UNIT

1

Nuclear Science and Technology

Text A

The Ultimate Battery

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1 The Voyager probes, beginning what would prove to be the longest journeys ever taken by objects from Earth in 1977, have now left the solar system and Voyager 2 is sending back measurements of interstellar space. However, a crucial aspect of that success is seldom celebrated: Those probes sure do have good batteries.

2 In the day-to-day grind of life, batteries never seem to last long enough. We must juice up our phones every day, laptops seem to constantly thirst for their power cables, electric cars only go so far before they fizzle out. It is enough to make you want a new type of power supply.

3 We may be edging closer to exactly that. The Voyager probes employ a weak nuclear power source that, being radioactive, is considered dangerous to use on Earth. But there is a closely related form of energy that packs even more of a punch and could work safely in an average car. It is a long shot. The last time this outlandish technology was seriously considered, 20 years ago, it ended in a broiling controversy. However, now the U.S. Army has it firmly in its sights and has conducted an experiment that might just give it a new lease of life.

4 Most of the ways we store energy involve chemistry. When we burn petrol in a car engine, we are releasing energy stored in chemical bonds. Similarly, lithium-based batteries in devices like mobile phones work by allowing charged ions to flow. But there is greater power to be had if we look beyond chemistry, inside the atom itself.

5 Each atom consists of a nucleus made of particles called protons and neutrons orbited by a cloud of electrons. These protons and neutrons are usually melded together in the extreme temperature and pressure inside a star, and if you delve into an atom's nucleus in the right way, you can extract some of that awesome power. The main way we do that is nuclear fission, in which a nucleus releases neutrons that can then split more atoms, causing a chain reaction that releases huge amounts of energy. That is the way the world's 440-odd nuclear energy plants work. There is also nuclear fusion, which is potentially much more powerful, but relies on smooshing together nuclei in a controlled fashion that we haven't yet mastered.

6 The Voyager probes get their power in a different way: They make use of natural radioactivity. Some atoms are unstable and spit out a chunk of matter and energy now and again. It could be a cluster of two protons and two neutrons (alpha radiation), an electron (beta radiation) or raw energy in the form of gamma rays.

7 We can't predict when a specific atom will decay in these ways, but we can say how long it will take for half of the atoms in a lump of radioactive material to do so. This is its half-life and the number can vary widely. Some radioactive materials vanish in seconds. Plutonium-238 has a half-life of 87.7 years, which is why it was chosen as the power source for Voyager 2. The plutonium dribbles out a stream of alpha particles, generating heat that is turned into electricity by the probe's three roughly suitcase-sized radioisotope thermoelectric generators.

8 Radioactivity has a bad reputation, but not all types are equal. Gamma radiation penetrates human tissue most deeply and is dangerous. Beta radiation isn't so bad. Alpha radiation doesn't get through the skin, so it is only damaging if it gets loose inside you. In fact, pacemakers were powered with well-contained radionuclide thermoelectric generators until the early 1970s.

9 The concept that the U.S. Army is eyeing up is a kind of nuclear power that blends some of the best bits of the other types—it could be powerful, safe and long-lasting. It depends on the fact that the protons and neutrons of a particular element can be clustered together in different arrangements in an atomic nucleus. These are called isomers and each has a different energy. Atoms usually reside in what is normally their most stable isomer, the ground state. Higher energy isomers tend to quickly rearrange themselves back to this state. But there are a few high-energy isomers that hang around for a long time.

Pent-up Energy

10 In 1998, Carl Collins at the University of Texas used a particle accelerator to prepare one of these stable high-energy isomers, called hafnium-178m2 (the m2 notation means this is the second isomer of hafnium-178). He then fired X-rays at its nucleus and claimed that this shifted the nucleus to its ground state, releasing a burst of gamma rays. These would be hard to tap as an energy source because they are so dangerous, but Collins saw it as proof of principle that nuclear isomers could be useful power sources. He thought they could even be used as a new type of nuclear bomb.

11 Many scientists ridiculed Collins's claims, arguing that he had to put in more energy to trigger the isomer shift than he got out. Plus, the fact that you need a particular

accelerator to make the hafnium isomer meant it could only be produced in small quantities at great expense. The episode became known as the "hafnium controversy".

