4s[1\ 1/2]^o - 5p[2\ 1/2]$</td>
<td>19.6</td>
<td>4.86</td>
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<td></td>
<td>$4s'[1/2]^o - 5p'[1\ 1/2]$</td>
<td></td>
<td>-19</td>
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<td>4200</td>
<td>$4s[1\ 1/2]^o - 5p[2\ 1/2]$</td>
<td>22.6</td>
<td>6.74</td>
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<td>4259</td>
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<td>4272</td>
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<td>8.89</td>
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<td>24.2</td>
<td>7.19</td>
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<td>4510</td>
<td>$4s'[1/2]^o - 5p[1\ 1/2]$</td>
<td>24.9</td>
<td>8.52</td>
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<td>2.30</td>
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<td>4596</td>
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<td>7.35</td>
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<td>5.91</td>
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<td>Wavelength (Angstroms)</td>
<td>Transition$^1$</td>
<td>E (eV)</td>
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<td>E (eV)</td>
<td>$\sigma^2$</td>
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<tr>
<td>6297$^b$</td>
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<td>6871$^b$</td>
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<td>5.65 -19</td>
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<td>6965$^b$</td>
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<td>21.3</td>
<td>1.65 -18</td>
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<tr>
<td>7067$^b$</td>
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<td>19.2</td>
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### Effective Line Excitation Cross Sections of Argon I

(continued)

<table>
<thead>
<tr>
<th>Wavelength (Ångstroms)</th>
<th>Transition</th>
<th>E (eV)</th>
<th>$\sigma$</th>
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<tbody>
<tr>
<td>7353&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$4p[2 1/2] - 4d[3 1/2]^*$</td>
<td>24.9</td>
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<td></td>
<td>$4p[1 1/2] - 6s[1 1/2]^*$</td>
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<tr>
<td>7372&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$4s[1 1/2]^* - 4p'[1 1/2]^*$</td>
<td>23.9</td>
<td>1.95</td>
</tr>
<tr>
<td>7383&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>19.5</td>
<td>4.07</td>
</tr>
<tr>
<td>7504&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$4s'[1/2]^* - 4p'[1/2]$</td>
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<tr>
<td>7515&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>$4s[1 1/2]^* - 4p[1/2]$</td>
<td>19.4</td>
<td>6.22</td>
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<td>28.0</td>
<td>5.40</td>
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<tr>
<td>7635&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>$4s'[1/2]^* - 4p'[1/2]$</td>
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<td>7948&lt;sup&gt;c&lt;/sup&gt;</td>
<td>$4s'[1/2]^* - 4p'[1/2]$</td>
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<td>5.50</td>
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<tr>
<td>8006/8015&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>$4s[1 1/2]^* - 4p[2 1/2]$</td>
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<td>8115&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>8264.5&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>8425&lt;sup&gt;c&lt;/sup&gt;</td>
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## Effective Line Excitation Cross Sections of Argon II

Fischer (115)

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<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>Transition (^1)</th>
<th>(2\sigma)</th>
<th>(E) (eV)</th>
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<tr>
<td>4332 (^a)</td>
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<td>4371 (^a)</td>
<td>3d(^4)D - 4p(^4)p(^o)</td>
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<td>4426 (^a)</td>
<td>4s(^4)p - 4p(^4)D(^o)</td>
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<td>4430 (^a)</td>
<td>4s(^4)P - 4p(^4)D(^o)</td>
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<td>4579 (^a)</td>
<td>4s(^2)P - 4p(^2)S(^o)</td>
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<td>4609 (^a)</td>
<td>4s(^1)D - 4p(^1)P(^o)</td>
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<td>4657 (^a)</td>
<td>4s(^2)P - 4p(^2)P(^o)</td>
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<td>4726 (^a)</td>
<td>4s(^2)P - 4p(^2)D(^o)</td>
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<td>59.9</td>
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</tbody>
</table>
a. Data taken from Fischer (115). The method used to obtain the normalized factor was through Fischer's comparison of the excitation function for the 4358 Å line with that obtained by Hanle and Schaffernicht at 60 eV.

b. Data taken from Hermann (288). The maxima of the cross sections were read and converted to cm² by dividing by the number of atoms/cc at 1 Torr pressure and 0° C (3.539 x 10⁻¹⁶ atoms/cc).

c. Data taken from Volkova (344, 755). The data were normalized to the value given in (772).


2. σ is in units of cm² with the order of magnitude indicated in the column. The cross section was measured at the maximum unless otherwise noted.

