

HISTORY OF SCIENCE IN EUROPE · COURSE 5

The Construction of a European Science

...and the Advent of Quantum Mechanics

How a small, cross-border conversation among physicists survived two world wars, then rebuilt itself as CERN, Euratom, and a continent of shared laboratories.

FRAMING THE CHAPTER

One conversation, told through letters and laboratories

Chapter 4 traced the scientific journal as the physical medium of European science. This chapter follows two complementary media — the personal letter, and the small, recurring international conference — through the episode that puts them under the most pressure: the invention of quantum mechanics, c. 1900–1933. Quantum theory was not built by one nation and exported to the others; it was built by a genuinely continental conversation, in which nearly every European country of scientific weight was represented by a figure of the first rank.

1

A conversation, not a nation

Solvay conferences and cross-border letters carried quantum mechanics from Berlin to Zurich to Cambridge to Copenhagen.

2

Twice broken

Two world wars scattered — and, for a time, weaponised — the very community that built the theory.

3

Deliberately rebuilt

CERN, Euratom, and a cluster of shared laboratories at Grenoble answered a single lesson: never go it alone again.

4

A parallel logic

The founding of shared science and of political Europe run alongside each other — once, they share the very same treaty.

What follows traces that arc in five stages, §5.1 through §5.5.

5.1
CHAPTER 5 · A EUROPEAN SCIENCE & QUANTUM MECHANICS

A Continental Conversation Before the Quantum

Kinetic theory and statistical mechanics were already a cross-border argument, decades before Planck's quantum.

5.1 · STATISTICAL MECHANICS, ALREADY EUROPEAN

A running, multi-national argument, before 1900

The kinetic theory of gases — explaining a gas's pressure, temperature, and viscosity as the statistical result of vast numbers of colliding molecules — was itself assembled across borders over the second half of the nineteenth century.

M

James Clerk Maxwell

Scotland

Derived the statistical distribution of molecular speeds, 1860.

B

Ludwig Boltzmann

Austria

Generalised a full statistical mechanics. His 1872 H-theorem — deriving irreversibility from reversible collisions — was promptly challenged by his own countryman, Johann Loschmidt.

W

J. D. van der Waals

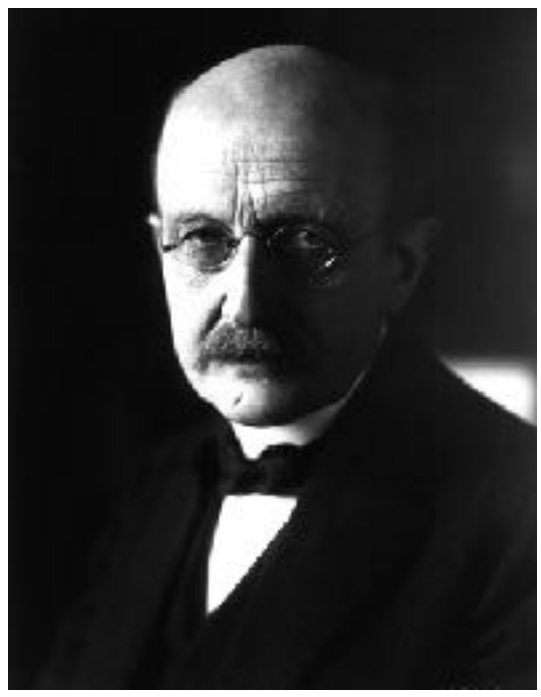
Netherlands

1873 equation of state explained why real gases depart from ideal behaviour, and predicted liquid–gas continuity — Nobel Prize in Physics, 1910.

Scottish, Austrian, Dutch — the statistical treatment of matter was already an international, correspondence-and-journal argument by the century's end.

5.1 · THE QUANTUM EMERGES FROM THAT TRADITION

Planck, Einstein, and an already-international method



Max Planck (1858–1947), Berlin.

- 1 **Planck, Berlin, 1900** introduces energy quantisation — which he himself long regarded as a mere mathematical expedient — to make Boltzmann's statistical methods, which he had long resisted, yield the correct black-body radiation formula.
- 2 **Einstein, 1905** takes the quantum far more literally: light itself is absorbed and emitted in discrete packets (later called photons) — explaining the photoelectric effect.
- 3 **Einstein, 1907** returns explicitly to Boltzmann's framework: quantising the vibrations of atoms in a solid resolves a long-standing anomaly in measured specific heats at low temperature.

From its first decade, the new quantum physics was an extension of an already-international statistical tradition — not a fresh national departure from it.

5.2
CHAPTER 5 · A EUROPEAN SCIENCE & QUANTUM MECHANICS

One Country, One Voice: The Solvay Conferences

From 1911, roughly thirty physicists, invited by name, gathered every few years to argue quantum theory face to face.

