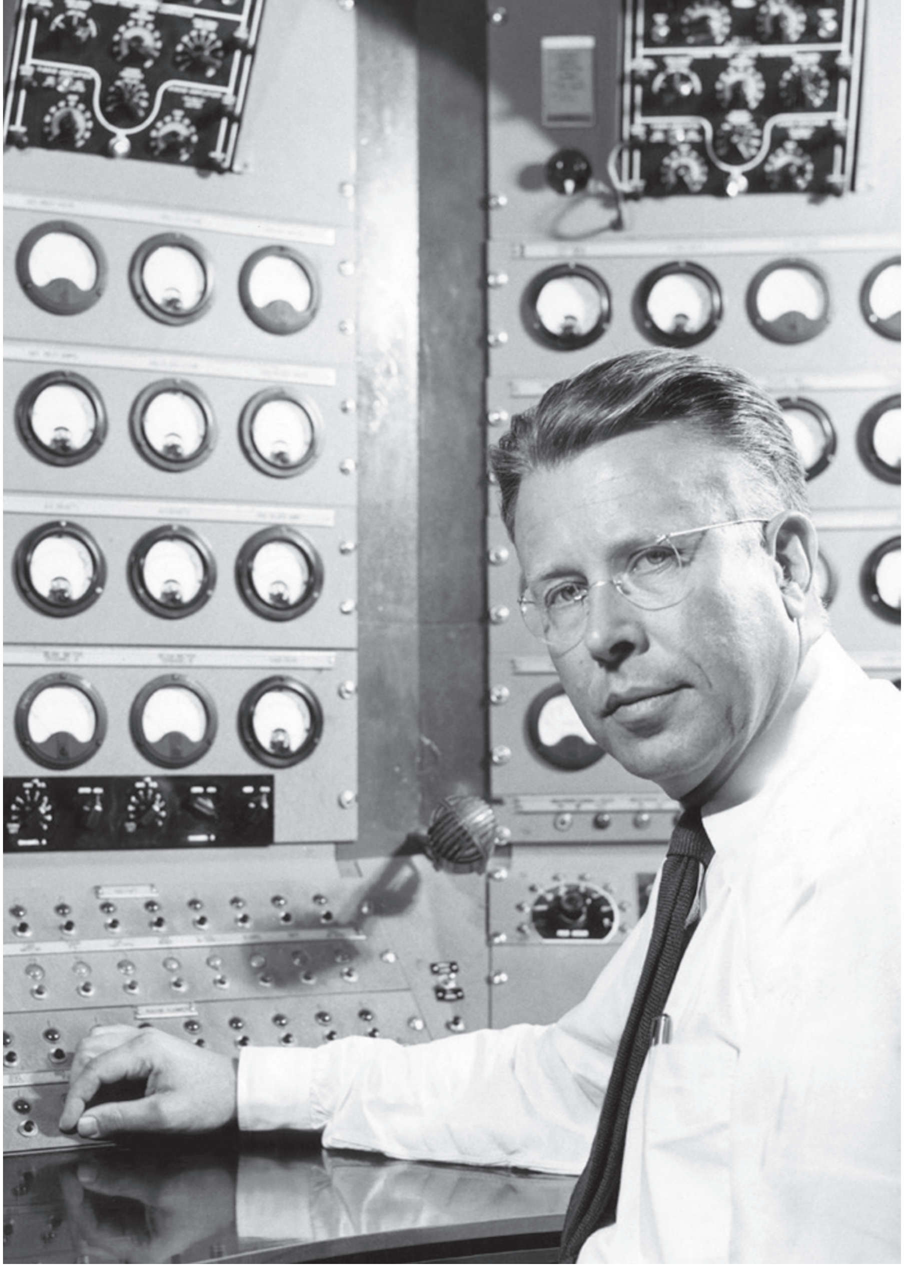

EVERETT COLLECTION HISTORICAL/ALAMY

Ernest Lawrence co-invented the cyclotron particle accelerator.

PARTICLE PHYSICS

Inside the Rad Lab

Jon Butterworth relishes a tome on the research and the personalities that drove a century of smashing physics.

