The elastic cross section and the exchange force have been calculated on the hypothesis that only the processes $N \rightleftarrows P+e^{-}+n$ with the electron in a positive energy state can occur. If one admits in addition the symmetrical and perhaps plausible possibilities $P \rightleftarrows N+e^{+}+n$, the exchange energy is increased by a factor of 2 and the elastic cross section by a factor of 4.

The writer wishes to acknowledge suggestion and valuable discussion of these considerations on the part of Professor J. R. Oppenheimer.

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Ionization by Positive Alkali Ions as Measured by a Balanced Space-Charge Method

The minimum speeds at which ionization occurs when gas atoms are struck by accelerated positive alkali ions has been investigated for several gases and ions. By allowing the ionization to take place in a region containing a space-charge limited current of electrons, it has been possible to observe with great accuracy the formation of new positive ions because of the strong effect of positive ions on the electron current.[1] This method has the great advantage of being highly or completely insensitive to secondary electrons liberated from the walls and thus surmounts the greatest difficulty encountered in other methods.[2]

The electron space-charge was produced inside a cylindrical anode having an axially placed hot filament cathode. By using two such cylinders and filaments balanced against each other in a bridge circuit, with the filaments connected in parallel, and by allowing the ionization to take place in only one cylinder, all undesirable fluctuations in the space-charge current were eliminated. Extremely small changes in the electron current could thus be measured accurately.

Table I shows the results obtained (the numbers are the ion speeds in volts at which ionization was observed to start with the indicated ion and gas).

TABLE I.

TABLE I. *Ion energies in electron-volts at which ionization was observed to start.* (The dash indicates that no ionization was observed when ion speeds up to 530 volts were used.)

	Na^+	K^+	Rb^+	Cs^+
Ne	130±2	86±2	232±4 ?	—
A	105±3	82±2	135±3	340±2
N_2	88±2	79±2	260 ?	—
CO_2	95 ?	75±2		—

The manner of taking readings was to raise the speed of the beam and to observe the resulting deflection of the galvanometer measuring the difference of electron currents in the two cylinders. As the voltage was raised, the galvanometer showed no change in deflection (or very slight change) until the critical ionizing speed (see table) was reached. At this point the galvanometer started deflecting strongly, the deflection rising linearly with the voltage. The case of Cs^+ in A was the only exception. In this case the deflection started rather gradually, the range from 340 to 370 volts being covered before a linear deflection was reached.

The accuracies given are only approximate. They cover principally the errors that may arise from voltage gradients whose effect on the positive ion beam is unknown. Such gradients never spread over a range greater than five volts in the course of the measurements. Results could always be reproduced well within the errors given. A few results, as indicated, are doubtful because of the weakness of the ionization.

The results tend to be lower than those obtained by Beeck and Mouzon,[3] roughly by about the same multiplying factor. It is suggested that their results may have been higher because of space-charge retarding of the positive ion beam. The principal evidence for this is that at the higher speeds such as are necessary for Cs^+ in A the difference disappears. The higher voltages would naturally tend to eliminate space-charge effects.

If energy and momentum are to be conserved in a collision, the maximum energy available for outside work such as ionization or excitation is easily calculated to be the initial energy of the positive ion beam multiplied by the factor $m_2/(m_1+m_2)$, where m_2 is the mass of the gas atom and m_1 is the mass of the colliding ion. The application of this factor to the values in the table above gives the results in Table II.

TABLE II. *Reduced voltages available for ionization.*

	Na^+	K^+	Rb^+	Cs^+
Ne	60.8	29.3	44.7	—
A	66.8	41.9	43.0	78.5
N_2	48.3	33.0	64.2	—
CO_2	62.4	38.8		—

This reduction factor still does not bring the ionizing energies down to the true ionization potentials of the gases involved. There is no apparent correlation among the reduced voltages; the chief point of interest is that they are all fairly low (under 100 volts).

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[1] K. H. Kingdon, Phys. Rev. **21**, 408 (1923).
[2] See, for example, R. M. Sutton and J. C. Mouzon, Phys. Rev. **35**, 695 (1930); T. J. Câmpan, Phys. Zeits. **30**, 858 (1929); O. Beeck, Ann. d. Physik [5] **6**, 1001 (1930); and others.
[3] O. Beeck, and J. C. Mouzon, Ann. d. Physik [5] **11**, 858 (1931).