of the decay curve [the $J=\frac{1}{2}$ and $\frac{3}{2}$ components of the $(1s2s2p)\,^4P_J$ multiplet] is less than about $2\times10^{-9}$ sec, so that a good separation of the long-lived $J=\frac{5}{2}$ component is possible. With the precision at hand, it was not possible to extract unique lifetime or population information about the $J=\frac{1}{2}$ and $\frac{3}{2}$ states in the beam. The analysis is complicated by the possibility of cascades and by the unknown variation of the relative populations of the $J=\frac{1}{2}$ and $\frac{3}{2}$ states with beam energy.

Our lifetime value for the $(1s2s2p)\,^4P_{5/2}$ state of $O^{5+}$ is somewhat lower than the experimental value of Dmitriev *et al.*[4] of $(4.4\pm0.8)\times10^{-8}$ sec, measured by the charge-change method. Our value is only slightly lower than the value of $3.1\times10^{-8}$ sec calculated by Manson[5] using single-configuration Hartree-Fock wave functions but it is distinctly lower than the value $7.5\times10^{-8}$ sec calculated by Balashov *et al.*,[6] who used screened Coulomb functions for the bound electron.

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# Electron-Impact Excitation of Auto-Ionizing Levels in Cesium*

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Auto-ionizing states in Cs between 12 and 20 eV have been studied by electron impact. The retarding-potential-difference method was used to obtain an electron beam with energy spread of about 0.1 eV. To determine the threshold energies, inelastically scattered electrons were analyzed by the trapped-electron method. We have been able to identify about 20 levels, and the agreement with spectroscopic data is excellent. A peak appearing at 12.80 eV is probably due to the quartet states observed by Feldman and Novick.

## I. INTRODUCTION

The structure that is sometimes seen in electron-impact ionization curves, as well as certain anomalies in vacuum ultraviolet absorption experiments, can in many cases be attributed to the process of auto-ionization. Series of auto-ionizing levels in atoms and molecules result from the excitation of an inner-core electron or from the simultaneous excitation of two electrons. The levels are located above the first ionization potential and can, in principle, decay via one of the following two channels: (i) by a radiative transition to a bound state of the atom below the ionization poten-

