separation $r$ there is on the average a time element $\tau$ characterizing a probable transition. Recombination depends on the chance that the ions are within $r$ cm of each other for a time $t$ sufficiently large compared to $\tau$ to insure transition. At a value of $r=r_0$ where $\tau$ is such that say 90 percent or more encounters result in transition we can then roughly fix the limiting collision radius.

In our present ignorance we can certainly set $r_0$ as greater than the kinetic theory diameter of the ion, and it may well be 10 times as large. One may then apply these considerations to the ionosphere. At 100 km Humphreys[3] gives the pressure as 0.0067 mm and the temperature of the order of 55 or more below °C. I will use $-73$°C. On this basis $\epsilon$ for $(O_2)_2^+$ will be $4.24\times10^{-3}$ and $\alpha=1.61\times10^{-8}$. For the same gas $\alpha_r=\pi r_0^2(c_+^2+c_-^2)^{\frac{1}{2}}$ with $r_0=4\times10^{-8}$ and $4\times10^{-7}$ cm, respectively, gives $\alpha_r=2\times10^{-10}$ and $\alpha_r=2\times10^{-8}$ *independent of the pressure*. Thus in the ionosphere unless $r_0>4\times10^{-7}$ cm the Thomson theory still applies.

Where electrical data from the ionosphere indicate values of $\alpha$ of the order of $10^{-10}$ one might assume that the recombination was no longer ionic but electronic.[4] This question can readily be answered if the oxygen content of the ionosphere is known. The work of Bradbury[5] gives the chance of electron attachment to $O_2$ molecules for a given electron energy. The ions once formed are stable. From the rate of ionization, the rate of electron attachment and the coefficient of recombination of ions the relative concentrations of the ions and electrons can be determined. If, as auroral spectra show, appreciable $O_2$ is present in the ionosphere it is probable that the negative carriers are largely ions.

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June 7, 1937.

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## Evidence for the Simultaneous Ejection of Three Neutrons from Elements Bombarded with Fast Neutrons

It has recently been shown[1] that most elements when bombarded by very fast neutrons yield radioactive isotopes corresponding to the ejection from the stable nucleus of one neutron in addition to the bombarding particle. It now appears that in certain cases the impinging neutron can eject two neutrons in addition to itself. This phenomenon is best shown in the case of scandium.

The stable isotopes in this part of the periodic table are shown in Table I. Also included in this table are certain of the known radioactive isotopes. Scandium possesses normally a single stable isotope of mass number 45. When radiated by the fast neutrons (10 to 20 Mev) from lithium, which is bombarded by 6 Mev deuterons, scandium becomes strongly radioactive. Chemical separation of the bombarded specimen shows that there are two radioactive periods both positive in sign in the scandium precipitate. These half-life periods are approximately 4 hours and 52 hours and are in agreement with the results of Walke[2] who identified the same scandium isotopes by bombarding calcium with deuterons and potassium with alpha-particles.

TABLE I. *Stable and radioactive isotopes in the vicinity of scandium.*

| | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
|---|---|---|---|---|---|---|---|---|---|
| K | 10 m | 93% | .01% | 7% | 16 h | | | | |
| Ca | | | 97% | | .7% | .1% | .2% | 2.4 h | |
| Sc | | | | 53 m | 4.1 h | 4.0 h | 52 h | 100% | $>a$ |
| Ti | | | | | | | | | 8.5% |

The reactions are then as follows:

$$\begin{aligned} {}_{21}\mathrm{Sc}^{45}+n &\rightarrow {}_{21}\mathrm{Sc}^{44}+n+n \\ {}_{21}\mathrm{Sc}^{44} &\rightarrow {}_{20}\mathrm{Ca}^{44}+{}_{+1}e \quad \text{(52 hr.)} \end{aligned} \tag{A}$$

$$\begin{aligned} {}_{21}\mathrm{Sc}^{45}+n &\rightarrow {}_{21}\mathrm{Sc}^{43}+n+n+n \\ {}_{21}\mathrm{Sc}^{43} &\rightarrow {}_{20}\mathrm{Ca}^{43}+{}_{+1}e \quad \text{(4 hr.)} \end{aligned} \tag{B}$$

Although there is no previously known case where three neutrons are ejected from an excited nucleus, such a process is not inconsistent with the recent consideration of excited nuclei proposed by Bohr.

When scandium is bombarded by neutrons of energy under 8 Mev neither the 4 hour nor the 52 hour period is observed. In addition to these periods in scandium, fast neutron bombardment always yields by the emission of an alpha-particle the 16 hour activity in potassium attributed to isotope $K^{42}$.

Among other elements that might show this phenomenon of multiple neutron ejection are copper and fluorine. In both cases there is evidence that the process occurs but the identification cannot be made as certain as in the case of scandium. The periods in fluorine corresponding to the ejection of two and three neutrons (i.e., $F^{18}$ and $F^{17}$) are 108 min. and 1.2 min., respectively. The similar isotopes in copper are $Cu^{62}$ and $Cu^{61}$ with half-life periods of 10 min. and 3.5 hr. The 3.5 hour period of $Cu^{61}$ is very weak compared to the strong 12.5 hour period of $Cu^{64}$.

This work has been made possible by a grant from the Horace H. Rackham Trust Fund.

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## On the Existence of Heavy Electrons

Different observers[1] believe they have found evidence for the existence of charged particles whose mass amounts probably to about fifty times the electron mass. Furthermore these particles seem to behave according to the Bethe-Heitler theory.[2]

The writer wishes to call attention to an explanation of the nuclear forces, given as early as 1934, by Yukawa,[3] which predicts particles of this sort.

Independently of Yukawa the writer arrived at the same conclusion: Kemmer has shown recently[4] that the formal conception of field theory proposed by the author[5]