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PHYSICS FORUM

Double Ionization of Atoms*

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The development of the subject of the multiple ionization of inner electron shells of atoms illustrates both the importance of the progress of technique in research in physics as well as the synthetic process in physical concepts and ideas which results in including within the scope of a single theory or closely related group of theories facts and previous theories seemingly quite diverse. Two quite different branches of research in x-rays contribute directly to our knowledge of multiple ionization; namely, studies of x-ray "satellites" and measurements of the widths of x-ray spectrum lines.

As a direct result of the Rutherford-Bohr atom model and the theory of the origin of spectral lines, the classical observations of Moseley on x-ray spectra were at once interpreted. The x-ray lines observed by Moseley and his immediate followers were due to transitions between energy levels arising from the absence of an electron from one or another of the electron shells. This concept is visualized in the energy level diagram which, subject to certain so-called "selection" rules, predicts the entire x-ray spectrum of singly ionized atoms.

Improvements in the technique of x-ray spectroscopy soon led to the discovery of many other lines which did not fit this single-ionization scheme. These lines came to be called "satellites," since they are usually found close to and on the short wave-length side of the "diagram" lines. A number of years of research led to the following generalizations among others, concerning satellites.

First, they are very numerous, the total number of satellites being in excess of the total number of diagram lines.

Second, the satellite structure associated with the several diagram lines varies greatly from line to line, both as to number and relative intensity of satellite components.

Third, satellites have a somewhat higher excitation potential than the corresponding parent lines.

Fourth, the intensity of satellites relative to the parent line varies rapidly with atomic number. There seem to be two kinds of variation. The satellites associated with the $K\alpha$ lines decrease rapidly and continuously in intensity from some 7 percent, of $K\alpha_1$ at S(16) to some 0.03 percent at Mo(42). With satellites associated with the $L\alpha$ line, one observes, first, an increase in relative intensity beginning at about atomic number Zr(40), arising to a maximum at about Pd(46) and dropping rapidly to almost zero at Te(52).

It was early suggested that satellites probably arise from some form of multiple ionization but it was not until the recent proposal of Coster and Kronig[1] that a working hypothesis was available to explain such puzzling observations as the rapid variation of intensity of satellites mentioned above in connection with $L\alpha$.

Doubly ionized atoms, essentially for the production of satellites, may be produced in either of two ways, (1) by direct impact of a cathode-ray electron possessing sufficient energy or (2) by the internal conversion of energy known as the Auger effect. It appears from the work of R. D. Richtmyer[2] that the satellites of $K\alpha$ owe their origin to atoms which have been doubly ionized by direct impact of cathode-ray electrons. Both the absolute intensity of satellites of $K\alpha$ and their variation in intensity with atomic number are qualitatively at least predicted by this theory.

Coster and Kronig suggested that the potential energy released by an inner-electron transition might, instead of being radiated from the atom as a quantum, be internally absorbed

* Abstract of retiring presidential address before American Physical Society, December 29, 1936.

[1] D. Coster and R. de L. Kronig, Physica **2**, 13 (1935).
[2] R. D. Richtmyer, Phys. Rev. **49**, 1 (1936).

"photoelectrically" in an outer shell of the atom and as a result the atom would be doubly ionized, and in a condition requisite to produce satellites. A given outer electron can be expelled by this process only if the energy released by the internal electron "jump" exceeds the binding energy of the outer electron. Dr. Ramberg has shown[3] that when the internal energy released exceeds by only a little the binding energy of the given outer electron, the probability of its expulsion becomes very great due to a process which is perhaps somewhat analogous to resonance in classical terminology. It is this circumstance which accounts for the relatively high intensity of the satellites associated with $L\alpha$ of Ag(47); and for the complete absence of the satellites at Ba(56). While much work yet remains to be done, in developing the finer details of the Coster-Kronig theory, a significant start has already been made in clearing up the origin of x-ray satellites which has long been an interesting puzzle. By turning the process around we shall obviously acquire through study of satellites a considerable extension of our knowledge of the processes of double ionization.

Observations on the widths of spectrum lines and absorption limits provide another, and relatively direct, approach to the question of double ionization. X-ray spectrum lines are much wider than would be predicted by the classical theory based on radiation damping. According to classical theory, the greater the damping experienced by the vibrating electron, the wider will be the emitted line. The transition of this concept to the quantum theory may be made by considering the mean lives of atoms in excited states: the shorter the mean life of a given excited state, the wider is that state and therefore the wider the lines produced by transitions from that state. Dr. Ramberg has shown[3] that the theory of line widths based upon the assumption that transitions between ionized states result in the emission of radiation, predicts line widths which are much narrower than observed. If mean life is inversely proportional to line width, transitions other than those which give rise only to radiation must take place. Again, the Auger effect is brought in to explain the discrepancy between observed widths and radiation widths. If an atom may leave a given state not only by the emission of radiation but also by the internal conversion of the released energy and the emission of an electron, the mean life of that state will be much less than if only radiation processes could take place. By the application of this concept, Dr. Ramberg[3] has been able to account satisfactorily for the widths of x-ray spectrum lines.

[3] E. G. Ramberg and F. K. Richtmyer, Phys. Rev. in press.

Developments in physical science of which the above is merely one rather small illustration, are made possible by the informal cooperation of scientists from all over the world. These scientists form a sort of international league from which strife, dissensions and recriminations are all but absent. When one scientist announces a new theory or a new discovery, his fellow scientists either accept it at face value or at most try to find out whether he is right. Seldom do they deliberately set out to *prove* him wrong. Though physics in particular and science in general may be our primary interest, in organizations such as the American Physical Society, we must remember that in a larger way we are citizens and members of society with all the obligations which we must assume in return for the privileges which we enjoy. I believe it to be our duty as one small contribution which we can make to clearing up this disgraceful mess in which the world now finds itself, to point out to our fellow citizens whenever occasion presents the advantages which we *have found* to come from international cooperation in science. Had there not been such international cooperation in scientific matters, world science even today would have been in a very primitive stage.