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# Think like a neutron

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*The Last Man Who Knew Everything: The Life and Times of Enrico Fermi, Father of the Nuclear Age* by David N. Schwartz
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Enrico Fermi is just the latest in a long line of 'last men who knew everything'. A handful of recent biographies claim the title for their subjects, which include the Renaissance naturalist Athanasius Kircher (*two* books); the German polymath Gottfried Wilhelm Leibniz; the early 19th-century English physicist Thomas Young; and the 19th-century American palaeontologist Joseph Leidy. Then there are 'men who knew too much' (Robert Hooke, Alan Turing, G.K. Chesterton and, predictably, Alfred Hitchcock) and those whose knowledge 'changed everything' (Shakespeare, Isaac Newton, James Clerk Maxwell). Everything-knowers are admired, though with qualifications: the 'know-it-all' is an intellectual bully or a bore, and one thing it's useful to know is when *not* to tell everyone that you know everything. It's no great surprise that there doesn't seem ever to have been a 'woman who knew everything' – while there are several books about women who 'knew too much'. It's often said that some quite ordinary people 'know everything', but that usually comes with qualifications too: you can 'know everything' if you win pub quizzes, or you can 'know everything' about birdwatching, or baking cakes, or *The Archers*. But the serious-minded books about those who 'know everything' tend to be about intellectuals, or certain kinds of intellectuals.

Everything-knowing depends both on the times in which you live and the position you occupy on the map of knowledge. It's a commonplace that our culture has become more and more fragmented over time: there's more stuff to know and more specialised ways to know it, though scholars were already complaining centuries ago that there was too much for any one person to know. Some fields have long been more likely than others to throw up people said to know everything. There are disciplines that focus on particular aspects of the physical, social and cultural worlds – invertebrate zoology or Micronesian anthropology or comparative linguistics, for example – but there are also a few disciplines whose knowledge is said to be 'fundamental', the basis of everything that can be known. Prominent among these are the physiology of the brain and atomic physics: the one giving accounts of how we come to know anything in the world, the other testifying to the basic structure of everything that exists. As Gilbert Ryle observed many years ago, these 'subsuming' disciplines do indeed 'know everything', even if it's properly said that the 'everything' they know is everything from a special point of view.

Enrico Fermi was an atomic physicist – so he was in the right line of work for an everything-knower. In 1926, at the age of 24, he was appointed professor of physics at the Sapienza University of Rome, where he built up a school of able and adoring young Italian researchers known as the 'via Panisperna boys', from the address of the university's physics institute. Acknowledged as a prodigy, he first won scientific fame for his work on the emerging problem of nuclear structure and, specifically, radioactive decay. In 1933 he produced an experiment-based theory about 'beta decay'. This is the emission of a negatively charged electron from a nucleus – an electron that, in the Alice in Wonderland world of quantum physics, hasn't actually been there until just before the moment of its exit. The theory incorporated an idea about what came to be called the weak nuclear force, acting at very short distances between subatomic particles and responsible for forms of radioactivity, and it also supported earlier claims for the existence of a virtually massless, chargeless particle that Fermi christened the 'neutrino' – an Italian-flavoured designation for 'little neutral one'.

Fermi won the Nobel Prize in 1938 for further investigations of radioactivity, drawing on the experimental skills of the via Panisperna boys. This work focused on 'slow neutrons': chargeless nuclear particles whose energy was reduced when they collided with nuclei of different sorts of materials, such as paraffin, water or graphite. It turned out that slow neutrons were much more effective in inducing radioactivity than fast ones. There was talk of commercial applications, and patent negotiations persisted through the 1940s. (Running up and down university corridors holding highly radioactive materials tight against his chest may have contributed to the stomach cancer that killed Fermi in his fifties.) Fermi was special in his generation of physicists in combining both theoretical and experimental skills, one sense – specific to physics – in which he knew everything. Gesturing at his infallibility, and his 'inside track to God', Italian students began to refer to the secular 26-year-old Fermi as 'Il Papa' – 'the pope' – and the name stuck.