3. The cross section was not measured at the maximum.

4. The data were normalized by multiplying by the gas kinetic cross section (6.15 x 10⁻¹⁶ cm²).
+ Zapesochnyi (1680)
K 4942A ($10^3 S_{1/2} \rightarrow 4P_{1/2}$)

CROSS SECTION (10^-16 cm²)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1680)

K 4965A ($8^1 D_{5/2} \rightarrow 4P_{3/2}$)

CROSS SECTION (10^-16 cm²)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1680)
K 5084A ($9^2S_{1/2} - 4^2P_{1/2}$)

CROSS SECTION ($10^{-20}$cm$^2$)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1680)

K 5112A ($7^2S_{1/2} - 4^2P_{1/2}$)

CROSS SECTION ($10^{-20}$cm$^2$)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1680)
K 5323A ($8^3S_{1/2}$ $\to$ $4^3P_{1/2}$)

CROSS SECTION (10^{-16} cm²)

ELECTRON ENERGY (eV)

+ Zapescchnyi (1980)

K 5360A ($6^2D_{5/2}$ $\to$ $4^2P_{5/2}$)

CROSS SECTION (10^{-16} cm²)

ELECTRON ENERGY (eV)

+ Zapescchnyi (1980)
+ Zapesochnyi (1680)
\[ \text{K 6965A (4}^2\text{D}_{\text{v,1}}, \text{4}^2\text{P}_{\text{v,2}}) \]

\[ \text{CROSS SECTION (10}^{-16}\text{cm}^2) \]

\[ \text{ELECTRON ENERGY (eV)} \]

+ Zapesochnyj (1680)

\[ \text{X Volkova (749)} \]
X Volkova (749)

θ Volkova (749); X Volkova (344).
Effective Line Excitation Cross Sections of Potassium

Zapesochnyi (1680)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>Transition</th>
<th>E (eV)</th>
<th>$\sigma$ ($10^{-18}$ cm$^2$)</th>
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<td>6938</td>
<td>$6,^2S_{1/2} \rightarrow 4,^2P_{3/2}$</td>
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<tr>
<td>12434</td>
<td>$5,^2S_{1/2} \rightarrow 4,^2P_{1/2}$</td>
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<tr>
<td>12523</td>
<td>$5,^2S_{1/2} \rightarrow 4,^2P_{3/2}$</td>
<td>4.</td>
<td>300.</td>
</tr>
</tbody>
</table>

*Cross sections were measured at the maximum.*
EXCITATION CROSS SECTIONS FOR SOME SPECTRAL LINES OF KRYPTON AND XENON

- L.M. Volkova, A.M. Devyatov & A.V. Kuralova

In the present work we determined the excitation cross sections for five lines of krypton and ten lines of xenon. The excitation function curves were plotted by the method of photographic photometry.

The electron gun consisted of an indirectly heated oxide-coated cathode and three electrodes. By appropriate choice of the electrode potentials relative to the cathode, we obtained the optimum operating condition for the electron gun: small variation in the magnitude of the electron current and shape of the electron beam with changes of the potential $V_3$ on the third anode, which controlled the energy of the exciting electrons. To determine the necessary experimental conditions we first checked the variation in the intensity of the spectrum lines as a function of the electron current at a pressure of 3·$10^{-3}$ mm Hg at which the electron free path in Kr (14 cm) is much greater than the dimensions of the impact space. The variation was found to be linear up to 1600 µa.

Fig. 1. Energy variation of the excitation function for four Kr II lines.
The measurements were carried out with a current of 400 µa. The main measurements for determining the energy dependence of the excitation functions were carried out by the conventional method of recording the spectra at different electron energies; the resultant spectrograms were then processed by the method of photographic photometry. We obtained the excitation functions for a number of lines of krypton and xenon. Part of the data were published in Refs. 3 and 4. Subsequently, we also measured the excitation function of four Kr I lines, which are shown plotted to an arbitrary scale in Fig. 1. It must be emphasized that the ordinates of these curves and those reproduced in the other figures are not comparable. Figs. 2 & 3 show the excitation function curves for the 4318/19 Å and 4351 Å Kr I lines. The curves for the 4318/19 Å line

Fig. 2

Fig. 2. Variation of the excitation function for the Kr I 4318/19 Å line: 1) determined by the usual procedure, 2) in a retarding electric field.

Fig. 3

Fig. 3. Variation of the excitation function for the Kr I 4351 Å line.

were obtained by the usual method and by the method of a retarding electric field\(^1,2\). In using the latter method, a retarding field capable of returning all the electrons before they enter the receiver, is applied between the cathode and the electron receiver. Thus the field in the impact space varies from the value of the voltage on the third anode (+50 v) to the retarding voltage (-6 v).