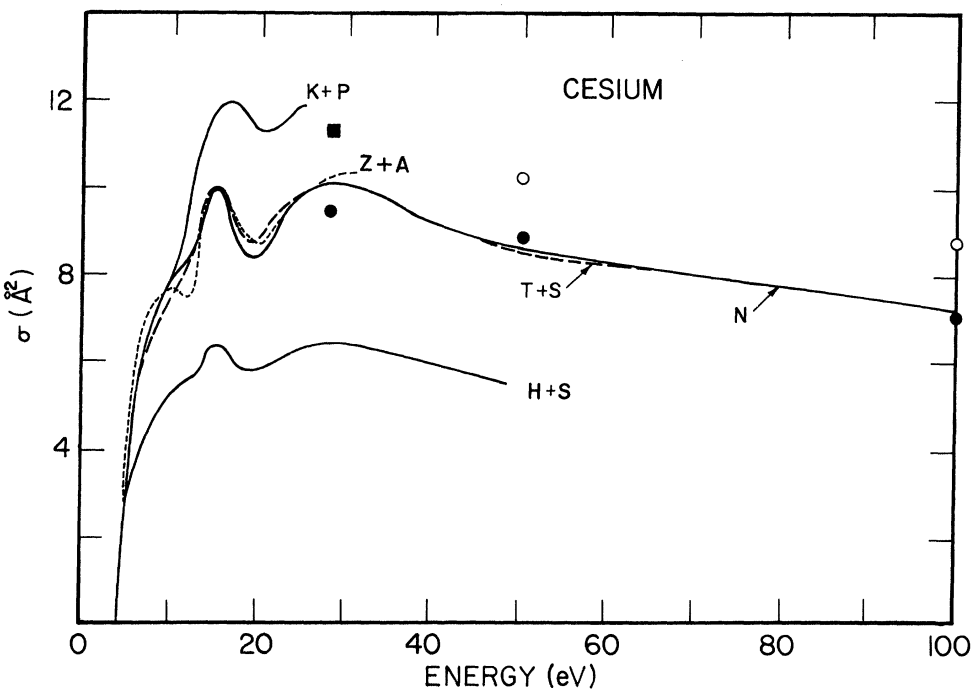


FIG. 1. Compilation of cross-section data for production of $Cs^+$ ions from cesium by electron impact: H+S, Heil and Scott (Ref. 17); K+P, Korchevoi and Przonski (Ref. 18); T+S, relative measurements of Tate and Smith (Ref. 21) normalized to the absolute measurements of Nygaard (Ref. 19); N, Nygaard (Ref. 19); Z+S, Zapesochnyi and Aleksakhin (Ref. 20); ■, Brink (Ref. 16); ●, McFarland and Kinney (Ref. 22); ○, McFarland (Ref. 23).

tial, or (ii) by a nonradiative transition to the ground state or to one of the excited states of the ion. In the nonradiative channel the process leads to the emission of a fast electron whose kinetic energy equals the difference between the energies of the initial and final states. This process is called *auto-ionization*, and it is the objective of this paper to report on electron-induced auto-ionization in cesium vapor.

In general, auto-ionizing levels[1] can be excited by photons,[2–4] electrons,[5–8] ions,[9–10] and fast atoms,[11] and can also be generated in a hot plasma by dielectronic recombination.[12] For these reasons, auto-ionization plays an important role in the interpretation of far-ultraviolet solar and stellar spectra. One interesting astrophysical aspect of auto-ionization is the extremely short lifetime of some of the levels involved, of the order $10^{-14}$ sec. This corresponds to a linewidth of about 100 Å, thus making the lines very efficient absorbers. Further details on the astrophysical significance are discussed by Goldberg.[13] The presence of auto-ionizing levels close to the ionization threshold in a number of metal vapors and gases contributes strongly to the total ionization cross sections both by electron impact[14] and by photoabsorption.[15]

In cesium, the lowest auto-ionizing level is located approximately 8 eV above the first ionization potential at 3.89 eV, and this rather isolated level, plus some others, can therefore be studied by electron-energy-loss techniques without too much interference from the ionization of the valence electron. In the literature,[16–23] there are indications that excitation of auto-ionizing levels may partly account for the structure in the cesium ionization cross section, which is shown in Fig. 1. Typical of all results is the pronounced peak around 15 eV. This feature coincides with the existence of a high number of $I^b$ levels[24] in the energy region between 12 and 19 eV.[2–4] For completeness, we should add that the broad maximum around 28 eV in Fig. 1 is due to the production of excited ions, whereas the lower maximum observed by Zapesochnyi and Aleksakhin[20] at 9 eV coincides with the maximum cross section for removal of 6*s* electrons.

By using the retarding-potential-difference (RPD) gun invented by Fox *et al.*[25,26] and the trapped-electron method developed by Schulz,[27] we have been able to excite and resolve about 20 of the $I^b$ levels, thereby gaining more knowledge on the ionization mechanisms in cesium.

In Sec. II are described general characteristics of auto-ionization, as well as specific auto-ionizing levels in cesium, the levels being those reported in the pioneering works of Beutler and Guggenheimer[2] and of Moore.[28] The apparatus and experimental procedure, the results, data analysis, and discussion are contained in Secs. III and IV.

## II. CHARACTERISTICS OF AUTO-IONIZATION

Auto-ionization processes have been observed in simple atomic as well as in complicated molecular systems. When bound electrons gain sufficient energy by some collisional mechanism, the atom may

