Muon-catalyzed fusion of hydrogen isotopes

a discovery by chance

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October 21, 2021

The invention of the bubble chamber [1, 2] and the subsequent development of this new device for experimentation in beams of high energy particles led to a flood of new results, notably in the field of hadron spectroscopy. Here we highlight an early result of bubble chamber operation at Berkeley that was unexpected and resulted from an 'open minded' and creative inspection and analysis of unusual 'events': the fusion of hydrogen and deuterium nuclei, 'catalyzed' by negative muons.

Bubble chamber pictures of muons stopping in liquid hydrogen

In [3] the 'byproduct' is described of an experiment using a K^- beam stopping in a 10-inch liquid hydrogen bubble chamber. The experiment was performed at the University of California Radiation Laboratory in Berkeley, with the aim of studying K^- decays. But the beam was 'contaminated' by large numbers of negative pions and muons. In Fig. 1 we reproduce a photograph of a stopping muon leading to the re-appearance of a muon close to the point where the incoming muon disappeared. The second muon decays to an electron and a neutrino that does not leave a track behind. At the decay point a 'kink' is therefore visible. The explanation of the observed pattern is as follows. The incoming muon loses energy when traversing the liquid hydrogen and comes to a halt. Upon careful inspection the radius of curvature of the track can be seen to decrease towards the end. The muon finds a hydrogen molecule and binds to a proton to form a thermal muonic atom of a much reduced size (by a facor of 200). When this system meets a deuterium atom, naturally present in small quantities in the liquid hydrogen filling the bubble chamber, the muon jumps to a deuterium nucleus which is energetically more favorable (135 eV). Now a p-d-μ^- molecule forms and because of the presence of the muon the Coulomb barrier between proton and deuteron is reduced to the level that nuclear fusion can take place. The excess energy is 5.5 MeV carried away as kinetic energy by the muon: $(p^+d^+\mu^-) \to {}^3He\ \mu^-$.

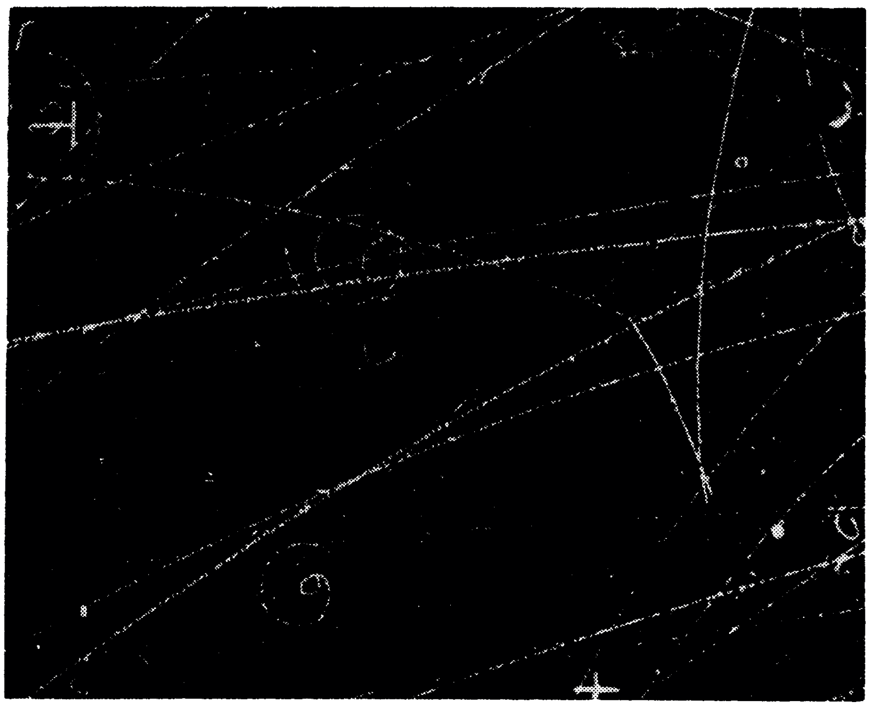

Figure 1: Picture taken using the 10 inch liquid hydrogen bubble chamber referred to in the text. A muon enters at the right top corner and stops after traversing about three quarters of the distance to the bottom of the picture. Close to the point where it stops, a little bit to the right, a muon track appears, travels upward and decays at the position of the 'kink' into an electron and an invisible neutrino.

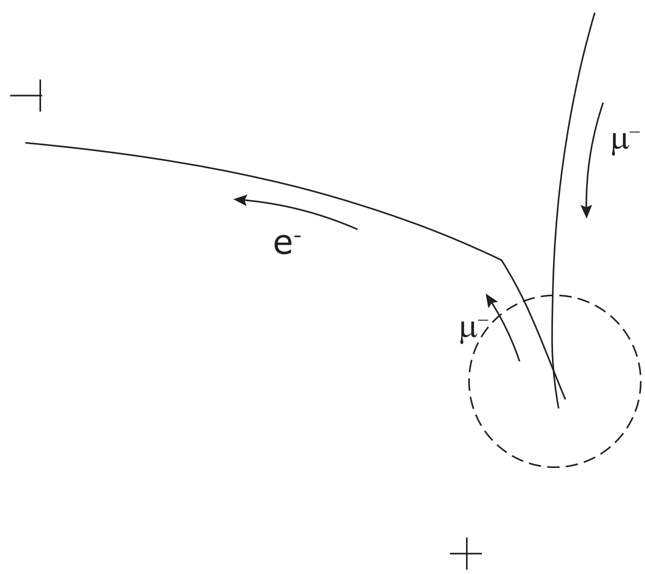

Figure 2: The event of interest in the bubble chamber picture of the previous figure highlighted. Notice the small but characteristic distance between the point where the incicent muon stops and where it disappears, after having moved thermally as a muonic hydrogen atom.

References

[1] Glaser, Donald A. "Some effects of ionizing radiation on the formation of bubbles in liquids." Physical Review 87.4 (1952): 665.

[2] Donald A. Glaser – Nobel Lecture (1960). https://www.nobelprize.org/prizes/physics/1960/glaser/lecture/

[3] Alvarez, Luis W., et al. "Catalysis of nuclear reactions by μ mesons." Physical Review 105.3 (1957): 1127.