By means of the formulas given in Ref. 1 one can determine the electron energy at each point in the electron beam. The essential condition for successful use of this method is that the lines of force of the electric field must be parallel to each other at the axis of the impact gap. To this end the diameter of the last anode and the receiver (37 mm) was made greater than the distance between them (20 mm) and the diameter of the electron beam (4 mm). The sides of the third anode and receiver, bounding the impact space,
were covered with a fine 250-mesh screen. Prior to each measurement the electron beam was photographed to determine the electron current density. As will be evident from Fig. 2, the curves outlined by the two different methods agree within the limits of the experimental error.

\[
\begin{array}{cccc}
\text{Line} & \text{Set} & \text{value of } \psi & \text{at set } V_3, V & \text{at } V_{3, \text{max}} \\
\hline
\text{Kr I} & 4233.29 & 20 & 0.63 \pm \tau & 0.63 \pm \tau \\
\text{Kr II} & 4273.57 & 20 & 0.8 \pm \tau & 0.8 \pm \tau \\
\text{Xe I} & 4351.26 & 20 & 0.8 \pm \tau & 0.8 \pm \tau \\
\text{Xe II} & 4356.89 & 20 & 1.9 \pm \tau & 1.9 \pm \tau \\
\text{Xe I} & 4401.27 & 60 & 0.34 \pm \tau & 0.34 \pm \tau \\
\text{Kr I} & 4404.97 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\text{Kr I} & 4414.81 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\text{Kr I} & 4462.40 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\text{Kr I} & 4603.03 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\text{Xe II} & 4656.50 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\text{Xe II} & 5044.62 & 60 & 0.038 \pm \tau & 0.038 \pm \tau \\
\end{array}
\]

We also measured the absolute excitation cross sections \( \sigma \), for the five lines of Kr and the ten lines of Xe, the excitation function curves for which were given in Refs. 3 & 4. The absolute cross section values were determined by comparing the intensity of the investigated lines with the intensity of the continuous spectrum of a tungsten ribbon filament lamp of a known brightness temperature. This method of determining absolute cross sections is described in Ref. 5. The cross section values for the five lines of Kr and ten lines of Xe are listed in the accompanying table. The uncertainty in our measurements is evaluated as \( \pm 30\% \).

Physics Faculty, Moscow State University

References

Kr 4318/4319A

CROSS SECTION (10^-23 cm²)

ELECTRON ENERGY (eV)

0 Volkova(474)

Kr 4351A

CROSS SECTION (10^-23 cm²)

ELECTRON ENERGY (eV)

0 Volkova(474)
**Effective Line Excitation Cross Sections of Krypton**

Volkova (474)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>E* (eV)</th>
<th>σ (10^{-20} cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4263</td>
<td>20</td>
<td>0.65</td>
</tr>
<tr>
<td>4274</td>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>4464</td>
<td>20</td>
<td>1.19</td>
</tr>
</tbody>
</table>

*Guk (1325) and Devyatov (607) give relative data indicating a maximum cross section near 20 eV.*
Rb 7758A \((5^1\text{D}_{3/2} \rightarrow 5^3\text{P}_{3/2})\)

CROSS SECTION \((10^{-17}\text{cm}^2)\)

ELECTRON ENERGY \((\text{eV})\)

- Zapesochnyi (1969)

Rb 7800A \((5\,^3\text{P}_{3/2} \rightarrow 5\,^1\text{S}_{1/2})\)

CROSS SECTION \((10^{-17}\text{cm}^2)\)

ELECTRON ENERGY \((\text{eV})\)

- Zapesochnyi (1981)
Rb$^+$ 4776A (8=5)

+ Shimon (2366)

- Zapesochnyi (1801)
- Zapesochnyi (1969)
\[ \text{Rb } 3587/3592A \ (7 \text{P}_{3/2,1/2} \rightarrow 5 \text{S}_{1/2}) \]

\[ \text{CROSS SECTION (10^{-19}cm^2)} \]

\[ \text{ELECTRON ENERGY (eV)} \]

0 Shimon(2366); Zapesochnyi(1969).

See Footnote 10.

\[ \text{Rb } 4202A \ (6 \text{P}_{3/2,1/2} \rightarrow 5 \text{S}_{1/2}) \]

\[ \text{CROSS SECTION (10^{-19}cm^2)} \]

\[ \text{ELECTRON ENERGY (eV)} \]

0 Shimon(2366); Zapesochnyi(1969).

See Footnote 10.
\( \theta \) Shimon (1966); Zapesochnyi (1969).

See Footnote 10.

- Zapesochnyi (1969)
\[ \text{Rb 5150A (} 10^2 \text{D}_{\frac{3}{2}} \rightarrow 5^2 \text{P}_{\frac{5}{2}} \text{)} \]

- Zapesochnyi (1969)

\[ \text{Rb 5195A (} 9^2 \text{D}_{\frac{3}{2}} \rightarrow 5^2 \text{P}_{\frac{1}{2}} \text{)} \]

\[ \theta \text{ Shimon (2366); Zapesochnyi (1969).} \]

See Footnote 10.
- Zapesochnyi (1969)

0 Shimon (1966); Zapesochnyi (1969).

See Footnote 10.
\( \text{Rb 5322A (10}^{2}S_{1/2} \rightarrow 5P_{3/2}) \)

\[
\begin{array}{c|c|c|c|c|c|c|c|c|c}
\hline
\text{Electron Energy (eV)} & 0 & 6 & 12 & 18 & 24 & 30 \\
\hline
\text{Cross Section (10}^{-18}\text{cm}^2) & 8.0 & 6.0 & 4.0 & 2.0 & 0 & 0 \\
\hline
\end{array}
\]

\( \text{Shimon (2366); Zaposchynyi (1969).} \)

See Footnote 10.

