It can be shown[3] that, if forces are of sufficiently short range, the energies of configurations of maximum isotopic spin (i.e., those consisting of neutrons only, or of protons only) may to a fair degree of approximation be given in terms of the eigenvalues of Casimir's operator[4] for the group of symplectic transformations which leave invariant the form

$$\sum_{m=-j}^{j}(-1)^{m-\frac{1}{2}}\phi_1(m)\phi_2(-m),$$

representing the zero-order eigenfunction of two particles having resultant $J=0$. In this way, a classification of states is obtained[3] according to their seniority s, defined in analogy with Racah[5] as being the smallest value of N for which a state of given symplectic symmetry appears.

With short-range forces of arbitrary exchange nature (provided they are attractive for the ^1S interaction of two like nucleons) the lowest state in this approximation will have $s=0$ or 1 according as N is even or odd. From this, it follows immediately that the lowest level of the configuration $(l_j)^N$ has $J=0$ or $J=j$ according as N is even or odd, as found empirically by Jensen *et al.*,[1] and Mayer,[2] and verified to be so in a number of cases by Mayer[6] for a contact interaction.

Using the powerful group-theoretical methods of Racah[7] and of Jahn[8] the wave functions, properly antisymmetrized and classified according to seniority, have now been obtained for all the states of the configurations of 2, 3, and 4 particles of a given kind, neutron or proton, for $j=3/2$, 5/2, and 7/2. (The work is being extended to 5 and 6 particles in special cases, and to $j=9/2$.) In terms of the fractional parentage coefficients the energy matrices may be written down immediately in the form of Slater integrals.

The relative positions of levels have been studied as a function of the range of the interaction, using for definiteness Gaussian wave functions $\chi_l\sim r^l\exp[-\frac{1}{2}(r/a_0)^2]$, and a Gaussian potential $V(r)\sim\exp[-(r/a)^2]$ with a "symmetric" exchange operator, the range then being measured by a/a_0. Putting $\langle r^2\rangle_{\mathrm{Av}}=r_0^2A^{\frac{2}{3}}$, where A is the atomic weight, and $r_0=1.4\times10^{-13}$ cm, and taking $a=2.2\times10^{-13}$ cm, one obtains for the $1d$ and $1f$ shells $a/a_0\approx0.9$ as a rough measure of the range of the force relative to the nuclear extension. However, the ordering of levels has been studied for ranges $0\leq a/a_0\leq2$, and thereby Kurath's[9] results have been confirmed and considerably extended.

There are several interesting consequences regarding the low-lying states of nuclei which it is the main purpose of this note to report. A detailed report will follow elsewhere.

1. *Even-even nuclei.* The lowest excited states of a configuration $(l_j)^N$ with even N belong to seniority $s=2$, which includes the levels $J=2, 4, \cdots, 2j-1$, in that order with $J=2$ lowest; all have even parity. This is the most likely explanation of the Goldhaber and Sunyar rule,[10] that the first excited state of even-even nuclei has $J=2$ and even parity. Recently Robinson and Madansky[11] have observed the first two excited states of Ce^{140}; these are found to have $J=2$ and 4 in accordance with the above predictions. Several other instances are also quoted by these authors.

