Ionization Produced by 5-Mev Alpha Particles in Argon Mixtures

C. E. Melton, G. S. Hurst, and T. E. Bortner
Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee
(Received May 17, 1954)

It is shown that when small amounts of impurities are added to argon extra ionization is produced by alpha particles moving through the gas. These effects are studied as a function of the ionization potential of the added impurity and it is found that the ionization increases even when the ionization potential is much higher than the well-known metastable state of argon.

INTRODUCTION

It is known that small traces of impurities in some of the noble gases greatly increase the amount of ionization produced by alpha particles losing their energy in the gas.[1,2] Most of the investigations have been concerned with helium, and the decrease in the value of W (alpha-particle energy divided by number of ion pairs produced) was attributed to a discharge of the metastable state of the noble gas by an impurity which had an ionization potential less than or equal to the metastable level. In this reaction the impurity was ionized and the resultant ion pairs collected, thus lowering the W value. For example, if argon, whose ionization potential is 15.7 volts, is added to helium, the reaction

$$He^* + A \rightarrow He + A^+ + e^-$$

can take place since the excitation energy of the metastable state of helium (He^*) is greater than the ionization potential of argon. In fact, Biondi[3] has measured the cross section of this reaction and reports 1.0×10^{-16} cm^2. Sharpe[4] found an increase in ionization when carbon dioxide was added to argon. This increase could not be explained by the type of reaction described above since the ionization potential of carbon dioxide is greater than the metastable state in argon.

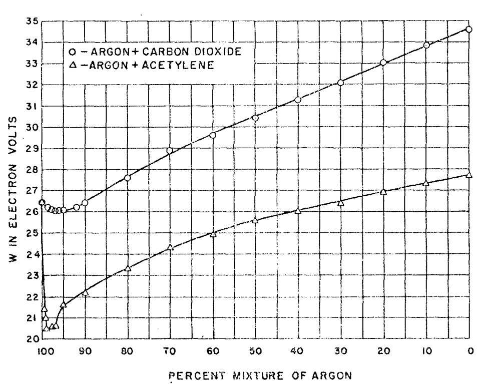

Fig. 1. W values for Pu alpha particles in mixtures of argon+carbon dioxide and argon+acetylene.

[1] Jesse, Forstat, and Sadauskis, Phys. Rev. **88**, 417 (1952).
[2] T. E. Bortner and G. S. Hurst, Phys. Rev. **90**, 160 (1953).
[3] M. A. Biondi, Phys. Rev. **88**, 660 (1952).
[4] J. Sharpe, Proc. Phys. Soc. (London) **A65**, 859 (1952).

In the present work a systematic study of argon was made by adding to it other gases in measured percentages and observing their effect on the W value. The gases for the argon mixtures were selected to meet the requirement of a continuous range of ionization potentials from 8.5 ev to 15.7 ev, in order to study the effect both above and below the well-known metastable state in argon at 11.5 ev.

A somewhat similar investigation was carried out concurrently in Europe by Bertolini, Bettoni, and Bisi.[5] The results for the five gases they studied compare favorably with the results of this investigation; however, the complete results from this investigation do not support their conclusion, namely, that the lower the ionization potential of the foreign gas the higher the maximum ionization. The five gases for which they reported results will support this conclusion, but this is not true for other gases, as is shown by Fig. 7.

EXPERIMENTAL RESULTS

A description of the apparatus has previously been reported.[6] An uncollimated Pu^{239} alpha source was placed in the center of a large parallel-plate ionization chamber, and the ionization produced was measured by means of an accurately calibrated capacitor, a stable high-voltage supply, a vibrating-reed electrometer, and a potentiometer. Great care was exercised to assure purity of the gases investigated. They were obtained in the extra pure form and further purified by fractional distillation. In some cases the ionization was measured during a continuous gas flow through the chamber.

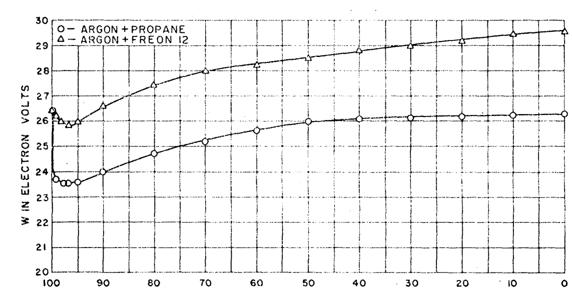

Fig. 2. W values for Pu alpha particles in mixtures of argon+propane and argon+Freon-12.

[5] Bertolini, Bettoni, and Bisi, Phys. Rev. **92**, 1586 (1953).
[6] T. E. Bortner and G. S. Hurst, Phys. Rev. **93**, 1236 (1953).