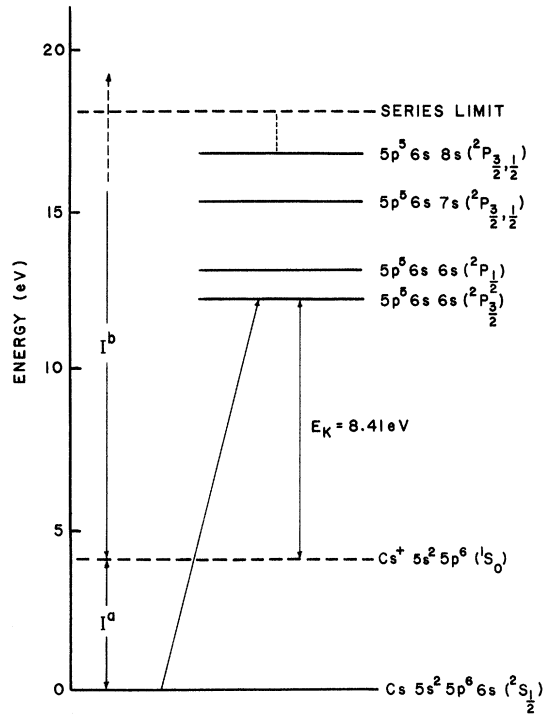


FIG. 2. Simplified cesium term diagram. Bound states below the first ionization potential fall within the $I^a$ category and are not included. As an example of auto-ionizing levels ($I^b$) we give the series with $5p^5 6sns$ electron configuration. Energies and state designations are from Moore's tables (Ref. 28).

be excited to one of its "discrete" states embedded in the continuum. The decay of these states can be either radiative or nonradiative, the latter process being known as auto-ionization. If the probability of auto-ionization is close to unity, the excited state can no longer be considered discrete because of the strong mixing with the continuum. The line then becomes broadened and the energy indistinct, with corresponding lifetimes of the order of $10^{-13}$–$10^{-15}$ sec. On the other hand, long-lived metastable quartet states may exhibit lifetimes of about $10^{-5}$–$10^{-6}$ sec, as reported by Feldman and Novick.[5]

In the alkali elements, due to the high binding energy of the inner-core electrons, excitation of any of these may lead to a series of discrete states well beyond the first ionization limit. In cesium, for instance, one of the inner electrons ($5p$) in the $5p^6 6s$ ground-state configuration becomes excited and results in a bound state with electron configuration $5p^5 6s 6s$. This state ($^2P_{3/2}$) is located 12.3 eV above the ground state of the atom, as illustrated in the simplified-term diagram in Fig. 2, and may decay to the ground state of $Cs^+(^1S_0)$ by ejecting a fast electron with a kinetic energy of 8.41 eV. Auto-ionization levels may form Rydberg series, and as an example we show some of the levels with $5p^5 6sns$ configuration in Fig. 2. In addition to the $5p6sns$ sequence given as an example here, we have been able to excite and identify several states of other series and discuss these results in a subsequent section. We notice in Fig. 2 that the energy range of the $I^b$ states has no upper bound. However, the probability of exciting very high-energy levels decreases rapidly with increasing binding energy.

Most of the present knowledge on auto-ionization levels and mechanisms arises from analysis of spectroscopic data, in particular the absorption measurements of Beutler and Guggenheimer in 1934,[2] the spark emission measurements of Boyd in Sawyer in 1942,[29] and the very recent absorption experiment of Connerade.[4] In comparing the previous investigations as summarized in Moore's tables[28] and Connerade's discussion,[4] we have noticed several discrepancies in the assignments of $J$, $L$, and $S$ values and in level designations. There has been a change in emphasis of notation, since the early works by Beutler and Guggenheimer used $L$-$S$ coupling, whereas Connerade used the $J_c$-$K$ coupling scheme proposed by Racah.[30] In the $L$-$S$ coupling scheme, the spin-orbit interaction is often assumed to be small compared to the Coulomb interaction, so that the orbital momentum $l_i$ of each electron couples strongly to each other to give $L$, and the spin $s_i$ of each electron couples to give $S$.

In Racah's method, on the other hand, an atomic system is treated as a sum of a parent ion and an external electron. The possible term values are obtained from $\vec{L}$ and $\vec{S}$, constructed by the expressions

$$\vec{L} = \vec{L}_p + \vec{l}_e \,, \tag{1}$$

$$\vec{S} = \vec{S}_p + \vec{s}_e \,, \tag{2}$$

where subscripts $p$ and $e$ stand for parent ion and external electron. Since the excited electron is in an outer shell, its electrostatic interaction with the parent ion is weaker than the spin-orbit interaction of the parent ion. Furthermore, the electrostatic interaction of the excited electron is stronger than the spin-orbit interaction between the excited electron and the parent ion. The quantum number $\vec{J}$, as defined by Racah, is

$$\vec{J} \equiv \vec{K} + \vec{s}_e \,, \tag{3}$$

where

$$\vec{K} = \vec{J}_p + \vec{l}_e \tag{4}$$

and $\vec{J}_p$ is the angular momentum of the parent ion.