I approached Michael Hiltzik's *Big Science* with trepidation. I work on the biggest particle accelerator ever built — the Large Hadron Collider, which features in this tale — but the book looked heavy, at least in the gravitational sense, and I am not a fan of hagiographies. However, I was soon gripped. This is an astonishing story: US physicist Ernest Lawrence is at its core, but its scope is broad and full of context and characters.

Big Science spans the development of particle accelerators, the emergence of a team-driven approach to research, the beginning of serious large-scale military, industrial and government sponsorship of science and the inception of fission and fusion weapons. Sometimes Lawrence is a cipher, cynically jumping from one funding source to another. At others he is a visionary leader of teams of genius, or an overstretched human being whose judgement and health eventually fail him.

The cyclotron, co-invented by Lawrence in 1932, takes advantage of the relationship between the magnetic force needed to bend the path of a particle in a circle, the radius of the circle and the speed of the particle, to whizz particles around a loop and accelerate them to formerly unattainable velocities. Previously, physicists relied on natural sources to smash atoms. Ernest Rutherford's scattering experiment, which gave us the first look inside the atom, used α-particles emitted by radioactive radium. Other discoveries, such as that of the muon, were made by observing high-energy particles that bombarded Earth from space. The cyclotron offered beams much more intense than those from space, and of vastly higher energy than those from radioactive decay.

Big Science: Ernest Lawrence and the Invention that Launched the Military-Industrial Complex
MICHAEL HILTZIK
Simon & Schuster: 2015.

The ever larger and more efficient machines at Lawrence's Radiation Laboratory in Berkeley, California — the 'Rad Lab' — from 1931 onwards provided a bonanza of finds. Elements discovered there (such as lawrencium) carry the names of Rad Lab scientists. The group also supplied labs worldwide with isotopes for use in medicine.

The tensions between these sometimes conflicting priorities are convincingly described, as are Lawrence's methods of research management. When governments hymn impact and interdisciplinarity, they must surely hold the Rad Lab as a Platonic ideal. It is hard to beat the impact of developing the method of enriching uranium for the first atomic bomb. And Lawrence's team of obsessive scientists and engineers could be the definition of interdisciplinarity.

That team is the prototype for numerous cultural references. In Terry Pratchett's Discworld novel series, the High Energy Magic building at the wizards' Unseen University references the 1930s Rad Lab, with its camp beds, coffee and high-voltage atom-smashing. Lawrence's physician brother John bringing mice to be irradiated, and kicking off hadron cancer therapy; the violet deuteron beam used to impress visitors; the electromagnetic noise that meant that a light bulb pressed against any piece of copper piping would light up: all are examples of the potential for breakthrough and disaster. It is a world away from the Ivy League heights of US academia, or the "small science" citadels of Europe — Cambridge, Copenhagen, Göttingen and Manchester, which led physics into the quantum era but hungered for the technologies being born in Berkeley.

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The growth of the Rad Lab's reputation ▶

and of US physics in general are well narrated. The newcomers made mistakes and missed opportunities, but European physicists — including such giants as Rutherford, James Chadwick and Pierre and Marie Curie — maintained a dialogue, and respected them. Lawrence and his team stayed engaged, increasingly willing to admit to errors as their confidence grew, and generous with their know-how in helping to start other accelerator programmes as the 'Cyclotron Republic' grew.

Compelling characters abound. There is the mysterious and influential Alfred Loomis, a patron of science who achieves the feat of "being a public figure without letting the public in on it". Later, there is Lewis Strauss (pronounced 'Straws'), Washington DC insider, chair of the Atomic Energy Commission and die-hard opponent of a nuclear-test-ban treaty. Lawrence seems to have easily formed bonds with exceptional people, but these sometimes shattered, as with Manhattan Project leader J. Robert Oppenheimer, causing damage and dismay.

Lawrence transformed strikingly from a man who insisted that politics had no place in the lab to one who played high-stakes political games around the credibility of scientific advice on nuclear-weapon development — and fired outstanding scientists because they refused to sign an oath of loyalty. The Rad Lab drew talent, but much of it leaked or was driven away as Berkeley became identified with the anti-communist McCarthyism — under which people were branded un-American and unemployable — that abounded in the military–industrial complex that it had helped to create.