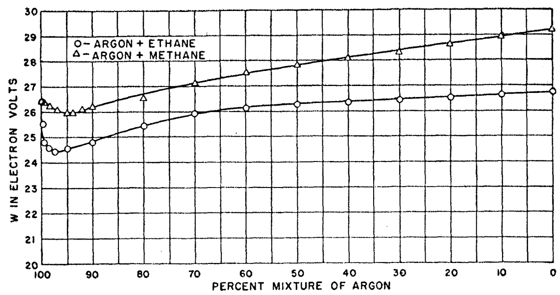

FIG. 3. W values for Pu alpha particles in mixtures of argon+ethane and argon+methane.

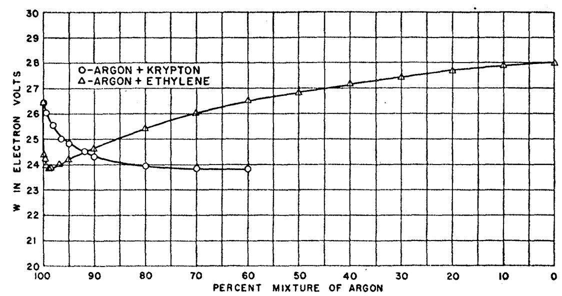

FIG. 4. W values for Pu alpha particles in mixtures of argon+krypton and argon+ethylene.

In Figs. 1–6 results are given for argon and various gas mixtures. The value of W in electron volts per ion pair is plotted on the ordinate, and the percent mixture of each gas on the abscissa. The percent of argon is given at each point; the remaining percentage consists

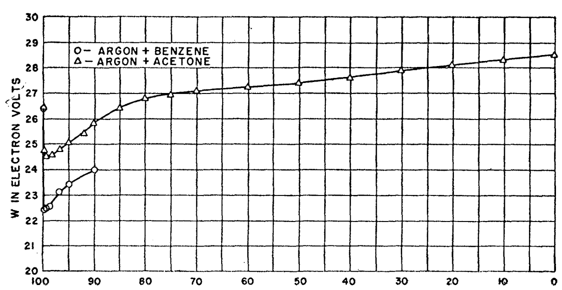

FIG. 5. W values for Pu alpha particles in mixtures of argon+benzene and argon+acetone.

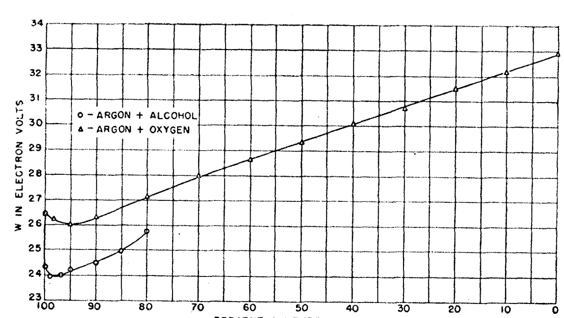

FIG. 6. W values for Pu alpha particles in mixtures of argon+alcohol and argon+oxygen.

of the gas indicated. It is interesting to note that large increases in ionization occur at very small percentages of impurities in argon. Acetylene gives a greater effect than any other gas investigated although it has an ionization potential much higher than some of the other gases. The results shown in these figures are believed to be correct to within one-half of one percent.

Figure 7 is a plot of the minimum W values observed, as a function of the ionization potentials of the gas component which is added to argon. The numbers in parentheses are the percents of the impurities required to give the minimum values for W. In the case of krypton the plotted "minimum" W value, 24.2, is simply the W value at the mixture giving the maximum deviation of the experimental curve from a straight line drawn through the W values of pure argon and pure krypton.

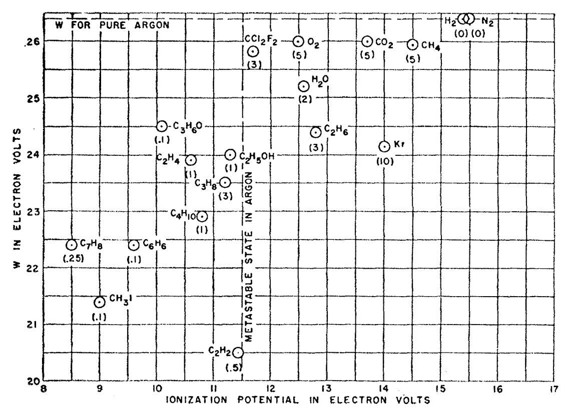

FIG. 7. Summary of effects of impurities on minimum W values for alpha particles in argon. The numbers in parentheses are the percents of the impurities required to give the minimum values of W.

CONCLUSIONS

Figure 7 indicates that any gas with an ionization potential of energy less than 15 ev will produce a decrease in the value of W when added to argon. There seems to be little correlation between the ionization potential of the gas and the decrease in the W value, except that in general the effect is greater if the ionization potential is less than the 11.5-volt metastable level in argon.