12 Other high-energy isomers might get around the problems. For example, tantalum-180m occurs naturally, if rarely, in mineable tantalum deposits. Silver-108m produces beta radiation, which is less dangerous and easier to tap. None of this makes isomer power a safe bet, but the pay-off from creating an effectively unlimited energy source may make it worthwhile. A similar rationale applies to the £11.6 billion being spent on the ITER (International Thermonuclear Experimental Reactor) fusion reactor in France, even though it is intended merely as a technology demonstration and won't generate power.

13 Collins's approach was to get all the pent-up power of an isomer out in one go. But there is, in principle, a different and arguably more useful method. We have known about it for decades; it just hasn't been properly pursued.

14 Imagine you have a lump of radioactive isomer that, like hafnium-178m2, is high energy but stable. You could have this sitting safely in a container for a long time because it emits barely any radiation. When you need some power, you convert a small amount of it into its ground state, which is less stable and begins to radioactively decay quickly. This gives you a generator akin to the one in Voyager 2, but which can be cranked up in power at will.

15 James Carroll at the U.S. Army Research Laboratory in Adelphi, Maryland, has been investigating whether interconverting isomers in this way is possible. One potential way to do it, first proposed in 1976, involves firing an electron at an isomer and it being absorbed into an orbit around the nucleus. This prompts the protons and neutrons to rearrange. It is called nuclear excitation by electron capture (NEEC).

16 Carroll and his team used a particle accelerator at Argonne National Laboratory near Chicago to create a beam of molybdenum-93m atoms, with a half-life of about 7 hours. This beam was travelling at about 10 percent of the speed of light, fast enough to strip away some of the atoms' electrons. It was then smashed into a target, which injected electrons back into the nuclei, while nudging them into a less stable isomer. This isomer decayed so quickly that the researchers couldn't observe it. But they inferred it was created by the gamma rays it produced. The work, published in 2018, is the first time NEEC had been demonstrated.

17 "The experiment has been a significant step forward, but the jury is out regarding whether or not it is a breakthrough for NEEC," says Philip Walker, who studies nuclear isomer physics at the University of Surrey, U.K. This is largely because there is a dispute

over how much energy can be wrung out of isomers. Carroll's figures suggest that the process could produce 5 joules of energy for every joule put in, assuming 1 percent of atoms undergo NEEC.

18 Adriana Pálffy at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, isn't so sure. Her calculations suggest that a billion times fewer atoms should be depleted through radioactive decay. If true, that raises questions about where the energy that Carroll saw is coming from. "The experimental results may be valid, but their interpretation of what happened in the process cannot be correct," says Pálffy.

19 Carroll admits that isomers are far from being of practical use as batteries. But the arguments that applied after Collins's work still apply: There are other isomers that could be more accessible and easier to harness. The trouble is that the exact properties of isomers are tough to calculate, and we won't know how suitable they are until we try them.

20 At the moment, there is no sense of how isomer shifting could be done at a smaller scale than in a particle accelerator. Still, there is ample drive to get isomer batteries to work because they would pack gigantic amounts of energy into a small volume. "Isomers can store energy with a capacity of up to over gigajoules per gram," says Rzadkiewicz. That's a million times more than lithium-ion batteries, and tens of thousands of times more than petrol.

Risk and Reward

21 Carroll says an uncrewed army vehicle known as a SMET, used to carry soldiers' equipment, could run for 163 days on 1 kilogram of americium-242m. The current version runs for three days on 20 litres of petrol. Drones or robot submarines could also be given isomer energy sources. It is easy to see why the Army is interested.

22 Safety is going to be a concern for anything with "nuclear" in its name, and if isomer power produces gamma rays, that will preclude its use. But if isomers can be found that emit beta or alpha particles, it could be feasible. Plenty of people work close to stores of materials used for radiotherapy and diagnostics. "The amounts of radioactive material needed for a battery are probably less than the material routinely shipped around hospitals," says Patrick Regan at the University of Surrey.

23 Isomer power is the longest of long shots. But then many of our greatest achievements seemed that way at the beginning. When the space race began, who would have thought that, just decades later, we would have sent a probe beyond the edge of the solar system? (*New Scientist*, September 26, 2020)

Exercises

I Fast reading

Task 1 **Tick (√) the statement that most closely reflects the writer's point of view.**

( ) A. Nuclear fusion is the future of energy source.