\( \text{Rb 5391A (10}^{2}S_{1/2} \rightarrow 5P_{5/2}) \)

\[
\begin{array}{c|c|c|c|c|c|c|c|c|c}
\hline
\text{Electron Energy (eV)} & 0 & 6 & 12 & 18 & 24 & 30 \\
\hline
\text{Cross Section (10}^{-18}\text{cm}^2) & 1.6 & 1.2 & 0.8 & 0.4 & 0 & 0 \\
\hline
\end{array}
\]

\( \text{Shimon (2366); Zaposchynyi (1969).} \)

See Footnote 10.
- Zapesochnyi (1969)

- Zapesochnyi (1969)
- Zapesochnyi (1969)

+ Zapesochnyi (1969); 0 Shimon (1966).

See Footnote II.
See Footnote 10.

See Footnote 11.
θ Shimon (2366); Zapesochnyi (1969).
See Footnote 10.
Effective Line Excitation Cross Sections of Rubidium
Zapesochnyi (1969)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>Transition</th>
<th>E (eV)</th>
<th>( \sigma ) (10(^{-18}) cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>4923</td>
<td>( 1^2D_{3/2} \rightarrow 5^2P_{1/2} )</td>
<td>4.8</td>
<td>.53</td>
</tr>
<tr>
<td>5017</td>
<td>( 1^2D_{3/2} \rightarrow 5^2P_{1/2} )</td>
<td>4.8</td>
<td>.73</td>
</tr>
<tr>
<td>5023</td>
<td>( 1^2D_{5/2} \rightarrow 5^2P_{3/2} )</td>
<td>4.8</td>
<td>1.07</td>
</tr>
<tr>
<td>5088</td>
<td>( 10^2D_{3/2} \rightarrow 5^2P_{1/2} )</td>
<td>4.8</td>
<td>.85</td>
</tr>
<tr>
<td>5362</td>
<td>( 8^2D_{3/2} \rightarrow 5^2P_{1/2} )</td>
<td>4.86</td>
<td>2.29</td>
</tr>
<tr>
<td>6071</td>
<td>( 8^2S_{1/2} \rightarrow 5^2P_{3/2} )</td>
<td>4.45</td>
<td>3.15</td>
</tr>
<tr>
<td>7280</td>
<td>( 7^2S_{1/2} \rightarrow 5^2P_{1/2} )</td>
<td>4.2</td>
<td>11.9</td>
</tr>
<tr>
<td>13236</td>
<td>( 6^2S_{1/2} \rightarrow 5^2P_{1/2} )</td>
<td>3.5</td>
<td>160.</td>
</tr>
<tr>
<td>13667</td>
<td>( 6^2S_{1/2} \rightarrow 5^2P_{3/2} )</td>
<td>3.5</td>
<td>160.</td>
</tr>
<tr>
<td>14574</td>
<td>( 4^2D_{3/2} \rightarrow 5^2P_{1/2} )</td>
<td>3.4</td>
<td>230.</td>
</tr>
<tr>
<td>15289</td>
<td>( 4^2D_{5/2} \rightarrow 5^2P_{3/2} )</td>
<td>3.4</td>
<td>230.</td>
</tr>
</tbody>
</table>

*Cross sections were measured at the maximum.*
See Footnote 25
See Footnote 25

See Footnote 25
+ Guk (1325); Volkova (474).
See Footnote 25
See Footnote 25.
- Zapesochnyi (1972)
Cs 3876/3889A (8^3P_{3/2,1/2}-6^3S_{1/2})

- Zapesochnyi (1972)

Cs 4555A (7^3P_{3/2,1/2}-6^3S_{1/2})

+ Zapesochnyi (1972)

See Footnote 12.
+ Zapesochnyi (1972)
See Footnote 12.

+ Zapesochnyi (1972)
See Footnote 12.
- Zapeschnyi (1972)

See Footnote 12.
+ Zapesochnyi (1972)
See Footnote 12.
Cs 5574.4A (12\textsuperscript{1}S\textsubscript{0} - 6P\textsubscript{5/2})

- Zapesochnyi (1972)

Cs 5635A (16\textsuperscript{1}D\textsubscript{5/2} - 6P\textsubscript{5/2})

+ Zapesochnyi (1940, 1972)

See Footnote 12.
Cs 5664A (9'^D_{5/2} \rightarrow 6'^P_{3/2})

CROSS SECTION (10^{-16} cm²)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1972)

See Footnote 12.

