We are proceeding to study patterns in oblique applied fields by combining with the vertical bar electromagnet a larger electromagnet (Du Bois type) producing horizontal fields. The exchange of lines for spaces with change in the direction of the normal component persists as long as the fine lines are observable. In agreement with previous observers we find that the fine line pattern itself changes as the field parallel to the surface increases and may be made very nearly invisible.

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Progression of Nuclear Resonance Levels with Atomic Number

In a recent letter to the *Physical Review*[1] one of us pointed out that the resonance levels for alpha-particle disintegration seem to vary linearly with the atomic number. A tentative explanation was given in terms of standing waves within the potential barrier. In the present note we offer a more adequate explanation in terms of particle interaction.

For the six elements Be, B, N, F, Mg, Al, resonance levels are found with energies differing by increments proportional to the change in nuclear charge. The mean increment for an increase in charge of two units (a difference of an alpha-particle) is $1.1\pm0.3\times10^{-6}$ ergs. A second series of levels is found with approximately the same increment although the experimental data are less complete. The straight lines joining the values of the resonance energies in each series plotted against nuclear charge are roughly parallel to the line joining the minimum penetration energies (or barrier heights) which are much harder to define and measure than the resonance energies themselves. The linear increase of barrier height with nuclear charge implies that the radius of the inside of the potential wall is at least approximately a constant.

Resonance levels correspond to energies of unoccupied alpha-particle states inside the nucleus. For approaching alpha-particles of these energies the penetration probability rises to unity. There is as yet no theoretical method of determining the actual positions of the virtual alpha-particle levels for a given nucleus. This is, however, not necessary if the *change* in energy of a particular level from nucleus to nucleus is considered. We make the suggestion that the difference between the energies of corresponding alpha-ray resonance levels in elements of atomic numbers Z and $Z+2$ is in general due to the interaction of two alpha-particles: (1) the alpha-particle added to the nucleus in passing from the first element to the second, (2) the alpha-particle, the virtual presence of which gives rise to the resonance. Since the radius of the inside of the barrier is sensibly constant for these elements, this interaction accounts very simply for the approximately linear increase in the resonance energy as we pass from, say, boron to nitrogen.

It is also possible, on the basis of simple assumptions, to explain the order of magnitude of the energy differences. Let us assume that one alpha-particle is localized near the center of the nucleus while the other is bound in one of the stationary states of the nucleus. If the latter is regarded as a barrier of infinite height and radius r_0, the radial part of the ψ-function for any one of the stationary states has the form

$$R=Ar^{-\frac{1}{2}}J_{l+\frac{1}{2}}(kr)$$

where k is determined by the condition that $J_{l+\frac{1}{2}}(kr_0)=0$. Let us assume the interaction to be of the Coulomb type. We then obtain for ΔE, the energy difference in question,

$$\Delta E=4e^2k\int_0^\xi J^2{}_{l+\frac{1}{2}}(x)dx\Big/\int_0^\xi J^2{}_{l+\frac{1}{2}}(x)\cdot xdx,$$

where ξ is a root of $J_{l+\frac{1}{2}}(x)$. If we assume the alpha-particle to be bound in the lowest S-state ($l=0$, ξ is the first root) the result is: $\Delta E=2.3\times10^{-6}$ ergs, if it is in the lowest P-state ($l=1$, ξ is the first root) $\Delta E=1.7\times10^{-6}$ ergs. For higher states the results are somewhat smaller. The value for r_0 here chosen is 10^{-12} cm. This is probably not too high because the finite actual height of the barrier causes the charge of the alpha-particle to penetrate into the walls of the barrier.

The significant fact seems to be that the Coulomb energy alone produces the correct order of magnitude for ΔE, but that the results are numerically too high. This is in line with the known circumstance[2] that the deviations from Coulomb interaction between alpha-particles diminish the repulsion. As is seen, the correction here amounts to about 50 percent of the Coulomb energy itself.

The change in the position of the resonance level from one element to the next, e.g., from beryllium to boron, is to be understood in a similar manner. The increment in energy is here due to the interaction between a proton and an alpha-particle, and this should be approximately half the ΔE calculated above. A general linear progression in the position of nuclear resonance levels with atomic number is thus explained.

It is to be expected that the resonance level of B^{10} lies higher than that of B^{11}, for the latter contains one neutron more than the former, and a "free" neutron should produce a negative energy of interaction with an alpha-particle. The experimental results so far indicate that this is actually the case but are not sufficiently accurate to permit more than a speculative value for the difference.

The suggestions here presented may be of guidance in the absence of a correct nuclear theory. The similarity of this explanation with that of the progression of atomic resonance states is of course evident.

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[1] E. Pollard, Phys. Rev. **45**, 218 (1934).
[2] H. M. Taylor, P.R.S.A. **134**, 113 (1931).