( ) B. A new type of nuclear energy resource—high-energy isomers—could create long-lasting batteries.

( ) C. The power source of Voyager probes is unique and has aroused interest of researchers.

( ) D. Isomers are hard to harness as the exact properties of isomers could not be calculated.

II Annotating skills

Task 2 **Find texts that describe experiments and analyze them in detail. An example has been given for you. Then find two more experiments from Text A.**

Example:

In 1998, Carl Collins at the University of Texas used a particle accelerator to prepare one of these stable high-energy isomers, called hafnium-178m2 (the m2 notation means this is the second isomer of hafnium-178). He then fired X-rays at its nucleus and claimed that this shifted the nucleus to its ground state, releasing a burst of gamma rays. These would be hard to tap as an energy source because they are so dangerous, but Collins saw it as a proof of principle that nuclear isomers could be useful power sources. He thought they could even be used as a new type of nuclear bomb.

Process of the experiment: In 1998, Carl Collins used a particle accelerator to prepare hafnium-178m2. He then fired X-rays at its nucleus.

Result: He claimed that this shifted the nucleus to its ground state, releasing a burst of gamma rays.

Significance: A proof of principle that nuclear isomers could be useful power sources and could even be used as a new type of nuclear bomb.

Evaluation: First, gamma rays would be hard to tap as an energy source because they are very dangerous. Second, he had to put in more energy to trigger the isomer shift than he got out. Third, energy could only be produced in small quantities at great expense.

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Process of the experiment: ______________________________

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Result: ______________________________

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Significance: ______________________________

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Evaluation: ______________________________

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2. ______________________________

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Process of the experiment: ______________________________

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Result: ______________________________

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Significance: ______________________________

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Evaluation: ____

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III Reading for specific information

Task 3 **Read Text A carefully, but as fast as you can. Try to answer as many questions as you can without referring to the text.**

1. When did the Voyager probes begin their space journeys?
2. Which aspect of the Voyager probes' success is seldom mentioned?
3. In what way is energy stored in petrol?
4. What is the way that the world's nuclear power plants work?
5. Why do we fail to get steady energy from nuclear fusion?
6. How do the Voyager probes get their power?
7. What is the half-life of Plutonium-238?
8. Which is the most harmful to our health, gamma radiation, beta radiation or alpha radiation?
9. What isomers did Carl Collins experiment with?
10. When has NEEC been demonstrated for the first time?

Task 4 **Read the text and try to find the text-referring words in the table. Note down the idea or word(s) that each one refers to. The first one has been done for you.**

Text-referring word(s)	Refers to...	Paragraph
However, a crucial aspect of *that* success is seldom celebrated	the Voyager probes, which have taken the longest journeys ever from Earth in 1977, have now left the solar system and Voyager 2 is sending back information.	1

(Continued)

Text-referring word(s)	Refers to...	Paragraph
We may be edging closer to exactly *that*		3
That is the way the world's 440–odd nuclear energy plants work		5
We can't predict when a specific atom will decay in *these* ways		7
These are called isomers and each has a different energy		9
Other high-energy isomers might get around *the problems*		12
Whether interconverting isomers in *this way* is possible		15

IV Language enhancement

Task 5 **Locate the phrases in the text and complete the table below by explaining the meaning of each italicized word in your own words. Pay attention to the writer's choice of the adjective or adverb for emphasis. The first one has been done for you.**

Phrase	Meaning	Paragraph
crucial aspect	extremely important	1
constantly thirst		2
closely related		3
seriously considered		3
extreme temperature		5
awesome power		5

(Continued)

Phrase	Meaning	Paragraph
arguably more useful method		13
properly pursued		13
practical use		19
gigantic amounts		20

Task 6 **Locate the words or phrases in the text and try to work out their meanings in context. Think about how the writer uses these words and phrases below and the effect the writer's use of language has on the reader. The first one has been done for you.**

Word or phrase	Meaning	Paragraph
day-to-day grind of life	routine tasks or activities that are boring and take up a lot of time and effort	2
juice up		2
fizzle out		2
pack a punch		3
give it a new lease of life		3
a cloud of electrons		5
smoosh together		5
half-life		7
get loose		8
eye up		9
tap		10
proof of principle		10
pent-up		13