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SUPERCONDUCTING NUCLEAR PARTICLE DETECTOR

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Recently the cryotron was proposed as a detector of nuclear particles.[1] An even simpler detector should be possible, capable of discriminating between particles of different ionizing power. It would consist of a narrow, thin film of current-carrying superconductor cooled well below its transition temperature, in series with a small resistance. Should an ionizing particle pass through the film, the current will be reduced and a voltage pulse will appear across the resistor.

The previous discussion was in terms relating to the superconducting energy gap. The detector response can also be examined in terms of heat transfer from a decaying microplasma (the particle track) imbedded in a superconducting medium at temperature T_0. If the radial temperature profile in a cylindrical track has the form suggested by Seitz and Koehler[2] and Brooks,[3] the radius of a region attaining the maximum temperature T_m for Q units of heat injected per unit length is[4]

$$r = [Q/e\pi c\rho(T_m - T_a)]^{1/2}, \qquad (1)$$

where c is the specific heat, ρ the density, and T_a the ambient temperature of the medium. For fission-fragment tracks in mica, where T_d is the decomposition temperature (~1200°K), the radius is $r_d \sim 200$ Å.[5,6] At such temperatures, heat loss by radiation is negligible compared to loss by conduction, so that further radial growth is due to adiabatic slumping of the thermal spike.

If we choose tin as the superconductor and use the same Q as for mica (since the range is nearly the same), the radius of the region switched to normal is

$$r_n = [c_d\rho_d(T_d - T_a)/c_n\rho_n(T_n - T_0)]^{1/2} r_d, \qquad (2)$$

where $T_n = T_c = 3.75$°K is the boundary temperature of the normal region. For $T_0 = 3$°K, $r_n \simeq 0.8$ micron. This is conservative since $Q \ll Q_0 = E/JR$, where E is the energy and R the range of the fragment. Indeed, if the initial lattice temperature at the axis of the spike is about 1/200 of the electron temperature T_e,[7] it may exceed 10^5 °K, suggesting an r_n of about 4 microns.

For an alpha particle,

$$Q_\alpha \simeq (E_\alpha/E)(R/R_\alpha)Q. \qquad (3)$$

Comparing a 5-MeV alpha with a 60-MeV fission fragment, $Q_\alpha \sim Q/30$. Hence $r_n(\alpha) \simeq 0.15$ micron.

Traversal of a film 1000 Å thick and 10 microns wide by the fission fragment or alpha particle should cause a change in resistance from zero to about 1 ohm and 0.2 ohm, respectively, by inserting a transverse strip of normal material in the path of the current. The film should not be thinner, so as to avoid permanent damage due to overheating which has been observed in thin metal foils irradiated with fission fragments.[8] For a current of 5 mA, half the critical current, the voltage change across a 10-ohm resistor in series with the superconductor should be at least 4 mV for the fission fragment and 1 mV for the alpha particle. The current may provide discriminator bias in virtue of its magnetic field which will control the ratio of superconducting to normal volume in the film.

The resistivity[9] ($\eta = 6.53\times10^3 \ln\Lambda/T_e^{3/2}$) of the initial microplasma due to an alpha particle is estimated to be about 10^{-7} ohm-cm, if $\ln\Lambda \sim 10$ and T_e is calculated from $T_e \sim (E_\alpha/JR_\alpha)/c_n\rho_n\pi r_d^2$ to be $\sim10^8$ °K. Though η is large compared to that for the superconductor, it is smaller than the resistivity of the decaying thermal spike. The high resistivity, therefore, comes late in the evolution of the particle track. The rise time can be estimated to be $t_r \sim 10^{-11}$ second,[2] the time for the temperature to decay to the melting temperature where the resistivity becomes large. The resistive region will not grow due to Ohmic heating, because the rate of heat conduction across one-twelfth the correlation distance[10] for $T_n - T_0 = 0.75$°K is more than 10^4 times the rate of evolution of Joule heat. There will not be a "dead time," therefore. An order-of-magnitude estimate of the resistivity fall time is $t_f \sim r_\alpha/v_s$, where the speed of growth of a superconducting filament[11] piercing the disordered region is $v_s \sim 10$ cm/sec for tin. Thus, $t_f \sim 1$ microsecond.

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NUCLEAR POLARIZATION OF He^3 GAS BY METASTABILITY EXCHANGE WITH OPTICALLY PUMPED METASTABLE He^3 ATOMS

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We have found that exchange of metastability during collisions between ground-state and $^3S_1$ metastable He^3 atoms provides an extremely effective nuclear magnetic relaxation process for the ground-state He^3 atoms. We have exploited this mechanism in conjunction with optical pumping of $^3S_1$ atoms in weak magnetic fields to produce a high degree of nuclear polarization in He^3 gas at room temperature. We wish also to report the detection of magnetic resonances of both He^3 ground-state and $^3S_1$ atoms by conventional optical-pumping techniques.

The experimental arrangement employed is similar to that described by Colegrove and Franken for optical pumping of He^4 metastables.[1] Circularly polarized one-micron pumping light ($2\,^3P - 2\,^3S$) from a helium lamp is passed through an absorption cell containing He^3 gas, a small fraction of which is maintained in the $^3S_1$ metastable state by an rf discharge. The pumping light tends to produce a polarization of the metastable He^3 atoms. However, as a consequence of metastability exchange collisions,[2]

$$He^3 + He^{3*} \rightarrow He^{3*} + He^3$$

(where the asterisk indicates an atom in the $^3S_1$ metastable state), the incident and emerging ground-state He^3 atoms may have magnetic quantum numbers differing by ±1, while the corresponding metastables differ in their magnetic quantum numbers by ∓1. The net result of such exchange processes is to introduce mutual spin-flip operators connecting ground-state and metastable atoms. We find that the interaction involving these operators predominates in determining the ground-state He^3 nuclear magnetic relaxation rate; hence, neglecting the thermal equilibrium Boltzmann factors, the ground-state He^3 nuclei