Cs 5746A (11'S_{1/2} \rightarrow 6'^P_{3/2})

CROSS SECTION (10^{-16} cm²)

ELECTRON ENERGY (eV)

+ Zapesochnyi (1972)

See Footnote 12.
Cs 6034A \((10^7 \text{cm}^2)\)

- Zapernych (1972)

Cs 6213A \((8^2 \text{D}_{3/2} \rightarrow 6^2 \text{P}_{3/2})\)

+ Zapernych (1972)

See Footnote 12.
+ Zapesochnyi (1972)
See Footnote 12.

- Zapesochnyi (1972)
Cs 6432/6473A (9F→5D)

+ Zapesochnyi (1972)

See Footnote 12.

Cs 6586A (9S₁₀→6Pₓₙ₁)

+ Zapesochnyi (1972)

See Footnote 12.
- Zapesochnyi (1972)

See Footnote 12.
+ Zapesochnyi (1972)

See Footnote 12.
+ Zapesochnyi (1040, 1972)
See Footnote 12.
See Footnote 12.
Effective Line Excitation Cross Sections of Cesium
Zapesochnyi (1972)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>Transition</th>
<th>E (eV)</th>
<th>$\sigma (10^{-18} \text{ cm}^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5154</td>
<td>$1^4P_{3/2} \rightarrow 1^2P_{1/2}$</td>
<td>4.5</td>
<td>.73</td>
</tr>
<tr>
<td>5199</td>
<td>$1^3D_{3/2} \rightarrow 1^2P_{1/2}$</td>
<td>4.5</td>
<td>1.15</td>
</tr>
<tr>
<td>5257</td>
<td>$1^2D_{3/2} \rightarrow 1^2P_{1/2}$</td>
<td>4.5</td>
<td>1.73</td>
</tr>
<tr>
<td>5341</td>
<td>$1^2D_{3/2} \rightarrow 1^2P_{1/2}$</td>
<td>4.45</td>
<td>1.66</td>
</tr>
<tr>
<td>5407</td>
<td>$1^2D_{5/2} \rightarrow 1^2P_{3/2}$</td>
<td>4.5</td>
<td>2.94</td>
</tr>
<tr>
<td>6010</td>
<td>$2^2D_{3/2} \rightarrow 2^2P_{1/2}$</td>
<td>4.6</td>
<td>8.27</td>
</tr>
<tr>
<td>8761</td>
<td>$2^2D_{3/2} \rightarrow 2^2P_{1/2}$</td>
<td>4.1</td>
<td>115.</td>
</tr>
<tr>
<td>9172</td>
<td>$2^2D_{5/2} \rightarrow 2^2P_{3/2}$</td>
<td>4.1</td>
<td>115.</td>
</tr>
<tr>
<td>10024</td>
<td>$4F_{5/2} \rightarrow 5D_{3/2}$</td>
<td>6.0</td>
<td>98.</td>
</tr>
<tr>
<td>10123</td>
<td>$4F_{7/2} \rightarrow 5D_{5/2}$</td>
<td>6.0</td>
<td>98.</td>
</tr>
<tr>
<td>13589</td>
<td>$2^2S_{1/2} \rightarrow 2^2P_{1/2}$</td>
<td>3.1</td>
<td>165.</td>
</tr>
<tr>
<td>14695</td>
<td>$2^2S_{1/2} \rightarrow 2^2P_{3/2}$</td>
<td>3.1</td>
<td>165.</td>
</tr>
<tr>
<td>30100</td>
<td>$5^2D_{3/2} \rightarrow 6^2P_{1/2}$</td>
<td>3.1</td>
<td>280.</td>
</tr>
<tr>
<td>34892</td>
<td>$5^2D_{5/2} \rightarrow 6^2P_{3/2}$</td>
<td>3.1</td>
<td>280.</td>
</tr>
</tbody>
</table>

* Cross sections were measured at the maximum.
+ Bacon (2938)
See Footnote 14.

+ Bacon (2938)
See Footnote 14.
\textbf{Hg 
3650A \textit{(6} D, 6 P)}

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{cross_section_graph.png}
\caption{Cross section vs. electron energy graph for Hg 3650A \textit{(6} D, 6 P\textit{).}}
\end{figure}

- Anderson\textit{(2626)}; X Jongerius\textit{(176)}.

\textbf{Hg 
3655A \textit{(6} D, 6 P)}

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{cross_section_graph2.png}
\caption{Cross section vs. electron energy graph for Hg 3655A \textit{(6} D, 6 P\textit{).}}
\end{figure}

X Anderson\textit{(2626)}; O Schaffernich\textit{(1262)}.

See Footnote 15.
- Anderson(877); Jongerius(176).

