Structure of Atomic Nuclei. II

It seems to be possible to regard the lighter nuclei as if their only constituents were protrons and neutrons. The writer[1,2] has suggested that closed shells exist, and that this may explain the presence of the "clusters" of nuclei discovered by Barton.[3] The center of the cluster seems to lie about where the shells would be half-completed, provided that the closed shells correspond to the masses 36, 64, 100, 144, etc. On the simple model above, Zn 64 would have 30 protons and 34 neutrons, and it is hard to attach any particular significance to this arrangement. Also, one is rather at a loss to explain just what the constitution of Cl 37 is, unless it is admitted that after a closed shell has once become filled, stability conditions may favor the existence of holes in the closed shell for certain heavier isotopes.

To avoid these difficulties, one way is to adopt a tentative suggestion made to the writer by Prof. Dirac. This is that electrons may have a separate existence in certain nuclei, since β-type disintegrations exist. That is, that there are at least three types of primary particles, namely proton, neutron, and electron. The neutron is not to be thought of as a combination of proton and electron, but simply as a fundamental building-stone. Finally, the total angular momentum of the nucleus is integral or half-integral according as the total number of such independent particles is even or odd. This suggestion throws light on other phenomena and necessitates a revision of some earlier concepts.

In the central field of A 36, which has 18 protons and 18 neutrons, a neutron and an electron seem to be stabler than just a neutron. When they are added, Cl 37 is the result. One added proton gives A 38, and another proton K 39, where branching occurs. A neutron may be added, and an electron either added or taken away, resulting in the isobars A 40 and Ca 40, respectively. The existence of these isobars seems to support the hypothesis of nuclear electrons.

If to Ca 40 a neutron and electron be added, there is obtained the nucleus K 41, which emits β- and γ-rays. This nucleus contains 20 protons, 21 neutrons, and one electron. It may be that the presence of this electron is partly responsible for the radioactivity of K 41, and that Sc 45 (and possibly Cl 37) will also have similar properties. Nuclei up to A 36 cannot disintegrate with emission of primary β-rays, owing to the absence of free electrons.

The isotopes thus far reported for the mass range $36 < M \leqq 64$ are Cl 37, K 39, Ca 40, A 40, K 41, Ca 44, Sc 45, Ti 48, Cr 50, V 51, Cr 52, Cr 53, Cr 54, Fe 54, Mn 55, Fe 56, Ni 58, Co 59, Ni 60, Cu 63, and Zn 64. It has already been noted[4] that "isotopes only become numerous for atomic numbers > 29." A glance at the distribution of isotopes seems to show one that a new regularity begins at $M = 64$, and this we associate with the hypothesis that a closed shell has been formed. That is, Zn 64 is to consist of 32 protons, 32 neutrons, and two electrons. Though many points are missing in this mass range, still there are certain regularities apparent. For instance, the groupings Cr 50—V 51—Cr 52, Fe 54—Mn 55—Fe 56, and Ni 58—Co 59—Ni 60 are similar. It is probable that a fourth, Zn 62—Cu 63—Zn 64, exists. From Fe 54, Mn 55 may be formed by the addition of a neutron and an electron, and Fe 56 by the further addition of a proton. The total angular momentum of the Mn 55 nucleus is half-integral, so that it must contain an even number of electrons, namely two, as one would also expect for Fe 56. The nuclei Cr 50, Fe 54, Ni 58, and Zn 62 should, on the above basis, contain one electron and have half-integral spin values.

In addition to the isotopes A 38, Ca 42, Ti 46, K 43, and Sc 47 predicted by Beck,[5] we would suggest V 49 or Ti 49, Fe 57 and 58, Ni 61 and 62, and Zn 62 as rather probable.

The isotopes which have been found for the mass range $64 < M \leqq 100$ are Cu 65, Zn 66–68, and 70, Ga 69 and 71, Ge 70–77, As 75, Se 74, 76–78, 80, and 82, Br 79 and 81, Kr 78, 80, 82–84, and 86, Rb 85 and 87, Sr 86–88 Y 89, Zr 90, 92, and 94, Nb 93, Mo 92, 94–98, and 100, and Ru 96, 98–102, and 104. For most elements of even atomic number in this range, the isotopes have a mass range of about eight, as is exemplified by Zn 64–70, Ge 70–77, Se 74–82, Kr 78–86, Mo 92–100, and Ru 96–104. Accordingly, it might be expected

[1] J. H. Bartlett, Jr., Nature **130,** 165 (1932).