One of the most successful methods in calculating energies and transition rates is the close-coupling approximation[31] which utilizes the eigenvalue expansion of the total wave function for the system, thereby generating second-order differential equations

describing the auto-ionizing electrons. Auto-ionization has also been treated as a scattering problem[32] or as a resonance effect.[33] These approaches have been successful in dealing with simpler atomic or molecular systems, and expansion to more complex systems is presently being attempted by several workers.[34] In view of the relevance of auto-ionization in astrophysics and atomic structure, both theoretical and experimental advancements seem to be tentative and incomplete. The results obtained during this investigation constitute a first attempt to excite the previously known doublet states by electron impact and to supplement information on the quartet states studied by Feldman and Novick.[5]

## III. EXPERIMENTAL ARRANGEMENT

The well-known techniques of the RPD electron gun[25] and trapped-electron[27] cylindrical collision chamber were used in this investigation. The major features are as follows: The low-energy portion of the electrons pulled out from the indirectly heated cathode in Fig. 3 was retarded and cut off by the slightly negative potential at the small-aperture electrode marked R. The dc potential at this electrode was superimposed by a small ac signal with amplitude 0.12 V peak to peak and frequency ($f$) 29 Hz. By using phase-sensitive detection[35] one

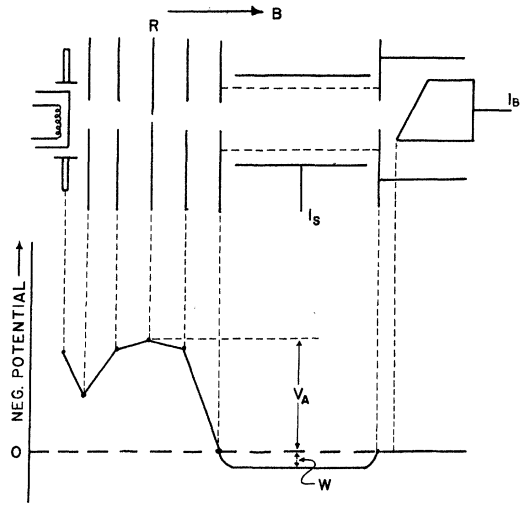


FIG. 3. Apparatus. The principle of the RPD electron gun and trapped-electron collision chamber is illustrated by the schematic potential diagram. The aperture in the retarding electrode was 0.5 mm diam. Characteristic dimensions for the collision chamber are total length of 30 mm and radii of 8 and 6 mm for the cylindrical collector and grid generating surface, respectively. Both the electron-beam current $I_B$ and the trapped-electron current $I_s$ were measured with Keithley 610B electrometers. The total energy of the beam electrons in the collision region is determined by the sum of the accelerating voltage $V_a$ and the well depth $W$.

can measure a transmitted or scattered electron current within a narrow energy interval determined by the peak-to-peak sinusoidal voltage applied to the retarding electrode. Typical beam currents were of the order of $10^{-8}$ A. An axial magnetic field was used to guide the electron beam; the magnitude of this field will be discussed later.

The principle of Schulz's trapped-electron method[27] is to perturb the potential along the axis of the cylindrical collision region by applying a potential difference between the grid and the surrounding cylindrical collector. This leads to the following two effects: (i) The energy of the beam electrons in the collision region is determined by the sum of the accelerating voltage $V_a$ and the well depth $W$. (ii) Inelastically scattered electrons will be trapped in the well if their energy after collision is less than $W$. They arrive at the collector by diffusing against the radial electric field. As a result, the trapped-electron current will increase and exhibit sharp maxima when the incident electron energy approaches the energy of bound atomic states. (Notice that the electrons that did not suffer collisions are transmitted to and collected at the beam collector to the right in Fig. 3.) The width of the trapped-electron current peaks is approximately equal to $[W^2+(\Delta E)^2]^{1/2}$, where $W$ is the well depth and $\Delta E$ is the energy spread in the electron beam. The width given by the above expression is entirely due to the experimental method used. A wide peak would also appear if the lifetime of a state is very short. In practice, the well depth was determined by applying a negative voltage to the cylindrical detector and observing the subsequent shift in the electron-beam retarding curve, as discussed by Burrow and Schulz.[36]

