Quantum caesium

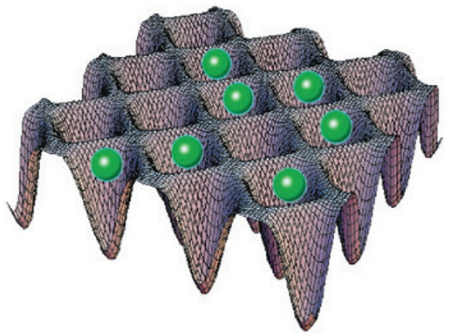
Eric Ansoborlo and **Richard Wayne Leggett** discuss the chemical and radiological characteristics that make caesium a captivating element but also a troublesome contaminant.

The fifty-fifth element in the periodic table, caesium, is an alkali metal and a close physical and chemical analogue of neighbours rubidium and potassium. As a soft ductile element with a low melting point of 28.4 °C, it is one of the few elemental metals to be liquid near room temperature. It is extremely reactive, pyrophoric and explosive in contact with water — thus unsurprisingly hazardous. With its large atomic radius, it readily loses its only valence electron to adopt the +1 oxidation state. It also tends to form covalent bonds and exhibit high coordination numbers (6 to 8), which serves in chemical separation from other cations, such as K^+ in nuclear waste remediation.

Element 55 was discovered in 1860 by Robert Bunsen and Gustav Kirchhoff while analysing a sample of mineral water with their recently invented spectroscope. They named the new element from the Latin word *caesius,* meaning sky blue, for the bright blue lines in its emission spectrum.

Among caesium's 40 known isotopes, with mass numbers ranging from 112 to 151, only one is stable (^{133}Cs). The most common radioisotope is the uranium and plutonium fission product ^{137}Cs, which has a half-life ($T_{1/2}$) of 30 years. ^{137}Cs decomposes by β decay to ^{137m}Ba, a short-lived ($T_{1/2}$ = 2.6 min) radionuclide that emits high-energy γ radiation. This makes ^{137}Cs a long-lived source of high-energy γ radiation, which has found uses in industry, such as in logging devices and levelling gauges, and in medical therapy for cancer treatment. Unfortunately, these same radiological properties make ^{137}Cs a troublesome environmental contaminant — even more so because of its high mobility.

Caesium can migrate long distances in the air before depositing on the ground. It mainly concentrates in the topsoil (~95%), although it is predominantly internalized by plants through their leaves. Its mobility in fresh water depends on its ability to adsorb certain particles and colloids from the soil[1]. Caesium then enters the animal and human food chain by consumption of contaminated water, plants, mushrooms, meat, fish and milk.



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A considerable amount of ^{137}Cs has been released into the environment over the years: ~10^{18} Bq were dispersed in nuclear test fallout from 1950 to 1963, ~10^{17} Bq in the 1986 Chernobyl accident, and an estimated 10^{16} Bq in the 2011 Fukushima accident. It was also caesium, albeit in much smaller quantity, that led to one of the most tragic radiological incidents in history. In 1987 Goiânia, Brazil, scavengers — unaware of what the substance was — opened a sealed ^{137}Cs source they had found at an abandoned medical clinic. The fascinating blue glowing powder was sold to a junkyard owner, who shared it with many family members and acquaintances. When the source of sudden illnesses among those who had handled the sample was finally identified, an investigation found that about 250 people had been subjected to readily measurable contamination, and about 20 had received dangerous radiation levels. Four, including a four-year-old child, died soon after exposure.

The biological behaviour of caesium in animals and humans is similar to that of potassium, although caesium generally traverses cell membranes more slowly than its lighter analogue[2]. Soluble forms ingested or inhaled are almost completely absorbed to blood and distributed throughout soft tissues, with skeletal muscle accumulating most of the body's content within 1–2 days. Caesium then leaves the body within a few months in adults and a few weeks in young children. The recommended treatment for decorporation of radiocaesium is orally administered Prussian blue (ferric ferrocyanide, $Fe_4[Fe(CN)_6]_3$), which binds to caesium atoms secreted into the gut and prevents their reabsorption to blood.

On a different note, a novel application of stable caesium uses an inherent time-keeping ability that is quantum mechanical in nature. In 1967, the International System of Units (SI) defined the second as 9,192,631,770 periods of the wavelength of light associated with the transition between two 'hyperfine' energy levels of the ground state of the ^{133}Cs atom (pictured). Since then, caesium has been widely used in atomic clocks[3].

In an interesting turn of events, the ubiquitous anthropogenic isotope ^{137}Cs generated in recent decades by nuclear fallout has found an unexpected use. Measurement of its characteristic γ emissions serves as a non-destructive method of determining whether a purportedly extremely old wine was indeed produced before the nuclear age.

Thus, caesium has proved to be a mixed blessing to mankind, a potentially hazardous environmental contaminant yet also a beneficial industrial and medical tool that keeps the time for clocks and wine. ❐

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Te I Xe Cs Ba La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu Hf