For Fusion Jam Tomorrow

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At 1 am on December 5, scientists at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in the US achieved a major breakthrough. For the first time they managed to squeeze out more energy from a nuclear fusion reaction than was pumped into it. Ignition, as this is known, is a major step in the long march of harnessing nuclear fusion to supply the energy needs of humanity. Energy from fusion could be a game changer, especially when humanity is facing a climate crisis and there is an urgent need to decarbonize our energy sources, because it would not have the problem of radioactive waste which currently plague fission or atomic energy.

Nuclear fission, the kind that we use in atomic reactors is the breaking up of heavy atomic nuclei like Uranium and Plutonium. Fusion on the other hand, is the fusing together of two light nuclei to produce a heavier nuclei. Since the mass of the resulting heavier nuclei is slightly smaller than the initial nuclei, the mass defect shows up as energy a la Einstein's famous equation.

Fusion is what powers the stars including our Sun as well as thermonuclear or hydrogen bombs. While fission is relatively easier to achieve, nuclear fusion is incredibly difficult. The reason is that the two nuclei are both positively charged and so repel each other. To bring them close enough for fusion to occur means overcoming this repulsion which is notoriously hard. One needs enormous temperatures and pressures for this. In the stars, the force of gravity of the star acting on the core is responsible for creating the conditions needed for fusion. In thermonuclear weapons, it is due to the shock waves from a plutonium bomb. For controlled fusion, the kind we could use for generating power, we need to be able to not only create the conditions for two nuclei to come together but also ensure that the energy needed to achieve this is less than that produced.

There are basically two kinds of technologies being researched for creating the conditions for fusion- one used almost universally is called the tokomak in which the nuclei are heated into a plasma and then compressed magnetically while the other is Inertial confinement which is the one used at NIF.

The NIF is a $3.5 billion facility originally built for research into thermonuclear weapons and properties of materials. It has the world's most powerful laser which delivers an extremely powerful laser pulse which only lasts for nanoseconds. This pulse is split up into 192 beams and these are focused on the target. The target is a pea-sized gold ball which houses the fuel. The fuel is a diamond capsule containing a frozen mixture of two isotopes of hydrogen, deuterium and tritium. The enormous energy of the lasers cause the capsule to collapse and create conditions required for fusing the hydrogen isotopes to helium and releasing energy.

Getting the conditions just right is an extremely difficult technical task- the fuel has to extremely cold (a few degrees above -273C), the vacuum chamber in which the experiment is carried out has to be near perfect and most importantly, the shape of the fuel capsule has to a perfect sphere. Even a small variation from these near-perfect conditions would make the experiment fail. If everything is right, fusion begins in the central core of the fuel and the energy released propagates outward in the capsule, causing more fusion and making the process self-sustaining. This is what is called ignition. What the scientists found was that the energy released in the process, 3.4 MegaJoules, was more than the energy that went into the reaction. Never before has this happened in the decades long history of fusion research.

However, all the hype about this one experiment being the panacea for all of humanity's energy problems is somewhat premature and misplaced. For one, although the energy balance for the reaction itself is positive, the energy used by the lasers to produce it was a 100 times more than that produced in the reaction. There is also the question of being able to do this on a near-continuous basis to make a viable energy source. Finally, the tritium required to make a commercially viable reactor using this technology is simply too rare and too expensive at the moment.

In a famous speech in 1954, the then chairman of the US Atomic Energy Commission said that nuclear power would soon be so plentiful that it will be too cheap to meter it. Even after decades of research, we are nowhere close to having viable fusion energy. The experiment at NIF is certainly a technical tour de force and is a major step towards it.

There is an old joke in the fusion community- getting net energy from fusion is always 20 years in the future. As the White Queen in "Through the Looking Glass" puts it, "It is never jam today, it is always jam tomorrow".

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