The average time $T_d$ it takes for the scattered electrons to diffuse out past the grid wires is given by the expression[27]

$$T_d = 0.26eB^2R^2/(m\nu_c V)\,, \tag{5}$$

where $e$ and $m$ are the electronic charge and mass, respectively, $B$ is the axial magnetic field in Wb/m$^2$, $R$ is the distance from the tube axis to the grid wires, and $\nu_c$ is the collision frequency for the slow electrons of energy $V$(volts). In order not to lose phase information, we require that the diffusion time be less than the inverse of the modulation frequency ($T_d < 1/f$). A too long diffusion time leads to an increase in space charge, which subsequently tends to broaden the energy resolution of the apparatus. However, this effect was not observed with total beam currents of about $10^{-8}$ A and magnetic fields of about 100 G. The magnetic field must be sufficiently large to prevent elastically scattered electrons and fast electrons generated in the auto-ionization process from reaching the cylindrical collector. Typically, the radius of gyration for a 10-eV electron is 0.8 mm at 130 G. The major por-

tion of the fast electrons will, therefore, be collected at, or go through, the large-aperture holes in the end plates of the collision chamber. For the reasons discussed here the apparatus was operated with magnetic fields between 100 and 130 G.

The energy scale was calibrated by comparison with known atomic structures, notably the excitation of the $6\,^2P_{3/2}$ state at 1.41 eV, the first ionization potential at 3.89 eV, and the auto-ionizing $^2P_{3/2,1/2}$ states at 12.3 and 13.5 eV, all in cesium. Additional information was obtained by admitting helium to the cesium-filled apparatus and measuring the He resonance[37] at 19.3 eV. The consistency of the energy scale thus obtained is within ±0.03 eV.

A spread in electron-beam energy arises from thermal spread of electrons leaving the cathode surface and from possible nonuniform distribution of contact potentials on electrode surfaces. Part of the thermal spread is discriminated against by the retarding potential at the small-aperture electrode in the electron gun. Since a metal surface in thermal equilibrium with cesium vapor is constantly replenished with cesium atoms, we have reasons to believe that differences in contact potential are essentially eliminated. The same observation has been made by Bullis.[38] Disadvantages from the cesium coating show up as leakage resistances on all ceramic insulators in the apparatus. This effect was minimized by operating the apparatus, except for the cesium reservoir, at an elevated temperature of 100 °C. The background pressure at that temperature was maintained by an ion pump to better than $10^{-8}$ Torr.[39]

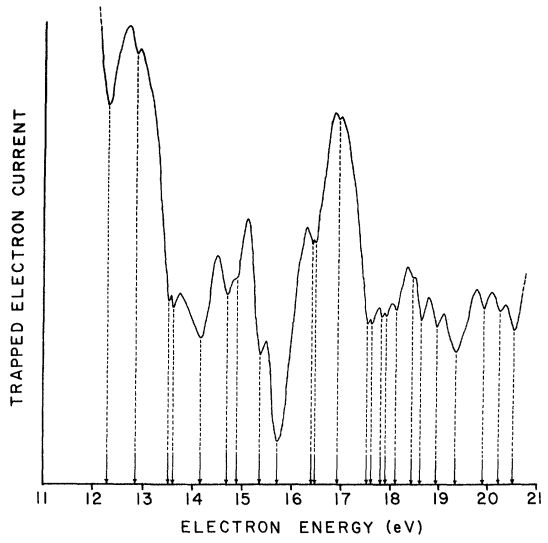


FIG. 4. Trapped-electron current (in arbitrary units) as a function of electron energy. The vertical arrows on the enery scale define levels compiled in Table I.