- Anderson(877); Jongerius(176).
- Anderson(877); X Jongerius(176).

- Anderson(877)
Hg 3901/3903/3906A (8 D₂₁₁, 8 D₂₁, 6 P₁₂)

- Anderson (877); X Jongerius (176).

Hg 4047A (7 S₁, 6 P₁₂)

- Anderson (2626)
Hg 4078A (7S→6P+)

Electron energy (eV)

- Anderson(877); X Jongerius(176).

Hg 4108A (9S→6P+)

Electron energy (eV)

- Anderson(877); X Jongerius(176).
Hg 4140A ($9^3S, +6^3P$)

Cross section ($10^{-24} cm^2$)

Electron energy (eV)

- Anderson (877)

Hg 4343/4347A ($7^3D, 7^3D, +6^3P$)

Cross section ($10^{-24} cm^2$)

Electron energy (eV)

- Anderson (877); X Jongerius (176).
Hg 4358A (7'S,6'P,)

ELECTRON ENERGY (eV)

1 Anderson (2626); 2 Riedel (303); X Jonker (176);
0 Hanle (92); □ Fischer (115).

Hg 4822A (14'P,7'S,)

ELECTRON ENERGY (eV)

Anderson (877)
Hg 4996/4897A (13 P₂,1→7 S₁)

- Anderson (877)

Hg 4996A (8 S₁→6 P₁)

- Anderson (877); X Jongerius (176)

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Hg 4970A (12\(^{2}\)P\(_{1}\),\(7\)^{5}\)S\(_{1}\))

Cross section \((10^{-20}\text{cm}^2)\)

Electron energy (eV)

- Anderson (877)

Hg 4981A (12\(^{2}\)P\(_{1}\),\(7\)^{5}\)S\(_{1}\))

Cross section \((10^{-20}\text{cm}^2)\)

Electron energy (eV)

- Anderson (877)
Hg 4992A (12^1P, 7^1S,)

- Anderson (877)

Hg 5026A (8^3S, 6^1P,)

- Anderson (877)
Hg 5103A (11^1P, 7^1S, )

CROSS SECTION (10^{-20}cm^2)

ELECTRON ENERGY (eV)

- Anderson (877)

Hg 5121A (11^1P, 7^1S, )

CROSS SECTION (10^{-20}cm^2)

ELECTRON ENERGY (eV)

- Anderson (877)
Hg 5138/5140A (11 P, → 7 S,)

CROSS SECTION (1.0 × 10^{-12}cm^2)

ELECTRON ENERGY (eV)

- Anderson (877)

Hg 5219A (14 P, → 7 S,)

CROSS SECTION (1.0 × 10^{-12}cm^2)

ELECTRON ENERGY (eV)

- Anderson (877)
- Anderson (877)
- Anderson (877)
Hg 5461A (7S, 6P_s)

Electron Energy (eV)

- Anderson (2626); X Jongerius (175); Õ Hanle (92).

Hg 5550A (11P_s, 7S_s)

Electron Energy (eV)

- Anderson (877)
Hg 5676A (9\(^1\)P\(_1\), 7\(^1\)S\(_0\))

Electron energy (eV)
- Anderson (877); X Jongerius (176).

Hg 5770A (6\(^1\)D\(_2\), 6\(^1\)P\(_1\))

Electron energy (eV)
- Anderson (877); X Jongerius (176).
Hg 5790/5791A (6^3D, 6^3D, 6^3P)

- Anderson (877); X Jongerius (176).

Hg 5804A (10^3P, 7^3S)

- Anderson (877)
- Anderson (877)

See Footnote 16.
Hg 6234A ($9^1\text{P}_2 \rightarrow 7^1\text{S}_0$)

CROSS SECTION (10^{-16}$ cm$^2$)

ELECTRON ENERGY (eV)

- Anderson (877)

Hg 6716A ($6^1\text{P}_1 \rightarrow 7^1\text{S}_0$)

CROSS SECTION (10^{-16}$ cm$^2$)

ELECTRON ENERGY (eV)

- Anderson (877)
Effective Line Excitation Cross Sections of Mercury

Anderson (877, 2626)

<table>
<thead>
<tr>
<th>Wavelength in Angstroms</th>
<th>Transition</th>
<th>E (eV)</th>
<th>( \sigma ) (cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5385/5389</td>
<td>( ^3P_{1,0} \rightarrow ^3S_1 )</td>
<td>15</td>
<td>9.0 \times 10^{-21}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>2.2 \times 10^{-20}</td>
</tr>
<tr>
<td>10140</td>
<td>( ^1S_0 \rightarrow ^1P_1 )</td>
<td>15</td>
<td>6.4 \times 10^{-18}</td>
</tr>
<tr>
<td>11287</td>
<td>( ^3P_2 \rightarrow ^3S_1 )</td>
<td>15</td>
<td>2.5 \times 10^{-17}</td>
</tr>
</tbody>
</table>
Effective Line Excitations of the 2nd Positive Bands of \( N_2 \)