Another sense in which Fermi could be said to know everything was the result of his characteristic way of approaching problems. A so-called Fermi problem or Fermi question is addressed by a back-of-the-envelope calculation that models how to approximate, or guess at, an answer when you haven't got much data or when the data aren't very good. A classic example, which he used to inculcate techniques of right reasoning in his physics students, is the question: 'How many piano tuners are there in Chicago?' The point wasn't so much to get the 'right answer' but to estimate a range within which the right answer might lie. Fermi once bragged to a colleague that he 'could calculate almost anything to an accuracy of ten per cent in less than a day, but to improve the accuracy by a factor of three might take him six months'. In Fermi reasoning, you start with the knowable population of Chicago, estimate the proportion of households that own a piano, make a plausible assumption about how much business there would have to be to support a piano tuner, and you end up with a figure for the number of tuners that should be correct within an order of magnitude – that is, within a factor of ten. Fermi's counsel to his talented daughter, Nella, was a lesson in the proper balance between rigour and practicality: 'Don't devote more time and effort to a problem than it's worth,' and 'Never make something more accurate than absolutely necessary.' One of his colleagues in Rome said that Fermi liked to think through problems that could be radically simplified; when they reached a point where complex maths was involved he 'generally left them. He didn't choose to go beyond that.' Fermi's method still proves a useful way of going about things in many domains. Fermi problems are widely used in management consultancy, engineering and government to gauge real-world reasoning powers. If you get a job interview at Google or McKinsey, you can reasonably expect to be posed such questions as 'How many golf balls can fit in a school bus?' or 'How much does the Empire State Building weigh?'

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David Schwartz is a science policy expert with a background in physics. His father was the Nobel-winning physicist Melvin Schwartz, who met Fermi in the 1950s and passed on his admiration of the great man. But beyond the physics, as Schwartz admits at the outset, there isn't a lot for a biographer to go on. He 'revealed very little of himself or his inner life. Diaries simply do not exist and personal letters are few and far between.' On the face of things, it was 'all physics, all the time.'

There have been great modern physicists who cared deeply about the philosophical foundations of their science (Einstein, Schrödinger, Bohr, Bohm); some who had artistic tendencies (Oppenheimer, the later Feynman, Einstein again); and very many – especially after Hiroshima – whose political involvements were intense and important to their sense of self. Fermi loved hiking, the outdoor life and manly physical games; he had pub-quiz-winner tendencies about all sorts of scientific things. He insisted on being recognised as the smartest person in any room – the alpha male who discovered the nature of beta decay – but, in general, he brought it off with charm, humour and a genuine desire to be helpful. Time and again he proved himself an effective motivator, mentor and manager of scientific egos almost as huge as his own. Fermi, you could say, knew everything about what he was interested in, but he cared about little beyond physics. He 'never carried himself as a particularly cultivated or cultured individual', Schwartz writes. 'He was obsessed with physics and aside from outdoor activities had little interest in anything else.' Neither philosophy nor art, literature or music meant much to him. Schwartz records that Fermi's wife, Laura Capon, once succeeded in dragging him to a performance of *South Pacific*, which was, for Enrico, a 'major concession to the musical arts'.

Fermi is a challenge for any biographer planning to display what's often called the 'human side’ of science, and an even bigger challenge to a biographer hoping to reveal the ‘inner life’ of their subject. A colleague once described Fermi as ‘someone with the personality of an Italian bureaucrat’, and his wife – a physicist who gave up science to be a dutiful spouse – records (with evidently bemused affection) that Enrico spent much of his honeymoon teaching her Maxwell’s equations. ‘It wasn’t that he lacked emotions,’ their daughter said, ‘but that he lacked the ability to express them.’ Their son, Giulio, disengaged himself from a father who wasn’t much engaged with him; he suffered from depression, and there was a suicide attempt. ‘His sensitive makeup,’ Schwartz coolly observes, ‘was simply ill-suited to life with Enrico.’ Fermi ‘may have been a world-class physicist, but he was not a world-class family man.’ At non-scientific problems – like raising the kids – he was evidently no better than the rest of us.

