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ABSTRACT

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Abstract

THEORY OF MU-MESIC MOLECULAR IONS AND CATALYTIC FUSION[1]

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Abstract

An interesting phenomenon, suggested by Frank[2] and Zeldovitch,[3] is the enhancement of nuclear fusion in a molecular ion in which an electron has been replaced by a heavy negative meson. The subsequent observation, in the liquid hydrogen bubble chamber, of the rejuvenation of μ mesons to energies of several Mev,[4] has a rather involved explanation. The interpretation is that these fast μ mesons have catalyzed nuclear reactions between hydrogen and deuterium through the following chain of events:

(a) The incident mesons are rapidly slowed down and captured by protons to form excited ($p\mu$) atoms, which quickly decay to low-lying Bohr levels.

(b) Some of the ($p\mu$) atoms undergo exchange collisions with deuterons, releasing the additional binding energy associated with the larger reduced mass.

(c) Some of the ($d\mu$) atoms form ($d\mu p$) molecular ions in subsequent collisions with protons.

(d) The nuclei of the molecular ion may then penetrate the Coulomb barrier and engage in a nuclear reaction. Because of the small size and high vibrational frequency of these ions, this process can frequently occur within the lifetime of the meson.

(e) The energy released in some of the nuclear reactions is given to the meson, which may then repeat the process.

A striking feature of the experiments is that in many cases gaps were observed between the stopping of the meson and its reappearance at a higher energy. Similar gaps also appeared in normal μ-e decay. As the deuterium concentration is increased the frequency of these gaps first increases and then drops toward zero. To verify this over-all interpretation it is necessary to study the various scattering, exchange, and molecular-ion-formation processes, together with the nuclear reaction rates involved. Various workers have treated these qualitatively;[5,6] however, their results are not in full agreement. In order to obtain better estimates, we have performed calculations based on the Born-Oppenheimer adiabatic approximation to the mesonic motion. Since the ratio of the mesic to the nuclear mass is appreciable, a variational approach was used to obtain the first-order corrections to the approximation. In the pd system this necessitates the

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1 Radiation Laboratory, University of California, Berkeley, California
2 F. C. Frank, Nature 160, 525 (1947).
3 Y. B. Zeldovitch, Doklady Akad. Nauk S.S.S.R. 95, 493 (1954).
4 L. W. Alvarez, et al., Phys. Rev. 105, 1127 (1957); Ashmore, Nordhagen, Strauch, and Townes, (to be published).

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solution of a pair of coupled second-order differential equations which are the analogs to the Schrodinger equation for the nuclear motion. In the pp or dd systems these equations are uncoupled. The numerical calculations for the various systems were carried out with an IBM 650 computer and an IBM 701 computer.

The calculations for the scattering cross section of (dμ) atoms by protons indicate an anomalously small cross section at energies from zero up to about 1 ev. The resulting long mean free path provides an explanation for the observed gaps for low deuterium concentrations. At higher concentrations the gaps are shortened by normal scattering from deuterons.

According to a phenomenological analysis of the catalysis,[6] the dependence of the yield on deuterium concentration is primarily obtained from the competition of $p\mu + d \rightarrow d\mu + p$ with nonreacting dead-end processes, such as natural decay and formation of (pμp) molecular ions. Our results for the exchange reaction and the molecular-ion formation lead us to believe that impurities were present in the chamber which resulted in further dead-end processes. The calculated rate of molecular-ion formation for the pd system makes the possibility of obtaining useful power from this scheme much less favorable than the previous estimates by Jackson.[5]

Further results such as scattering cross sections, binding energies, and reaction rates will be presented.

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[5] J. D. Jackson, Phys. Rev. 106, 330 (1957).
[6] T. H. R. Skyrme (to be published).