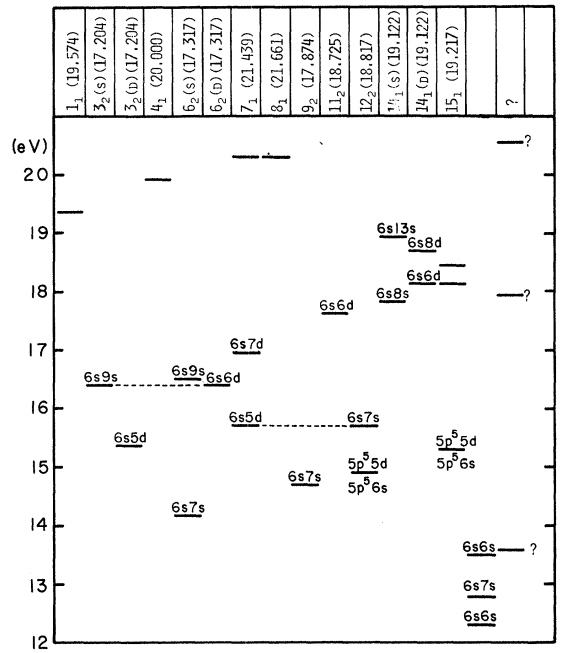


FIG. 5. Organization of levels within known spectroscopic series. The series limits on top of the illustration are from Wheatley and Sawyer (Ref. 41). Four of the levels have been listed in two different series; they are connected with broken lines if not immediately adjacent.

The objective of this work has been to study autoionization levels by electron impact, and not necessarily to determine absolute excitation cross sections. For this reason we did not observe the complete set of consistency checks suggested by Kieffer and Dunn,[40] but restricted ourselves to tests on the proportionality between the trapped-electron current and the product of beam current and cesium density. These tests were satisfied to within ±10%.

## IV. RESULTS AND DISCUSSION

It is important to realize that the trapped-electron method is capable of exciting and detecting both doublet and quartet states of an atomic system. This is an advantage over spectroscopic absorption measurements which are more or less confined to doublet states.

The contribution of the faster electrons in the electron beam tends to shift the "onsets" toward a slightly lower value by an amount equal to the spread in energy. Since the energy spread was shown to be constant over the operating energy range, its effect to each onset should be the same. On this background, we have chosen the "onsets," or characteristic breaks in curvature, as a measure of the threshold energy of the $I^b$ levels. With threshold energy here we mean the onset of a new channel. With this procedure we were able to distinguish adjacent