Politics was important to Fermi mainly insofar as it bore on the resources for doing physics. He and some of his students in Rome thought of physics as their own version of Aldous Huxley’s ‘soma’, an ideal drug that made it possible for them not to think too much about the outside world. In the late 1920s, Mussolini thought to add cultural lustre to his regime by establishing a Royal Academy in Rome. Fermi’s patrons lobbied to get him appointed, with a stipend doubling his university salary. Membership of the academy involved joining the National Fascist Party, which Fermi did in 1929. ‘He was certainly willing to play Mussolini’s game,’ Schwartz writes, ‘lending his name and his scientific prestige to the new Fascist institution.’ Early on at least, Fascism didn’t strike Fermi as all that bad: there were many Italians, including some Jews, who thought that the country might benefit from the smack of firm government.

For a long time, Fascism registered with Fermi mainly as ‘noises off’. Mussolini’s stamp of approval meant the bill was paid for Fermi’s physics (and a grand new house in Rome), but there is no evidence that Fermi was ever enthusiastic about the more unpleasant aspects of Fascist politics. The awkwardnesses came later. It was only as Mussolini came more and more under the influence of Hitler in the mid-1930s that the serious persecution of Italian Jews began. This was bad for Italian physics: important Jewish physicists stopped coming to Rome and Italian Jews were turfed out of their jobs. And there was a possibility it would be bad for Fermi’s family. His wife was Jewish (though, as the saying goes, not very; the Fermis’ two children were both baptised in the Church). However, Laura’s father, Augusto Capon, was an admiral in the Italian navy, and the family took it for granted that this, in addition to Fermi’s growing global fame, would keep them safe.

Fermi had long wanted to relocate to America, with its better-equipped universities, but Laura felt more deeply rooted in Italy and repeatedly resisted. Matters came to a head in December 1938, as increasingly virulent anti-Jewish policies were introduced. Fermi, who was about to be awarded the Nobel Prize for his slow-neutron research, quietly accepted an offer from Columbia University, and decided that he, Laura and the two children would go straight from Stockholm to New York. Fermi was one of the last of the great European physicists – Jewish or with Jewish connections – to flee.

Getting out of Italy would involve taking the train through Germany just weeks after *Kristallnacht*. No chances could be taken. Fermi applied to Mussolini's secretary for a permit to travel to Sweden and then on to the US for what he represented as a temporary stay. He was careful to add a request for instructions 'on actions that I might take in scientific circles in those countries'. Fermi was nominally Catholic (again, not very), and through his connections was able to get Laura a new passport without the designation indicating that she was Jewish. Just before they left Rome, Laura converted to Catholicism, and she and Fermi married again in the Church. There was a flutter of anxiety at the German border as the passports were checked, but all went smoothly. Not so smoothly, eventually, for Fermi's in-laws: Admiral Capon and his wife were among the Italian Jews rounded up in October 1943. Laura's mother died on the way to Auschwitz; her father was murdered in the gas chambers.

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Nobel Prize in hand, Fermi arrived in New York in January 1939. Shortly afterwards, startling news arrived of research that would fundamentally alter his understanding of his own investigations. Fermi's slow-neutron work had indeed induced radioactivity, and in his Nobel acceptance speech he mentioned the concomitant production of new 'transuranic' elements – heavier than uranium. However, while Fermi was on the boat to New York, the German scientists Otto Hahn and Fritz Strassmann announced the results of their neutron bombardment experiments, as interpreted by the Austrian-Jewish exiles Lise Meitner and Otto Frisch. They had discovered nuclear fission – the splitting of the uranium atom. It was an astonishing result, which Fermi now knew he had achieved – without realising it – years before in Rome. Given Einstein's definition of energy as mass multiplied by the square of the speed of light, the principle of atomic power was immediately established, along with the possibility of vastly destructive nuclear weapons. Fermi, Schwartz judges, 'had colossally misunderstood the results of his own neutron experiments, the very experiments for which he had just received the Nobel Prize. He would never quite get over the embarrassment of having been so wrong.' Even the pope was occasionally fallible.