5.2 · THE FIRST SOLVAY CONFERENCE, 1911

A private, deliberately international invitation

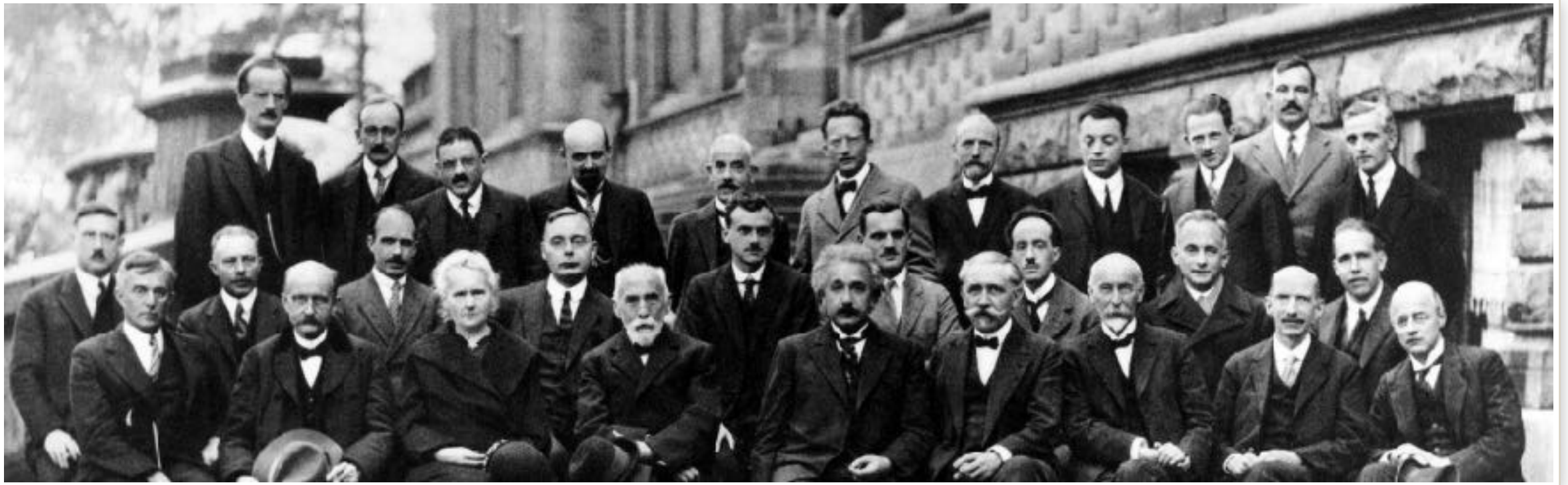
- **Ernest Solvay, Belgian industrial chemist** funded the first conference, Brussels 1911, on a single announced topic: “The Theory of Radiation and Quanta.”
- **Hendrik Lorentz chaired** the senior statesman of European theoretical physics chaired this and the recurring meetings roughly every three years, until his death in 1928.
- **Small, and by name** some twenty to thirty leading physicists, invited individually rather than as national delegations.
- **Discussion, then publication** several days of presentation and open discussion; proceedings subsequently published for the wider community.

Why by name, not by nation?

Inviting individuals rather than national delegations was itself a choice. As the closing note of this section explores, it tells us something real about where the true unit of this conversation actually lay — not, in the end, the nation-state.

5.2 · THE FIFTH CONFERENCE, OCTOBER 1927

“Electrons and Photons”



The Fifth Solvay Conference, Brussels, October 1927 — “Electrons and Photons.” Seventeen of the twenty-nine participants shown were already, or would become, Nobel laureates.

Werner Heisenberg's own verdict, given soon afterward: the conference “contributed extraordinarily to the clarification of the physical foundations of the quantum theory” — precisely because every major national tradition in European physics was seated at the same table.

5.2 · ONE VOICE PER COUNTRY, AROUND ONE TABLE

The roster, 1911–1933

Country	Key Figure(s)	Note
Germany	Max Planck, Albert Einstein, Max Born, Werner Heisenberg	quantisation; photons; matrix mechanics
Netherlands	Hendrik Lorentz, Paul Ehrenfest	chaired the conferences; Ehrenfest, Austrian-born, professor at Leiden from 1912
United Kingdom	Ernest Rutherford, Paul Dirac	Rutherford, New Zealand-born, at Manchester and Cambridge
France	Marie Curie, Louis de Broglie	Curie, Polish-born, working in France since 1891
Denmark	Niels Bohr	the “complementarity” interpretation
Austria	Erwin Schrödinger, Wolfgang Pauli	wave mechanics; the exclusion principle
Italy	Enrico Fermi	joined the roster somewhat later

5.2 • THE DEBATE THAT DEFINED 1927

Bohr and Einstein, arguing about the dice

The Fifth Conference staged an open confrontation, mainly between Bohr and Einstein, over how to interpret the still-new quantum mechanics: whether its probabilities reflect a genuine indeterminacy in nature itself, as Bohr's “complementarity” held, or merely the theory's present incompleteness, as Einstein insisted.