2. *Light nuclei.* For heavy nuclei, due to the Coulomb forces, the isotopic number is large, so that neutrons and protons have different configurations each having maximum isotopic spin; for these nuclei our discussion applies so far only to the interactions within the separate configurations. On the other hand, for the light nuclei whose isotopic number is small, particularly those with $M_T=0$ or $\frac{1}{2}$, it is proper to consider configurations $(l_j)^N$ of neutrons and protons mixed. In the case of the odd-odd nuclei, for sufficiently short-range interaction the lowest state is $J=0$; but for ranges of interest, i.e., $a/a_0\gtrsim0.7$, the lowest state is $J=2j$. In any case, these two states are close in energy, and isomeric transitions are likely. It is of interest to find that both Sc^{44} and Sc^{46}, presumably with $f_{7/2}^4$ and $f_{7/2}^6$ configurations, are isomeric.[10] For the odd mass nuclei in this region similar conclusions can be reached: e.g., in the case of $d_{5/2}^3$, the lowest state is $J=5/2$ only for ranges $\lesssim0.95$, for beyond this point the state $J=13/2$ is lowest; and similarly in the case of $f_{7/2}^3$ the 19/2-state competes with the 7/2-state. The cross-over point occurs in the region of the actual range; and the complete absence of such high spins among the observed ground states raises considerable doubt whether the conditions of jj-coupling are properly established in the light nuclei with masses $\lesssim50$. The work of Jahn[8] and the present author[12] on the other hand, shows that the correct spin values for light nuclei are obtained without ambiguity in LS-coupling, assuming small spin-orbit coupling. The transition point presumably lies in the f-shell, in the region of magic number 28, and work continues to attempt to establish such a transition more definitely. The discovery of isomeric transitions among the odd mass nuclei in this region, with $\Delta J=6$ and no parity change, would be a decisive factor.

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* On leave of absence from the Atomic Energy Research Establishment, Harwell, England.

[1] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949); Z. Physik **128**, 259 (1950).
[2] M. G. Mayer, Phys. Rev. **75**, 1969 (1949) and **78**, 16 (1950).
[3] B. H. Flowers, Harwell Report, A.E.R.E. T/R 713, 1951 (to be published in Proc. Roy. Soc., London).
[4] H. Casimir, Proc. Koninkl. Nederland Acad. Wetenschap. **34**, 844 (1931).
[5] G. Racah, Phys. Rev. **63**, 367 (1943).
[6] M. G. Mayer, Phys. Rev. **78**, 22 (1950).
[7] G. Racah, Phys. Rev. **76**, 1352 (1949).
[8] H. A. Jahn, Proc. Roy. Soc. (London) **A205**, 192 (1951).
[9] D. Kurath, Phys. Rev. **80**, 98 (1950).
[10] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[11] B. L. Robinson and L. Madansky, Phys. Rev. **84**, 1067 (1951).
[12] B. H. Flowers, Proc. Roy. Soc. (London) **A210**, 497 (1952).

Color-Center Formation in NaCl Containing Ag^+

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NEW data on color-center formation in NaCl-Ag^+ indicate that at room temperature electrons are trapped at complex Ag^+-centers, whereas at liquid nitrogen temperature electrons are trapped primarily at single Ag^+ ions to form Ag^0 atoms.[1] The pertinent data may be summarized as follows:

(1) NaCl-Ag^+ exhibits Ag^+ absorption bands at 2090A and 2180A[2] which become narrow and decrease in magnitude when the temperature is lowered to that of liquid nitrogen. An additional band appears at 2300A for Ag^+ concentrations above 0.05 wt percent which also becomes narrow but differs from the others by increasing in magnitude with decreasing temperature.

(2) For low Ag^+ concentrations x-irradiation at room temperature yields color-center bands at 2750A, 3050A, and 3300A[3] in

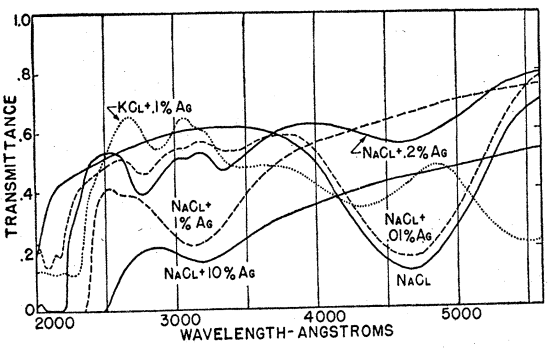

FIG. 1. Transmittance of NaCl, NaCl-Ag^+, and KCl-Ag^+ at room temperature after x-irradiation for 5 minutes at room temperature.