There is a possibility that the increase in ionization for the cases where the ionization potential is greater than the metastable state is due to an excited level in argon. Despite the fact that the lifetime of an atom in an excited level is short, it makes an appreciable number of collisions with other molecules before returning to the ground level. Consider a mixture of argon (95 percent) and methane (5 percent) at atmospheric pressure and room temperature. Then if the average velocity of the argon atoms is assumed to be unaffected by the methane, the number of collisions

of the argon atoms with methane molecules would be approximately 10^8 per second per excited argon atom. The assumption that the cross section measured by Biondi for the destruction of metastable helium by argon applies to the argon-methane reaction leads to approximately 5×10^6 destructions (hence ionizations) per second per excited argon. Therefore an excited state lifetime of only a few microseconds would be long enough to explain the observed increases in ionization. The generally larger increases in ionization in impurities whose ionization potential is less than the 11.5-volt metastable state can be attributed to the utilization of the energy in the metastable state as well as that of the excited state in producing ionization.

PHYSICAL REVIEW VOLUME 96, NUMBER 3 NOVEMBER 1, 1954

Hyperfine Structure of Nitrogen*

MARK A. HEALD† AND ROBERT BERINGER
Sloane Physics Laboratory, Yale University, New Haven, Connecticut
(Received July 23, 1954)

The magnetic resonance spectrum of the ^4S ground state of atomic nitrogen-14 has been observed using the microwave absorption method. The magnetic-dipole hyperfine interaction constant is

$$A=10.45\pm0.02 \text{ Mc/sec.}$$

No evidence was obtained for electric quadrupole interaction.

INTRODUCTION

THE observation of magnetic resonance transitions between hyperfine sublevels in atoms is useful for measuring hyperfine interaction energies and, in many cases, for obtaining the nuclear moments as such. This is an important technique for evaluating nuclear quadrupole moments. The interaction of nuclear moments with a single valence electron outside closed shells can be calculated quite reliably.[1] A generally successful procedure for obtaining nuclear moments from a knowledge of the hfs interaction constants has been developed for this case and can be immediately extended to the case of a closed shell less one electron.[2] The situation with several valence electrons is considerably more complicated.[3] Goudsmit has evaluated theoretically the magnetic interaction for special configurations on *LS* coupling[4]; Breit and Wills have treated intermediate coupling.[5] Trees has developed generalized formulas, in terms of Racah's tensor algebra for complex spectra, for both the magnetic-dipole and electric-quadrupole interactions on *LS* coupling.[6]

In the present investigation the magnetic resonance technique has been applied to atomic nitrogen. It was initially hoped that fine-structure and hyperfine-structure interaction constants could be measured for both the ground and metastable states of the nitrogen atom, and that perhaps some estimate of the quadrupole moment of N^{14} could be obtained. However, useful analysis of observed spectra is severely limited by the presence of considerable configuration interaction in nitrogen. Experimental difficulties have prevented observation of magnetic resonance spectra from the metastable states. Observations in connection with the atomic-nitrogen source are, however, of some interest in the long-standing problem of "active" nitrogen.

The ground electronic configuration of the nitrogen atom is $2p^3$, which forms the Russell-Saunders terms ^4S, ^2D, and ^2P. The $^4S_{\frac{3}{2}}$ state is the normal ground state; the doublet states are metastable. It is well-known that the N^{14} nucleus possesses both magnetic-dipole and electric-quadrupole moments. According to the nonrelativistic *LS* coupling formulas of Goudsmit and Trees, the magnetic hfs interaction constant for the ground state vanishes; the constants for the metastable states are in the region of 100 Mc/sec. The quadrupole interaction vanishes for all states.

Since nitrogen is a light atom, deviations from *LS* coupling should be very small.[7] However, it is well-known that the observed electrostatic splittings of the ground-configuration terms depart significantly from those of *LS* theory, presumably because of configuration interaction with $2p^23p$ states.[8] Although the fine-structure intervals of the metastable doublet states would vanish according to *LS* coupling theory, small

* Assisted by the Office of Naval Research and the du Pont Company.
† du Pont Company Fellow in Physics. Now at Project Matterhorn, Princeton University, Princeton, New Jersey. This work is part of a dissertation presented to Yale University for the Ph.D. degree.
[1] H. B. G. Casimir, *Interaction Between Atomic Nuclei and Electrons* (Teyler's Tweede Genootschap, Haarlem, 1936).
[2] Davis, Feld, Zabel, and Zacharias, Phys. Rev. **76**, 1076 (1949).
[3] H. Lew, Phys. Rev. **91**, 619 (1953).
[4] S. Goudsmit, Phys. Rev. **37**, 663 (1931).
[5] G. Breit and L. A. Wills, Phys. Rev. **44**, 470 (1933).
[6] R. E. Trees, Phys. Rev. **92**, 308 (1953).
[7] D. R. Inglis, Phys. Rev. **38**, 862 (1931).
[8] E. U. Condon and G. H. Shortley, *Theory of Atomic Spectra* (Cambridge University Press, London, 1935), p. 198.