PERSPECTIVES: NUCLEAR FUSION

Evidence for Nuclear Reactions in Imploding Bubbles

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Humans owe their existence to the Sun, yet the basic source of solar energy production was not understood until the early 1900s. Before then, it was apparent that chemical reactions, which involve the rearrangement of atoms, do not release sufficient energy to power the Sun. It was not until nuclei and subatomic particles (such as protons, neutrons, and α-particles) were discovered that reactions involving these particles (nuclear reactions) were identified as the source of solar energy (*1*). It was found that nuclear reactions could release a million times more energy per reaction than chemical reactions.

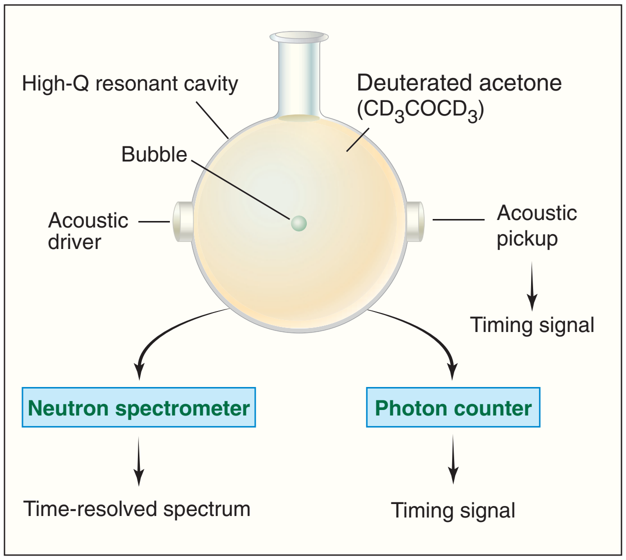
Our Sun, a rather ordinary star, produces energy primarily by fusing hydrogen nuclei (protons, p) via the reaction

$$\mathrm{p} + \mathrm{p} \rightarrow \mathrm{d} + \mathrm{e}^+ + \nu_\mathrm{e} + E_\mathrm{kin} \qquad (1)$$

where d is a deuteron (^{2}H), e$^+$ is a positively charged electron (positron), ν_e is an electron neutrino, and E_{kin} is the kinetic energy released. In nuclear energy units, $E_{kin} = 0.42$ MeV (where 1 MeV = 1.6×10^{-13} J). The deuterons produced in this reaction can further fuse with protons or other deuterons to form helium and heavier nuclei (*2*). Neutrinos interact only weakly with nuclei, and therefore most of them can escape from the Sun. With very large detectors, a few can be detected each day on Earth (*3*). By detecting solar neutrinos, we can verify that reaction 1 and similar fusion reactions (for example, d + d) take place in the core of the Sun.

For many years, scientists have strived to produce and study nuclear fusion processes in the laboratory. Because protons and deuterons carry the same charge (+1) and hence repel each other, the p + p and d + d reactions require overcoming Coulomb (electric) repulsion. This can be achieved in the laboratory with megavolt accelerators. Alternatively, one may try to reproduce the conditions at the center of the Sun, namely, high temperature (~10^7 K), high pressure, and high density. Several large magnetic (*4*) and laser implosion devices (*5*) have therefore been developed to study nuclear fusion. In these devices, strong magnetic fields or laser-induced implosion shock waves, respectively, provide the high densities and temperatures needed to initiate nuclear reactions.

In contrast to these large devices, Taleyarkhan *et al.* report on page 1868 of this issue (*6*) that they have achieved the conditions for d + d nuclear fusion with acoustic shock waves generated in a "table-top" sonoluminescence device (*7*, *8*). In such a device, a small gas bubble trapped in liquid is imploded using high-pressure sound waves. The imploding bubble reaches sufficiently high temperatures and pressures to emit a burst of light. In addition to photons, Taleyarkhan *et al.* report production of tritium and also the detection of high-energy neutrons correlated in time with the sonoluminescence compression shock wave associated with bubble collapse. They apparently achieved higher temperatures in the imploding bubble than are normally reached in sonoluminescence devices through careful selection and preparation of the liquid sample and optimization of other conditions such as temperature. Like neutrinos from the Sun, many of the neutrons, being uncharged, can escape the sonoluminescence apparatus, and some fraction is detected in special neutron detectors (see the figure). The authors present data indicating that the necessary densities and very high temperatures (≥10^6 K) needed to produce d + d fusion neutrons have been achieved.



A new table-top fusion device? Schematic illustration of the sonoluminescence apparatus used in (*6*) to observe sonoluminescence-induced nuclear emissions. The sketch is not to scale. [Adapted from (*7*)]

If the results are confirmed, this new, compact apparatus will be a unique tool for studying nuclear fusion reactions in the laboratory. But scientists will—and should—remain skeptical until the experiments are reproduced by others. Many, including the author, could not reproduce past claims made for table-top fusion devices (*9*). The experiments reported by Taleyarkhan *et al.* appear to have been carefully done and have been subjected to peer review. Hence the results are credible until proven otherwise.

It should be noted that the d + t fusion reaction is routinely used in table-top low-energy deuteron accelerators to produce 14.1-MeV fusion neutrons. However, these devices require the use of a special radioactive tritium (t) target and hence government licensing. [Taleyarkhan *et al.* use such a device to form the bubbles in their sonoluminescence sample (deuterated acetone).] Also, ultrafast, compact pulsed lasers interacting with solid or gas targets have recently been shown to accelerate protons, deuterons, and other ions to the velocities required to initiate nuclear reactions, including fusion (*10*). Given the data reported by Taleyarkhan *et al.*, scientists may also soon be able to study nuclear fusion and other nuclear reactions using table-top sonoluminescence devices (*11*).

References and Notes

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