be well evacuated before use. Samples grown from less pure supplies resulted in a great number of sharp lines which are probably due to the vibrational levels of impurity N_2 and O_2 molecules.[4] The intensities of these lines depended strongly on the temperature and they exhibited thermoluminescence. It was found that the addition of these impurities (and also of 0.2% Xe) quenched the intensity of the bands shown in the figures. Spectra which indicated the presence of impurities were discarded.

After the x rays had been shut off, weak emission was detected at 5.5 eV while the crystal temperature was raised. This thermoluminescence occurred between 38 and 53°K.

Since the reported luminescence bands were strongest when no known impurity emission was observed, we assume them to be due to intrinsic centers which are formed in the Kr lattice by the x rays. The dose dependence of the emission intensity supports this interpretation. Preliminary measurements on Ar and Xe indicate somewhat similar emission as shown in Fig. 1, but with different peak energies. This further supports the suggestion that the emission is due to intrinsic centers because the impurity emission was found not to depend strongly on the host. The series of broad bands in Fig. 2 can be fitted fairly well to Gaussian bands with equal half-widths of 0.10 eV and energy separations of 0.26 eV. It appears that two different centers may be involved in the emission since the dose dependence of the line at 4.20 eV and the band at 4.1 eV is the same but differs from the dose dependence of the structure between 4.5 and 6 eV.

Measurements of optically excited luminescence are planned, as well as ESR absorption experiments which could determine the connection between the emission and possible color centers in the noble-gas lattice.

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POSSIBILITY OF LIMITED PAIRON CONDENSATION IN DOUBLE-STRANDED DNA*

Robert M. Pearlstein
Biology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee
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From the viewpoint of the Copenhagen interpretation[1] of quantum mechanics, a living cell presents an enigma: The cell is an object at the "classical level," yet is controlled by molecules whose dynamics are in principle described quantum mechanically. Thus, for physicists, living organisms pose the question, "How do machines[2] arise from molecules?" It is the purpose of the present paper to suggest a pathway toward a possible solution to this molecule-to-machine enigma. This suggestion makes use of Little's general idea[3] that high-temperature pairons can exist, and of some very recent results of Krueger.[4]

Little's idea of an organic polymer that is superconducting at high temperatures (up to ≈3000°K) has been criticized by various authors.[5-7] These criticisms are of two types: (1) Even with a force sufficiently attractive to induce pair formation, pairon condensation is not possible in restricted geometries; (2) a sufficiently attractive pairing force does not exist at high temperatures. Assuming the correctness of Krueger's theorem ("... that condensation is always possible in a free-particle Bose gas confined to a strictly finite geometry"[4]), and insofar as pairons are approximately bosons, objections of type (1) appear to be overruled.

Without further consideration of the second class of objections to high-temperature pairing (which, so far, are objections specifically to plasmon pairing[5,7] in polymers of the Little type[3]), let us suppose that a high-temperature ($T_c \approx 3000$°K) pairing mechanism exists for certain electron pairs (hereinafter simply called pairons) in double-stranded DNA (Watson-Crick helix[8]), a polymer not of the Little type. In its double-stranded form, and in con-

trast to its single-stranded form, DNA can be idealized as a closely packed stack of hydrogen-bonded, purine-pyrimidine base pairs which form a cylinder whose structural integrity is preserved by the covalent bonds along each of the dual polydeoxyribose phosphate chains and by additional forces. Despite the fact that there are two kinds of base pairs, and two possible orientations for each kind of base pair in such a cylinder, the four distinct base pairs stack almost identically in the double helix.[8] The cylindrical cross section D^2 is about 120 Å^2, and the lattice constant along the cylinder axis is 3.4 Å. Each base pair contains seven double bonds, and thus, crudely, 14 electrons occupying π orbitals. This suggests the possibility of seven pairons per base pair, or a pairon density n such that $n^{-1/3} = 3.9$ Å. If the thermal de Broglie wavelength is no larger than 3.9 Å, Krueger's inequality (11) applies,[4] and for the DNA model states that

$$L \leq \frac{[1-(T/T_c)^{3/2}]D^2}{0.1678(T/T_c)n^{-1/3}}. \quad (1)$$

In Eq. (1), L is that length of the cylinder over which condensation occurs; other notation is Krueger's ($D = L_2 = L_3$).