The Germans had the scientific knowledge – 'the most dangerous information on the planet', as Schwartz puts it – but the world's leading experimental expert in slow-neutron work was now in the US, at the disposal of a government yet to be persuaded to provide the massive resources required for an atomic bomb programme. Within weeks of learning the German fission results, all the American and exiled European physicists were convening, convinced that a nuclear weapon was theoretically possible, but unsure what quantity of fissile materials would be required, whether and how they could be produced, and how such a device might be designed and assembled. In light of the Hahn and Strassmann results, Fermi was asked about the likelihood of a successful chain reaction occurring in uranium – that is to say, of a state of affairs in which a neutron splitting a uranium atom released more than one neutron, so propagating a cascade of nuclear fissions. Fermi surprised his colleagues by saying that such a chain reaction was only a 'remote possibility'. Even in 1939, the possibility of a self-sustaining uranium chain reaction was taken seriously by many Allied physicists. Asked what he meant by 'remote', Fermi replied with what was for him a common index of implausibility – '10 per cent' – to which his colleagues responded that a one in ten chance in such important matters shouldn't be treated as remote.

Despite his apparent scepticism, Fermi began carrying out small-scale chain reaction experiments at Columbia. Early in 1942, the work – now expanded and more richly resourced – was transferred to the innocuously named Metallurgical Lab at the University of Chicago. Fermi, by now persuaded of the possibility of self-sustaining fission, was put in day-to-day charge of the research, the purpose of which was to provide proof of principle for proceeding with a full-scale nuclear weapon programme. Fermi counted at this time as an 'enemy alien' – he didn't become an American citizen until 1944 – and his confidential work required FBI clearance. Even though the Feds' security report observed that 'he is undoubtedly a Fascist,' and recommended that he be kept away from secret work, Schwartz notes that Fermi knew very well how to keep government secrets; he didn't even tell his wife what he was up to. And he repeats the judgment that Fermi was apolitical, though blessed with a 'natural inclination to defer to authority figures', so making him a better fit than some of his colleagues with the militarily mandated secrecy of the Manhattan Project.

The Met Lab work began in a squash court under the stands of the University of Chicago's unused football stadium. It was high-level slide-rule engineering stuff, much of which was spun out of Fermi's fertile brain and based on his intuitive sense of how neutrons would flow. (A colleague later said that Fermi had learned how to 'think like a neutron'.) Fermi, Schwartz remarks, 'was utterly unafraid of the "quick and dirty" solution that worked'. The 'pile' Fermi and his co-workers constructed was, by later standards, a jerry-rigged contraption: a 27-foot-high lattice containing three-quarters of a million pounds of pure graphite bricks (as 'moderators', to slow the neutrons down) surrounding about a hundred thousand pounds of uranium metal and oxide slugs, with boron neutron detectors and cadmium neutron-absorbing control rods whose removal would enable the chain reaction to commence and whose reinsertion would, it was hoped, stop that reaction from running out of control, potentially poisoning the researchers and the whole neighbourhood. (The pile had neither radiation shielding nor a cooling system.) There are several versions of what Fermi said he would do if the chain reaction did run out of control: one is 'I will walk away – leisurely'; another is that he would run 'quick-like behind a hill many miles away'. In the event, on 2 December 1942 the pile safely 'went critical' and the world's first controlled, self-sustaining chain reaction took place. The scientists celebrated with Chianti drunk out of paper cups.

(Fermi customarily diluted his wine.) The concept of a uranium chain reaction was realised, and Il Papa was anointed 'the Father of the Nuclear Age'.

Others have dated the dawning of the nuclear age to the first atomic explosion, at Alamogordo, New Mexico on 16 July 1945. Fermi was there too. He spent much of his time from early in 1943 until Hiroshima shuttling between the Met Lab, now relocated to the Chicago suburbs, and the fissile-material-producing plants at Oak Ridge, Tennessee and Hanford, Washington, but from summer 1944 he was based at Los Alamos, where the bomb was designed. Seeing that an atomic bomb really was going to be built, Fermi appeared ambivalent. He struck J. Robert Oppenheimer, the scientific director at Los Alamos, as lacking in enthusiasm. Yet in 1943, when Oppenheimer wrote to Fermi about a plan to disperse radioactive substances sufficient to kill half a million Germans, Fermi replied that if such a plan were decided on, it would be better if work started on it right away. At Los Alamos, Oppenheimer designated Fermi as associate director, deploying him as a general-purpose problem-solver with a brief to get stuck into whatever projects interested him, giving him the special job of dealing with Edward Teller, who was obsessed with the possibility of proceeding directly to a fusion weapon.