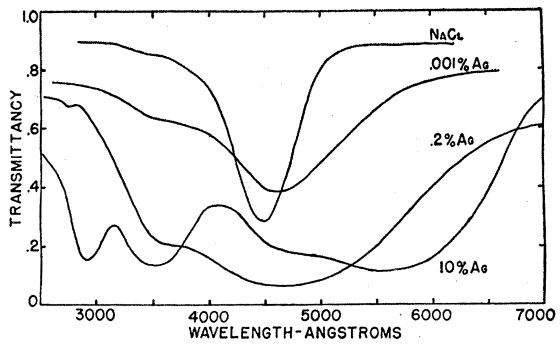

FIG. 2. Transmittancy (relative to the unirradiated crystal) of NaCl and NaCl-Ag^+ crystals at liquid nitrogen temperature after x-irradiation at liquid nitrogen temperature. The pure crystal was irradiated for 45 minutes, while the others were irradiated for only 5 minutes.

addition to the F band, M band, and V band, the latter band being superposed upon the Ag^+ bands. With increasing Ag^+ concentration the M band no longer appears, the F band weakens until it is completely suppressed, and the character of the Ag color-center bands changes (Fig. 1).[4]

(3) Optical bleaching of the F band enhances the Ag color-center bands. Illumination in the 2750A band bleaches it and strengthens the 3300A band and the F band. Similarly, illumination in the 3300A band bleaches it and strengthens the 2750A band.

(4) X-irradiation at liquid nitrogen temperature of crystals with low Ag^+ concentrations yields a strong, broad band at 4800A and a weaker band at 3700A (Fig. 2) which disappear on warming to room temperature. Illumination in the 4800A band bleaches it and also weakens the 3700A band. With increasing Ag^+ concentration the 3700A band increases relative to the 4800A band and additional bands are formed at 2900A and 5600A which are also unstable at room temperature.

The Ag^+ bands at 2090A and 2180A in NaCl-Ag^+ are most probably due to $4d^{10}-4d^95s$ transitions between states of the same parity which are forbidden in Ag^+ located in a perfect NaCl lattice but which become allowed as a result of interactions with lattice vibrations. The 2300A band which appears at higher Ag^+ concentrations is probably due to excitations of clusters of Ag^+[5] which are allowed because the symmetry about the Ag^+ is no longer cubic.

The Ag color-center bands which are formed by room temperature x-irradiation are due to allowed transitions of centers whose optical cross sections are comparable to that of the F center. Although one might expect Ag^0 atoms at normal Na^+ sites in NaCl to be stable, it does not seem possible to ascribe any one of these bands to such centers but rather to electrons trapped at complex Ag^+ centers whose concentrations are much lower than that of single Ag^+. Thus the 2750A and 3300A bands may be the result of F centers and M centers with neighboring Ag^+. The narrow 3050A band ($\approx$0.06-ev band width) which lies close in wavelength to the $^2S_{\frac{1}{2}}-{}^2P_{\frac{1}{2},\frac{3}{2}}$ Ag^0 doublet may, on the other hand, be due to Ag^0 atoms located at large lattice defects where they are only weakly coupled to the lattice. The bands formed at high Ag^+ concentrations are probably due to one or more electrons trapped at larger aggregates of Ag^+ and vacancies.

The very broad 4800A band formed at liquid nitrogen temperature is, on the other hand, attributed to electrons trapped at single Ag^+ to form Ag^0 centers at normal Na^+ sites. The weaker 3400A band is possibly due to trapped holes since it also disappears without the appearance or strengthening of other bands when the 4800A band is bleached optically. The most obvious explanation for the absence of a Ag^0 band in NaCl-Ag^+ at room temperature is that the Ag^0 center has a small thermal ionization energy due to the considerable repulsive interaction energy and to the overlapping of the charge distributions of the relatively large Ag^0 and the surrounding ions.