Jobe (2128)

<table>
<thead>
<tr>
<th>Wavelength (Angstroms)</th>
<th>( \nu',\nu'' )</th>
<th>E (eV)</th>
<th>( \sigma^* \left(10^{-18} \text{ cm}^2\right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3371</td>
<td>0,0</td>
<td>15</td>
<td>10.8</td>
</tr>
<tr>
<td>3577</td>
<td>0,1</td>
<td>15</td>
<td>8.5</td>
</tr>
<tr>
<td>3805</td>
<td>0,2</td>
<td>15</td>
<td>4.4</td>
</tr>
<tr>
<td>4059</td>
<td>0,3</td>
<td>15</td>
<td>1.2</td>
</tr>
<tr>
<td>4344</td>
<td>0,4</td>
<td>15</td>
<td>.34</td>
</tr>
<tr>
<td>4667</td>
<td>0,5</td>
<td>15</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>0,&gt;5</td>
<td>15</td>
<td>.08</td>
</tr>
<tr>
<td>3160</td>
<td>1,0</td>
<td>15</td>
<td>8.6</td>
</tr>
<tr>
<td>3339</td>
<td>1,1</td>
<td>15</td>
<td>.5</td>
</tr>
<tr>
<td>3537</td>
<td>1,2</td>
<td>15</td>
<td>3.1</td>
</tr>
<tr>
<td>3755</td>
<td>1,3</td>
<td>15</td>
<td>3.1</td>
</tr>
<tr>
<td>3998</td>
<td>1,4</td>
<td>15</td>
<td>2.2</td>
</tr>
<tr>
<td>4270</td>
<td>1,5</td>
<td>15</td>
<td>.60</td>
</tr>
<tr>
<td>4574</td>
<td>1,6</td>
<td>15</td>
<td>.26</td>
</tr>
<tr>
<td>4917</td>
<td>1,7</td>
<td>15</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>1,&gt;7</td>
<td>15</td>
<td>.10</td>
</tr>
<tr>
<td>2977</td>
<td>2,0</td>
<td>15</td>
<td>1.1</td>
</tr>
<tr>
<td>3136</td>
<td>2,1</td>
<td>15</td>
<td>3.2</td>
</tr>
<tr>
<td>3309</td>
<td>2,2</td>
<td>15</td>
<td>.20</td>
</tr>
<tr>
<td>Wavelength (Å)</td>
<td>v', v''</td>
<td>E (eV)</td>
<td>σ (^*) (10^{-18} \text{ cm}^2)</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>--------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>3500</td>
<td>2,3</td>
<td>15</td>
<td>.35</td>
</tr>
<tr>
<td>3710</td>
<td>2,4</td>
<td>15</td>
<td>1.0</td>
</tr>
<tr>
<td>3943</td>
<td>2,5</td>
<td>15</td>
<td>1.0</td>
</tr>
<tr>
<td>4200</td>
<td>2,6</td>
<td>15</td>
<td>.44</td>
</tr>
<tr>
<td>4490</td>
<td>2,7</td>
<td>15</td>
<td>.21</td>
</tr>
<tr>
<td>4815</td>
<td>2,8</td>
<td>15</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>2,&gt;8</td>
<td>15</td>
<td>.27</td>
</tr>
</tbody>
</table>

\(^{\dagger}\) The electronic transition for this system is C^3Π \rightarrow \text{B}^3Π.

\(*\) Cross sections were measured at the maximum.
See Footnote 18.
N\textsubscript{2} \textsuperscript{+} 4709A (0,2 band)

CROSS SECTION (10^{-18} cm\textsuperscript{2})

10\textsuperscript{-18} \rightarrow 10\textsuperscript{-19}

ELECTRON ENERGY (eV)

10\textsuperscript{11} \rightarrow 10\textsuperscript{15}

1 McConkey(1504); 2 Stewart(333); * Nishimura(5024); X Fowler(2923).

See Footnote 16.

N\textsubscript{2} \textsuperscript{+} 7081A (4,1 band)

CROSS SECTION (10^{-19} cm\textsuperscript{2})

10\textsuperscript{-19} \rightarrow 10\textsuperscript{-18}

ELECTRON ENERGY (eV)

10\textsuperscript{11} \rightarrow 10\textsuperscript{15}

* Srivastava(2964)

See Footnote 19.
++ Lee (3358)

See Footnotes 17 and 18.

---

Korol (3387)

See Footnote 20.
- Korol (3387)

See Footnote 20.

- Korol (3387)

See Footnote 20.
See Footnote 20.
\(- \text{Korol} (3387)\)

See Footnote 20.