TABLE I. Auto-ionizing levels in cesium.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Electron impact | Connerade[a] | | | Moore[b] | |
| $E$(eV) | $E$(eV)[c] | Limit | Assignment | $E$(eV) | Assignment |
| 12.30 | | | | 12.30 | $5p^5 6s^2(^2P^o_{3/2})$ |
| 12.80 | | | | $12.60 \pm 0.3$[d] | $5p^5 6s7s(^4P)$ |
| | | | | | $5p^5 6s5d(^4P)$ |
| | | | | | $5p^5 6s4f(^4G)$ |
| 13.50 | | | | 13.52 | $5p^5 6s^2(^2P^o_{1/2})$ |
| 13.60 | ? | | | ? | |
| 14.15 | 14.200 | $6_2$ | $5p^5 6s7s[2]_{3/2}$ | 14.20 | $5p^5 6s5d$, 2° (1/2) |
| 14.70 | 14.697 | $9_2$ | $5p^5 6s7s[2]_{3/2}$ | 14.697 | $5p^5 6s5d$, 5° (3/2) |
| 14.90 | 14.924 | $12_1$ | Cs II $5p^5 5d$ | | |
| | | | $5p^5 6s$ | | |
| 15.35 | 15.320 | $15_2$ | Cs II $5p^5 5d$ | | |
| | | | $5p^5 6s$ | | |
| | 15.310 | $3_2$ | $5p^5 6s5d$ | 15.310 | $5p^5 6s7s(^2P^o_{3/2})$ |
| 15.70 | 15.680 | $12_2$ | $5p^5 6s7s[2]_{3/2}$ | 15.680 | $5p^5 6s6d$ 9°(1/2, 3/2) |
| | 15.670 | $7_1$ | $5p^5 6s5d$ | | |
| 16.40 | 16.390 | $6_2$ | $5p^5 6s6d$ | 16.43 | $5p^5 6s7d$, 15°(1/2, 3/2) |
| | 16.420 | $3_2$ | $5p^5 6s9s$ | 16.45 | $5p^5 6s7d$, 16°(1/2, 3/2) |
| 16.50 | 16.500 | ? | ? | 16.45 | $5p^5 6s7d$, 16°(1/2, 3/2) |
| | 16.510 | $6_2$ | $5p^5 6s9s$ | 16.56 | $5p^5 6s9s(^2P^o_{3/2})$ |
| 16.95 | 16.952 | $7_1$ | $5p^5 6s7d$ | 16.96 | $5p^5 6s12s(^2P^o_{3/2})$ |
| 17.53 | ...[e] | | | | $5p^5 6s11s$ 22, (1/2, 3/2) |
| 17.63 | 17.626 | $11_2$ | $5p^5 6s6d$ | 17.67 | $5p^5 6s6d(^4P^o_{1/2})$ |
| | 17.650 | $11_2$ | $5p^5 6s6d$ | | 24°(1/2, 3/2) |
| | 17.669 | $11_2$ | $5p^5 6s6d$ | | |
| 17.85 | 17.824 | $14_1$ | $5p^5 6s8s[1]_{1/2,3/2}$ | 17.83 | $5p^5 6s6d^3 26°(1/2, 3/2)$ |
| 17.95 | ? | | | 17.91 | $5p^5 6s8s(^4P^o_{1/2})$ |
| 18.15 | 18.136 | $14_1$ | $5p^5 6s6d$ | | |
| | 18.200 | $15_1$ | | 18.13 | $5p^5 6s9s(2P^o_{1/2})$ |
| 18.45 | 18.456 | $15_1$ | | 18.38 | $5p^5 6s6d^3 26°(1/2, 3/2)$ |
| | | | | 18.52 | $5p^5 6s9s\ 2P^o_{1/2}$ |
| 18.70 | 18.717 | $14_1$ | $5p^5 6s8d$ | 18.64 | $5p^5 6s8d^3 30°$ (1/2, 3/2) |
| | | | | 18.78 | $5p^5 6s9d^3 31°$ (1/2, 3/2) |
| 18.95 | 18.923 | $14_1$ | $5p^5 6s13s$ | 18.93 | $5p^5 6s11d^3 34°$ (1/2, 3/2) |
| | | | | 18.96 | $5p^5 6s12d^3 35°$ (1/2, 3/2) |
| 19.35 | 19.317 | $1_1$ | | | |
| | 19.376 | $1_1$ | | | |
| 19.90 | 19.900 | $4_1$ | | | |
| 20.30 | 20.275 | $7_1$ | | | |
| | 20.395 | $8_1$ | | | |
| | 20.344 | $8_1$ | | | |
| 20.55 | ? | | | | |

[a]Reference 4.
[b]Reference 28.
[c]The original $cm^{-1}$ unit has been converted to eV for easier comparison.
[d]Reference 5.
[e]Connerade has observed about 13 levels between 17.5 and 17.55 eV.

levels separated by about one-half the estimated experimental resolution.

Figure 4 shows the trapped-electron current as a function of energy in cesium vapor at $10^{-6}$ Torr.[39] Most of the structure is due to auto-ionization states in Cs I in the energy range between 12 and 20 eV. The data analysis is reviewed in Table I, which contains information pertaining to threshold energies and assignments according to Beutler and Guggenheimer,[2] Moore,[28] and Connerade.[4]

In the first column in Table I are shown the energy values in eV as observed with our trapped-electron apparatus. Our values agree with spectroscopic data (columns 2 and 5) to within the resolving power of our apparatus. The spectroscopic resolution is, of course, superior to that attainable with electron monochromators. In columns 3 and 4 are depicted the series limits to which a particular line converges, as well as the electron configuration and $K$, $J$ values suggested by Connerade. (The series

limits in column 3 are the levels in Cs II.) Finally, in column 5 and 6 are shown the energy values, electron configurations, and level assignments of Moore.

A critical evaluation of Table I reveals a significant discrepancy with respect to configurations and level assignments. The discrepancy is due to difficulties in assigning the observed lines to any particular series because of the complexity of the spectrum. In the energy range between 15 and 18 eV, there are many possible configurations for each observed value in column 1.