With the German surrender in May 1945, attention turned to issues concerning the postwar nuclear world and most urgently the question of whether to use the bomb on a live Japanese target. Japan was known not to have a nuclear weapons programme, and the original justification for building the bomb had been to beat the Germans to it. Fermi was one of four Manhattan Project scientists on the interim committee assembled to advise the president, but his contribution seems to have been limited to estimates of how much uranium would be needed for postwar work. Some atomic physicists, especially back at the Met Lab in Chicago, were worried about the morality of dropping the bomb on the Japanese, proposing instead an offshore demonstration explosion to offer them a face-saving reason for surrender. Fermi originally seems to have supported the Chicago group but Oppenheimer beat him into submission. Schwartz suggests that his capitulation was 'generally consistent with Fermi's view of himself as a scientist with only limited expertise in political matters', reluctant to express 'any personal political or moral qualms'.

That fits with Fermi's position on nuclear weapons development after Hiroshima. Faced with Teller's enthusiasm for an H-bomb crash programme, Fermi signed a statement – 'probably drafted' by the Columbia physicist I.I. Rabi – condemning the enormously more destructive fusion weapon as 'an evil thing considered in any light ... wrong on fundamental ethical principles'. President Truman ignored the warning: the thermonuclear programme went ahead, and Fermi returned to Los Alamos to work on developing that 'evil thing'. Schwartz finds this apparent contradiction 'puzzling' and 'a mystery'. Fermi left no record of the thinking that led him back to Los Alamos, but Schwartz speculates that 'perhaps he wanted to be viewed as a patriot,' doing his duty as directed by the authorities. At the hearings in 1954 over Oppenheimer's communist background and associations, as the result of which he lost his security clearance, Fermi spoke in Oppenheimer's defence, but he was happier when he didn't have to get involved. Politics, as Schwartz puts it, was shot through by a 'combination of technical fact and value-based opinion', and on the whole Fermi preferred not to be there when it happened.

The Trinity Test at Alamogordo was one of those events where technoscience, politics, morality and even aesthetics spectacularly shared the stage. The atomic scientists present each reacted in their own way. Oppenheimer said he was reminded of verses from the *Bhagavad-Gita* ('Now I am become death, destroyer of worlds'); another physicist, Kenneth Bainbridge, said, 'Now we are all sons of bitches'; Rabi reflected that 'a new thing had just been born; a new control; a new understanding of man'; the mushroom cloud put Otto Frisch in mind of a 'red hot elephant balanced on its trunk'. Others tried, and failed, to find language adequate to describe the colours, the sound, the appearance and feel of the shockwave.

Fermi was different. He left no record of what he was thinking or feeling at the time, but we know that he saw Trinity as an opportunity for one of his famous exercises of rational estimation, a Fermi problem. First, he offered to take wagers from other scientists on whether the bomb would ignite the atmosphere, destroying New Mexico or even the entire world. Then, the evening before, he carefully prepared an experiment to estimate the bomb's explosive yield:

> About forty seconds after the explosion the air blast reached me, I tried to estimate its strength by dropping from about six feet small pieces of paper before, during and after the passage of the blast wave. Since, at the time, there was no wind, I could observe very distinctly and actually measure the displacement of the pieces of paper that were in the process of falling while the blast was passing. The shift was about 2.5 metres, which, at the time, I estimated to correspond to a blast that would be produced by ten thousand tons of TNT.

'He was so profoundly and totally absorbed in his bits of paper,' his wife recorded, 'that he was not aware of the tremendous noise.' The answer later calculated by the instrumentation specialists was 18 kilotons, but Fermi's answer was arrived at on the spot – and it was correct within an order of magnitude.

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