"The Rad Lab drew talent, but much of it leaked or was driven away as Berkeley became identified with McCarthyism."

The final chapter rushes through the formation of CERN in Geneva, Switzerland, and the failure of its US competitor, the Superconducting Super Collider, which was cancelled in the 1990s. It is a compliment to Hiltzik that, having initially worried about the book's size, I wanted more — in particular, on how CERN consciously distanced itself from the military aspect of the complex, and how the teamwork that Lawrence developed applies, or fails to, in collaborations of thousands rather than dozens. Lawrence had left the scene by then, but his influence still pervades academia, industry and politics. ■

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PHYSICS

The impulse of beauty

Joseph Silk revels in Frank Wilczek's treatise on how symmetry and harmony drive the progress of science.

AKG IMAGES

Through the mythological figure of Urizen, William Blake probed the nature of reductionism.

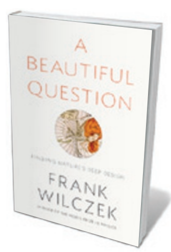
Can beautiful ideas drive science? In *A Beautiful Question*, physicist and Nobel laureate Frank Wilczek makes a potent case that they can, hinging on qualities that have served as pathfinders to empirical truth in the physical world. The greatest scientists, from Galileo to Albert Einstein, saw in physics almost infinite beauty, including symmetry, harmony and truth. Today, we fervently hope for a genius with a beauty-inspired Theory of Everything — or at least for the Large Hadron Collider at CERN in Geneva, Switzerland, to discover truth in supersymmetry.

A Beautiful Question is both a brilliant exploration of largely uncharted territories and a refreshingly idiosyncratic guide to developments in particle physics. Vast and eclectic, it covers everything from atomism to the Higgs boson, musical harmony to anamorphic art, dark matter to the origins of the Universe. Wilczek lays out a vision of truth and beauty inspired by great modern physicists and classical philosophers such as Pythagoras and Plato. Lavish illustrations exemplifying beauty in art and science, from William Blake's *Ancient of Days* to fractal images, are interwoven with quotations from luminaries in the arts and sciences, from Molière to John Archibald Wheeler.

Wilczek begins with the beauty-inspired seeds sown by the ancient Greeks, including the fundamentals of geometry, music and chemistry. The music of the spheres, which Pythagoras described as the hum from celestial bodies whose periodicities echoed a harmony that he alone heard, inspired him and his followers to develop harmonies between beauty, music, mathematics and science. Numbers governed all, from octaves to right-angled triangles. Through perspective, geometry revolutionized classical, then Renaissance, art; through the curvature of space, it revolutionized understanding of gravity. And Wilczek argues that colour, the epicentre of beauty, unites art with biology, chemistry and physics.

The search for symmetry generated enormous rewards in science, a gift that has kept on giving. In the nineteenth century, Michael Faraday gave an elegant display of empirical physics by mapping out the patterns of magnetic lines of force. He went on to show that moving magnetic fields generate electric fields, motivating mathematical physicist James Clerk Maxwell to develop his equations for electromagnetism. These epitomized a fundamental symmetry, allowing a magnetic field in motion to generate an electric field, and vice versa. The fields propagate through space, producing waves of light in all colours of the rainbow. Maxwell's equations also predicted that electromagnetic waves would propagate at frequencies beyond perception by the human eye. Inspired, Heinrich Hertz discovered radio waves. Beauty had succeeded far beyond any intent of Faraday's.

Wielding the sword of beauty to refine scientific thought has a remarkable heritage. Einstein put beauty first in conceptualizing the general theory of relativity. In the dreary postwar climate of 1919, worldwide headlines greeted the successful verification of one of his key predictions — the bending of light by gravity. Another triumph is the standard model of particle physics, whose symmetries led to prediction of the Higgs boson.



A Beautiful Question: Finding Nature's Deep Design
FRANK WILCZEK
Allen Lane: 2015.

Wilczek argues that the quantum core of modern physics, the zoo of elementary