

demand of nearly 0.5 kg per year to compensate for its decay into  $^3\text{He}$  and its inevitable long-term trapping in the vessel walls and pumping systems. Achieving advertised deuterium-tritium plasma performance could raise ITER's tritium replenishment need above 1 kg per year, about half the world's annual tritium manufacture beyond 2020 unless some fission reactors are dedicated to tritium production.

In principle, ITER's tritium requirement is somewhat compatible with  $^3\text{He}$  demand. Only a fraction of the injected tritium will be reacted even with multiple recycling, so much of the  $^3\text{He}$  from tritium decay might be recovered eventually from the vacuum pumping system, the plasma chamber wall, and the tritium recycling systems.

Fortunately for  $^3\text{He}$  users, the planned date for ITER to start up with only hydrogen plasmas continues to recede, and tritium usage is likely two decades away. Nevertheless, this looming conflict should highlight to energy-supply planners that despite claims of fusion being an infinite energy source, as a practical matter it is dependent on fission reactors for its fuel supply.

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**David Kramer has stated** the current helium-3 supply situation very well. However, he appears to be less informed about commercially available neutron detection systems. He states that backpack and handheld detection units being purchased by multiple government agencies all contain  $^3\text{He}$ . Nucsafes Inc has supplied military and police units internationally with backpacks, briefcases, and mobile systems that use lithium-6 glass fibers. The company has produced more than 10 million meters of the glass fiber. The  $^6\text{Li}$  detectors are more durable than gas-filled ones, are safer in hostile environments, and can be repaired with light-blocking tape even after having been shot with a high-powered rifle.

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**Helium-3, writes** David Kramer, "occurs at a ratio of 0.2 parts per million of  $^4\text{He}$ ." However, according to the International Union of Pure and Applied Chemistry,<sup>1</sup> the natural abundance of  $^3\text{He}$  is 1.37 ppm. Otherwise, the article was excellent.

## Reference

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## Reflections on Franck and photosynthesis

In a riveting article about physics Nobel laureate James Franck (*PHYSICS TODAY*, June 2010, page 41), his grandson Frank von Hippel notes that Franck, having decided in 1933 to devote the rest of his research career to trying to understand photosynthesis, moved to America. Actually, I would say that Franck kick-started his entry into photosynthesis research 11 years earlier, with a paper he and his student Günther Cario published.<sup>1</sup> It was the first demonstration of sensitized photochemistry and was demonstrated a year later by Cario for sensitized fluorescence.

In sensitized fluorescence, electronic excitation of a donor induces fluorescence of a spatially separated acceptor in the near field but not the far field. Theodor Förster, a student of Werner Heisenberg, provided the definitive step in 1948 with his celebrated theory of intermolecular energy transfer and fluorescence.<sup>2</sup> Förster's theory describes a donor-acceptor transfer as a "quantum jump"; that is, the donor's state jumps down and the acceptor's jumps up. A sequence of such excitation jumps is called a Förster-Dexter exciton. Its motion can be described as a random walk over the set of molecules involved.

Now flash back to 1938, when Franck was in Chicago and, with Edward Teller, published a paper that presented the first mathematical model of photosynthetic excitons.<sup>3</sup> Franck and Teller considered two possibilities: the Förster-Dexter exciton or the already familiar Frenkel exciton. The two are similar, except that the Frenkel exciton retains quantum phase information and so its motion cannot be described as a random walk.<sup>4</sup> Their paper was a goad to a long series of photosynthesis researchers, including me, because they ruled out both possibilities!

During my own research career, my collaborators and I theorized extensively about both possibilities, as others did then and still do now. Initially, I tended to favor the Förster-Dexter case,

the topic of my PhD thesis, but I continue to hold out hope that the more interesting Frenkel case will win the day. Most photosynthesis researchers doubt that: Chlorophyll molecules do not actually form a regular crystal lattice in plants, much less one in which the exciton wavefunction preserves phase information for up to a picosecond at 300 K. Though not yet demonstrated for chlorophyll, recently published experimental results with other photosynthetic light-harvesting pigments in plants provide convincing evidence for high-temperature phase preservation. Indeed, my hope that the Frenkel case will win out may soon be realized.

In 2004 Franck's former graduate student Jerome Rosenberg published a tribute to him in the journal *Photosynthesis Research*.<sup>5</sup> The 1964 paper by Franck and Rosenberg cited there is, to my knowledge, Franck's last paper on photosynthesis. I met Rosenberg two years earlier in Woods Hole, Massachusetts, when he and his assistant Charles Weiss Jr were there doing library research and I was starting the work that eventually led to my thesis. Franck himself came to Woods Hole in summer 1962 to give a public lecture on photosynthesis. By the time I arrived for the lecture, the crowd was spilling out the door. A larger venue was quickly located and I managed to find a front-row seat. I recall Franck at the lectern, leaning on his cane, mesmerizing the crowd, myself included.

Last year, at the 50th reunion of the Harvard class of 1959, I encountered Weiss, my classmate. Though we'd been out of touch for decades, and he out of photosynthesis even longer, the very first thing he wanted to know from me was whether his idea in the 1964 paper (for which he received acknowledgment) was still extant in the field. Chuck was nonplussed to learn that I didn't know the fate of his ideas; they were not in my area of expertise. As attested by Rosenberg's invited tribute in 2004, I do know that Franck's ideas abide in the field.

## References

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