\(\text{O}_2^+ 4878 \text{ Å (1,11 band)}\)

\(- \text{Korol} (3387)\)

See Footnote 20.
- Koral (1987)
  See Footnote 21.

X Nishimura (1958)
See Footnote 21.
See Footnote 21.
\( \text{O}_2^* \) 6026A (0,0 band)

\[
\begin{array}{c}
\text{CROSS SECTION (cm}^2) \\
10^{-12} \quad 10^{-11} \quad 10^{-10} \quad 10^{-9} \quad 10^{-8} \\
\text{ELECTRON ENERGY (eV)} \\
10^2 \quad 10^3 \quad 10^4 \\
\end{array}
\]

X Nishimura(1938); + Nishimura(1926).
See Footnote 21.

\[
\begin{array}{c}
\text{CROSS SECTION (10^{-17}cm}^2) \\
0.5 \quad 1.0 \quad 1.5 \\
\text{ELECTRON ENERGY (eV)} \\
0 \quad 100 \quad 200 \quad 300 \\
\end{array}
\]

\( \text{N}_2^* \) (0,0 band)

+ Latimer(1771)
See Footnote 18.
- Latimer(1771)

See Footnote 18.
X Nishimura (1700); + Nishimura (3024).

See Footnote 22.
ELECTRON ENERGY (eV)

$X$ Nishimura (1700); $+$ Nishimura (3024).

See Footnote 24.
FOOTNOTES TO FIGURES

1. (332) and (2021) normalized to \(0.18 \pi a_0^2\) using Fite (3262). The data are corrected for polarization, but not for cascading.

2. (3027) normalized to Born approximation, \(0.486 \pi a_0^2\) at 200 eV.

3. (2902) normalized to Born approximation at energies above 300 eV.

4. Cross sections for energies below 21.9 eV taken from (318). Cross sections for energies above 21.9 eV taken from (1090). (1090) normalized to (318) at 21.9 eV. (1088) data point is located at 20.4 eV to coincide with first peak of (318).

5. Upper curve (circles) shows the cross sections for the production of He\(^+\)(2S) from He\(^+\)(1S) including cascading contributions. Lower curve (diamonds) shows the cross section for direct excitation of He\(^+\)(2S) from He\(^+\)(1S).

6. The original (2929) data were for level excitations. We converted these data to line excitation cross sections using Tables 5.2 and 7.6 in (2929) and using the branching ratio obtained from Gabriel (886), Table 1.

7. (2838) converted the line excitation cross section using the branching ratio obtained from Gabriel (886), Table 1.

8. The original (2929) data were for level excitations. We converted these data to line excitation cross sections using Tables 5.2 and 7.6 in (2929) and using the branching ratio obtained from Miller (1455), Table 1, column B.

9. (2838) data were converted to line excitation cross sections using the branching ratio obtained from Miller (1455) Table 1, column B.

10. (2366) normalized to the value of the maximum cross section given in Table 1 of (1969) at the energy of the maximum cross section given in (2366).

11. (1078) and (2366) normalized to the value of the maximum cross section given in Table 1 of (1969) at the energy of the maximum cross section given in the respective papers.

12. (1040) normalized to the value of the maximum cross section given in Table 1 of (1972) at the energy of the maximum cross section given in (1040).

13. (1040) normalized to the value of the maximum cross section given in Figure 3 of (1801) at the energy of the maximum cross section given in (1040).
14. The initial state of the system is Ba$^+$ ($6^2S_{1/2}^+\).  
15. (262) data are relative. They have been normalized to (2626) at 50 eV.  
16. This line of Hg is unclassified (private communication from C. M. Sitterly).  
17. The initial state of the system is N$_2^+$ ($X^2\Sigma^+_G$). The electronic transition for this cross section is B$^2\Sigma^+_u$ $\rightarrow$ $X^2\Pi^+_G$.  
18. The electronic transition for this cross section is B$^2\Pi$ $\rightarrow$ $X^2\Pi$.  
19. The electronic transition for this cross section is A$^2\Pi_u$ $\rightarrow$ $X^2\Pi^+_G$.  
20. The electronic transition for this cross section is A$^2\Pi_u$ $\rightarrow$ $X^2\Pi^+_G$.  
21. The electronic transition for this cross section is b$^4\Pi_G$ $\rightarrow$ a$^6\Pi_u$.  
22. The electronic transition for this cross section is 2$\Sigma^+_u$ $\rightarrow$ 2$\Pi^+_G$.  
23. The electronic transition for this cross section is 2$\Pi^+(3/2)_u$ $\rightarrow$ 2$\Pi^+(3/2)_G$.  
24. The electronic transition for this cross section is 2$\Pi^+(1/2)_u$ $\rightarrow$ 2$\Pi^+(1/2)_G$.  
25. (1325) normalized to the value of the maximum cross section given in the Table of (474) at the energy of the maximum cross section given in (1325).
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