[2] J. H. Bartlett, Jr., Phys. Rev. **41,** 370 (1932).

[3] H. A. Barton, Phys. Rev. **35,** 408 (1930).

[4] Rutherford, Chadwick, and Ellis, "Radioactive Substances," p. 524.

[5] G. Beck, Zeits. f. Physik **47,** 407 (1928).

that strontium has isotopes between 84 and 92, and zirconium isotopes between 88 and 96. We note the groupings Zn 64—Cu 65—Zn 66, Ge 70—Ga 71—Ge 72, Se 74—As 75—Se 76, Kr 78—Br 79—Kr 80, Mo 92—Nb 93—Mo 94, and Ru 96—(Ma 97)—Ru 98.

In the mass range $100 < M \leqq 144$, the known isotopes are Ag 107 and 109, Cd 110–114, and 116, In 115, Sn 112, 114–122, and 124, Sb 121 and 123, Te 122–128 and 130, I 127, Xe 124, 126, 128–132, 134, and 136, Cs 133, and Ba 135–138. Since Sn and Xe have isotopes covering a mass range of twelve, this is probably true for other elements of even atomic number, and we should expect Te 118–130, Cd 106–118, Pd 100–112, and Ba 130–142.

Finally, a determination of the spin value for each isotope would be invaluable in deciding what the makeup of the nucleus is. For instance, Cl 35 has supposedly 17 protons and 18 neutrons, so that the closed shell lacks one d-proton. The ground state should therefore be an inverted D-doublet, the lower level of which would have a total angular momentum $I=5/2$, which is the value actually observed.[6] If Cl 37 does have an electron, then its spin should be either 2, 3, or 4. For this reason, it is not safe to assume, in unraveling a fine-structure pattern, that the nuclear spin for elements of odd atomic weight is capable of only half-integral values. At present, the information about nuclear spins is relatively meager, so that the rate of progress with nuclear stability questions is thereby limited.

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[6] A. Elliott, Proc. Roy. Soc. **127,** 638 (1930).

Luminosity of Sodium Flames

In a recent article by Bonner (Phys. Rev. **40,** 105, 1932) on the luminosity of sodium flames attention was called to the fact that the greater part of the absorption of the sodium light by such flames occurs at their surfaces. It follows from this that a sodium flame which does not have any cool surface, such as was used by Bonner, must show less absorption than those with which other experimenters have worked. It is, therefore, surprising to find the opposite of this indicated by Bonner's data for concentrated solutions of NaCl.

That this difference is due neither to a difference in the apparatus used for measuring the light nor to the system of units employed is shown by the fact that Bonner found with dilute solutions less absorption than did either Locher (Phys. Rev. **31,** 466, 1928) or myself (Phys. Rev. **38,** 699, 1931). Similarly this difference can not be explained by any uncertainty in my measurements regarding the effective center of the flames, as was suggested by Bonner, since an error due to such a cause would have made my results different from his in the same way and to the same extent with both dilute and concentrated solutions and such was not the case.

Because Bonner's data was so different from what one might expect, I repeated his experiments as nearly as I could with the apparatus which I had previously used. I found, however, that it was impossible to make accurate measurements of the length of the flame. Bonner had placed a non-luminous flame in front of the one into which salt was being sprayed, in order to keep the surface o the sodium flame hot. Due to diffusion of the sodium from one part into the other it was impossible to determine accurately the boundary between the two. If I measured the length of the sodium flame as if there were no diffusion from one part into the other, I obtained results which were much the same as those obtained by Bonner; but if I assumed that the sodium flame ended where it appeared to the eye to end, I obtained data similar to those which others have obtained. Bonner apparently assumed that it makes no difference how much diffusion there is from one part to the other. This would be entirely allowable, if it had been proven that a given amount of sodium gives the same amount of light irrespective of the number of flames into which it may be sprayed, but this is the assumption which Bonner is attempting to prove by his experiments and should not be assumed in the proof.

I believe, therefore, that one is justified in refusing to accept Bonner's experiments as definite proof of his conclusion.

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