In addition to the identified doublet levels included in Table I, we have consistently observed an onset at 12.8 eV, which coincides with the quartet states reported by Feldman and Novick[5] at 12.6 ± 0.3 eV. Our results offer a more accurate value for the onset of the quartet structure to within ±0.05 eV of 12.8 eV. We have not been able to identify the level or group of levels that appears at 20.55 eV.

To demonstrate the complexity of the auto-ionizing spectrum, we have displayed the levels of Table I in Fig. 5. Since the number of states observed by means of electron impact is much less than that observed by spectroscopic techniques, we do not have sufficient information to construct sets of Rydberg-type series, but only to invoke certain trends. Described in Fig. 5 are the observed levels arranged in terms of their energies and limits to which they may belong. The limits and the assignments are proposed by Connerade, except the $6s6s\,(^2P_{3/2,1/2})$ and $6s7s\,(^4F)$ states which can only be referenced to Moore's table[28] and Feldman and Novick's work,[5] respectively. Due to the uncertainties in assignments, four levels at 15.70, 16.40, 18.15, and 20.30 eV have been listed under different limits according to their possible assignment, and are connected with broken lines. In the last column are three unidentified levels " ?" at 13.60, 17.95, and 20.55 eV; the middle one may possibly coincide with the $5p^56s8s\,(^4P^\circ_{1/2})$ state reported by Moore.

Not included in this report is a large number of very sharp structures appearing between 20 and 30 eV, most likely due to the excitation of Cs II levels. We should also mention that we have observed bound levels around 50 eV, which might be caused by excitation of inner-core (5s) electrons.

One of the most pronounced difficulties in the analysis of spectroscopic absorption measurements is to assign the lines to particular series and from this to deduct the corresponding effective quantum numbers. The appearance of sharp and diffuse lines, for instance, presents itself as a valuable guide. By studying the scattering of electrons in the forward direction in an electron monochrometer-analyzer system we hope to develop quantitative procedures that will supplement the spectroscopic techniques, thereby obtaining more information on the high-energy structure of atomic and molecular systems. In particular, the oscillator strength for the doublet states can be determined by this method.

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# Energy Shifts Observed in Ni $K$ X Rays Produced by Fission-Fragment Collisions*

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The $K\alpha$ and $K\beta$ x rays of Ni produced by the passage of light fission fragments from the spontaneous fission of $^{252}$Cf through a thin Ni foil were found to be shifted up in energy by $69 \pm 11$ and $210 \pm 16$ eV, respectively, relative to the x rays produced by 6-MeV $\alpha$ particles and by photons from the decay of $^{241}$Am. These shifts are similar in character to those observed previously in 15-MeV oxygen-ion bombardments, but require extremely high ionic charge states to be explainable in terms of multiple inner-shell plus outer-shell ionization.

## I. INTRODUCTION

A study of x rays produced by the passage of fission fragments through matter, in which a cyclic dependence of the $K$- and $L$-shell ionization cross sections on the atomic numbers of the collision partners was observed, has previously been reported by Specht.[1] Recently, a similar $Z$ dependence of x-ray production cross sections has been observed by Kavanagh *et al.*[2] in ion-atom collisions between Cu and a wide range of heavy-ion projectiles having energies below approximately 10 keV/amu. These data have been interpreted as evidence for a mechanism in which inner-shell vacancies are produced by the promotion of electrons as a result of the crossing of quasimolecular states formed during collision. A model for this mechanism has been discussed by Fano and Lichten[3] and by Specht.[1]

Energy shifts have recently been observed by Burch and Richard[4] in $K$ x rays emitted as a result of 15-MeV oxygen-ion bombardments of Ca and V. These authors present evidence that multiple inner-shell ionization may be the cause of the observed x-ray energy shifts, but argue against the quasimolecular model from the point of view that the adiabatic approximations necessary in the quasimolecular model are not expected to be valid at these energies (~ 1 MeV/amu).

In his study of x-ray emission induced by fission fragments, Specht also noted energy shifts in the gross spectra of $K$ and $L$ x rays. In order to determine whether the x-ray energy shifts resulting from fission-fragment-induced x-ray emission display the same characteristics as those observed in the oxygen-ion bombardments, we have carried out a detailed examination, under high resolution, of the Ni $K$ x rays produced by the passage through a thin Ni foil of fission fragments emanating from a source of $^{252}$Cf. The results of this investigation