Since living organisms operate at a temperature $T \approx 300$°K, $T/T_c = 0.1$. Equation (1) then gives as the maximum possible value of L, $L_{\max} = 1800$ Å; or, $L_{\max} = 530$ base pairs = 180 codons (triplets of base pairs). Note that $L_{\max}$ is the same order of magnitude as the length of a cistron.[9]

Although naturally occurring DNA may contain 10^5 base pairs[10] (and even more), the preceding result shows the possibility of 10^3-10^4 pairons condensing within the cistrons of DNA. (This number of pairons is within a factor of 300 of the number of strongly overlapping pairons in bulk metallic superconductors.)[11] Accordingly, DNA would not be a superconductor in the ordinary sense, but would display some unusual electrical properties, such as high dc conductivity, non-Ohmic behavior, and a rise in ac conductivity above a characteristic frequency related to $L_{\max}$. It cannot be overemphasized that the experimental realization of such effects very much depends on the preparation of the experimental material. However, there is already some evidence for unusually high dc conductivity in bulk-prepared desiccated DNA.[12] Little[3] has already pointed out the futility of searching for a critical field or Meissner effect in suspected high-temperature superconducting polymers with available magnetic fields. (An experimental search for a critical field was nonetheless attempted using enzymes rather than DNA, with negative results.)[13]

One specific experimental test of pairon condensation in double-stranded DNA is suggested by some recent work on replication of the bacteriophage (bacterial virus) φX174 in the bacterium E. coli.[10] Each φX174 phage contains a single molecule of DNA which is single stranded. Upon infecting its host (E. coli), this DNA is converted into a double-stranded form. The double-stranded phage DNA is a covalently closed loop; that is, although the actual loop is intrinsically twisted (supercoiled) to some extent, its idealization is a toroid rather than a cylinder. The total length of the closed loop is $pL_{\max}$, with $p \simeq 5$ in the case of φX174 replicating in E. coli. The total resistance, R, of such a loop would clearly be very low if pairon condensation occurs as suggested here. In fact, the value of R as limited by thermodynamic fluctuations[14] would be vanishingly small if the loop (regardless of the magnitude of p) behaved like a conductor with $\xi_l \approx L_{\max}$.[15] Consequently, the lifetime of an induced current in the loop would be essentially infinite.[14] Thus, these loops, even unaligned, would display an immense dc diamagnetic susceptibility, perhaps as large as (but no larger than) 10^{10} that of benzene per mole.

Other experimental tests are, of course, possible. High-frequency experiments, although more difficult to perform, may prove to be decisive, especially if the ends of the hypothetical Krueger condensation regions in DNA were defined by "hard" boundary conditions.

If a pairon condensation as proposed here actually occurs in double-stranded DNA, its importance in biology may not be because of any "curious chemical selectivity," as suggested by Little,[3] but because a pairon condensation, and indeed a Bose-Einstein condensation, (1) increases order at the expense of free energy (while satisfying the H theorem), and (2) provides, under appropriate thermodynamic conditions, a spontaneous amplification of quantum phenomena to the "classical level."

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[2]A "machine," as the term is used here, is an assemblage of molecules with a number of macrostates, distinguishable classically, such that many microstates correspond to each macrostate. As so defined, machines include those devices used to make measurements on quantum systems. The implication of the present paper is that living organisms are, in some sense, "self-measuring" devices. See E. P. Wigner, Am. J. Phys. 31, 6 (1963), especially p. 14.

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ENERGY SPECTRUM OF CHARGED PARTICLES EMITTED FOLLOWING MUON CAPTURE IN Si^{28}

Stanley E. Sobottka and Edward L. Wills
Department of Physics, University of Virginia, Charlottesville, Virginia*
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Results of a high-resolution study of the charged-particle energy spectrum resulting after μ^- capture in Si^{28} are presented. The spectrum, attributed mainly to proton emission, exhibits a low-energy cutoff at 1.4 MeV and a maximum at about 2.5 MeV from which it decreases approximately exponentially with a decay constant of 4.6 MeV. A branching ratio of 0.15 ± 0.02 charged particle per capture was determined.

We have measured the energy spectrum and branching ratio for charged particle emission following muon capture in Si^{28} with a Si(Li) target-detector system. We achieved an energy resolution of about 150 keV by measuring the pulse-height spectrum from the silicon detector. The pulse height was a measure of the total energy shared by the emitted particle and recoiling residual nucleus. The energy resolution was limited mainly by the pulse-height defect for heavy charged ions in silicon detectors.[1]

Previous observations have been limited to nuclear emulsion experiments[2-5] with substantially poorer energy resolution and statistical uncertainties. Morinaga and Fry[4] have found that, of muon captures in light emulsion nuclei, 9.5% result in proton emission and 3.4% in alpha emission. Proton emission from Ag nuclei has been interpreted to be a result of muon capture on p-p pseudodeuterons at the nuclear surface by Singer[6] who estimated a branching ratio for this process. Capture on virtual pions exchanged by proton pairs was assumed by Bertero, Passatore, and Viano,[7] who calculated an energy distribution which had a peak at roughly the Coulomb barrier height. To the knowledge of the authors no detailed calculations of branching ratios or proton spectra have been made assuming an intermediate giant-resonance state excited by the muon-capture process.[8] However, Überall[9] has suggested that proton emission may indicate the presence of two-hole, two-particle states in the giant-dipole configuration. The data of the present experiment may help to distinguish between the above three mechanisms.

When negative muons stop in silicon, 35%