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[1] We are indebted to R. J. Ginther, L. R. Johnson, and W. Zimmerman for the NaCl-Ag^+ and KCl-Ag^+ specimens.

[2] A. Smakula, Z. Physik **45**, 1 (1927); M. Forro, Z. Physik **56**, 534 (1929).

[3] These bands were first reported by A. Smakula, Nachr. Akad. Wiss. Göttingen, Math.-physik. Kl., 110 (1929).

[4] E. Burstein and J. J. Oberly, Ninth Annual Conference on Physical Electronics, MIT (1949), p. 44.

[5] Schulman, Etzel, and Ginther, Conference on the Electrical and Optical Properties of Ionic Crystals, University of Illinois (1951), show that the 2300A band is due to Ag^+-Ag^+ pairs.

The Mechanism of the Trichel Pulses of Short Time Duration in Air*

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IN 1937, O'Day[1] observed that the apparently steady negative point corona in air at atmospheric pressure consisted of regular, relaxation, oscillator-like pulses. These pulses were independently discovered and studied in detail by Trichel.[2] Later studies of Loeb, Kip, Hudson, and Bennett,[3] and of English,[4] Loeb,[5] Miller and Loeb,[6] English and Loeb,[7] and finally of Bandel[8] have done much to clarify the mechanisms. It was recognized that the build-up of the discharge owing to inherent cathode instability[9] and a conditioning prethreshold Townsend[6,7] discharge was rapid and that the quenching of the ionization creating a pulse was caused by formation of a space charge of negative ions.[3,5,6] The repeat rate of the pulses thus depends on the creation and clearing time of negative ions from some vital region.[3,6] Difficulties were encountered when English[4] showed, by synchroscope studies of carrier movements in the point-to-plane gap, that at 760-mm pressure in air the total time for ionization and space charge choking was less than 4×10^{-7} sec. Matters became even worse when photomultiplier studies of such pulses in air by English[10] revealed that the rise of luminosity occurred in less than 1×10^{-8} sec, was nearly constant for 1.5×10^{-8} sec, and declined to zero in some 3×10^{-8} sec. Thus, choking took place in less than 2.0×10^{-8} sec. Studies of the fields along the axis of the gap[11] now permit better estimates of electron avalanche intensities before the positive ion space charges materially increase the ionization. The total ion creation in Trichel pulses has been measured by English[4] as well as estimated from Trichel's[2] data. It is close to 2×10^9 ions in the case considered. Other critical dimensions of the discharge had been derived by Loeb[5] and English and have recently been confirmed by Schindler and Weissler.[12] Minimum values of the second Townsend coefficient for photoelectric liberation from a cathode γ_p, as well as for the liberation by positive ion bombardment γ_i, have been observed at higher pressures in H_2 and N_2 by Lauer.[13] Very recently, Geballe and Harrison[14] have shown that in O_2 at field strength to pressure ranges of $X/p=30$ to $X/p=70$ electrons attach to O_2 by a dissociative attachment process, yielding O^- ions with a relatively constant cross section of 30×10^{-20} cm^2. With these data it is at once possible to account for the incredibly short time scale of the observations of English.[10] Using an exemplary corona with a 0.019-cm radius point and 3.1-cm gap at 760 mm in air, which starts at 5000 volts and yields 2×10^9 ions, the data[5] are as follows. The first avalanche starting from one electron creates about 6×10^4 ions and electrons. Distances involved in ionization are of the order of 4×10^{-2} cm/sec, and electron drift velocities at the lower X/p involved one of the order of 2×10^7 cm/sec. Avalanches thus occur in intervals of 2.0×10^{-9} sec. If γ for photon action is 5×10^{-5}, a minimum conservative[13] value at high X/p, then in 10 ionizing sequences, lasting 2.0×10^{-8} sec, there will be created 3.6×10^9 ions and electrons. In this time perhaps 0.01 of the positive ions have moved into the cathode surface in a continuously increasing stream and added their secondary emission to increase