“God does not play dice.”

— Albert Einstein, crystallising his objection to Bohr's interpretation.

“[The conference] contributed extraordinarily to the clarification of the physical foundations of the quantum theory.”

— Werner Heisenberg, on the Fifth Solvay Conference, soon afterward.

Neither man ever fully persuaded the other — the argument, unresolved at Solvay, continued for decades by letter (§5.3).

5.2 · HOW ELITE, HOW NATIONAL, REALLY?

The “one country, one voice” picture needs two qualifications

How small

Perhaps thirty people at any one Solvay meeting, out of a European population approaching 400 million — an elite, rarefied conversation, not evidence of broad-based unity. Most Europeans had no contact with it at all, while the continent as a whole was simultaneously rearming for, then fighting, two catastrophic wars.

How national

The “national” framing understates real mobility: Curie was Polish and French; Ehrenfest, Austrian and Dutch; Einstein moved between German, Swiss, and (from 1933) American affiliations; Pauli held posts in Germany, Denmark, Switzerland, and the US in turn.

If this conversation prefigured a “Europe of science,” its basic unit was the individual researcher — often stateless or multiply national by circumstance — not the nation-state sending its champion abroad.

5.3
CHAPTER 5 · A EUROPEAN SCIENCE & QUANTUM MECHANICS

The Connective Tissue: Correspondence Across Borders

Between conferences, the same community did its most consequential work by letter.

5.3 · LETTERS THAT DID THE WORK OF A CONFERENCE

Two exchanges, two decades

- 1 **Schrödinger, Zurich, winter 1925–26** develops wave mechanics after reading Einstein's paper on Louis de Broglie's 1924 doctoral thesis (proposing, in Paris, that matter should show wave-like behaviour). Einstein and Schrödinger corresponded directly as the equation took shape, Einstein's early encouragement helping persuade Schrödinger the approach was worth completing.
- 2 **Born and Einstein, 1916–1955** sustained a correspondence, collected in 1971 as *The Born-Einstein Letters*. Born had shown, in 1926, that quantum probabilities govern the outcome of any individual measurement — the two argued, as friends who never stopped disagreeing, over exactly the question Solvay staged in public: whether that reflects a genuine feature of nature, or only the limits of what we can know of it.

The same question the 1927 conference staged in public, argued in private, by post, for four decades.

5.3 • THREE FACES OF THE NETWORK

Three results this correspondence carried across borders



Max Planck

1858–1947

Berlin — the reluctant 1900 quantum.



Niels Bohr

1885–1962, shown 1927

Copenhagen — the “complementarity” interpretation.



Werner Heisenberg

1901–1976

Göttingen — matrix mechanics, 1925.

5.3 · TWO LETTERS FROM THE MARGINS OF THE NETWORK

How far the correspondence reached

- 1 **Satyendra Nath Bose, Dhaka, 1924** with no access to the European journals that had rejected an earlier paper of his, sent Einstein a manuscript re-deriving Planck's radiation law by a new way of counting light quanta. Einstein translated it himself, arranged its publication, then extended the method to matter — the origin of Bose-Einstein statistics.
- 2 **Wolfgang Pauli, December 1930** unable to attend a conference of nuclear physicists in Tübingen, wrote proposing a new, electrically neutral, probably undetectable particle to rescue the conservation of energy in radioactive beta decay — later named the neutrino.



Wolfgang Pauli (1900–1958).

“Dear Radioactive Ladies and Gentlemen...”

— opening of Pauli's letter, read aloud in Tübingen in his absence.

5.3 · PAUL DIRAC, WORKING MOSTLY ALONE

Cambridge, 1926–1928



Paul Dirac, 1933 — the year of his Nobel Prize.

1

Unified rival formulations his 1926 thesis — the first doctoral thesis anywhere on quantum mechanics — reconciled Heisenberg's matrix mechanics and Schrödinger's wave mechanics within a single, more general formalism of his own.

2

The 1928 equation combined quantum theory with special relativity for the electron. It unexpectedly admitted negative-energy solutions Dirac took to predict a real particle — identical in mass, opposite in charge.

3

Confirmed, 1932 Carl Anderson detected exactly such a particle — the positron — in cosmic-ray tracks. Dirac shared the 1933 Nobel Prize in Physics with Erwin Schrödinger.

4

The quietest man at any conference colleagues at Cambridge and at Solvay informally defined the “dirac” as a rate of one word per hour — the largest conversational output his acquaintances thought plausible.

5.4
CHAPTER 5 · A EUROPEAN SCIENCE & QUANTUM MECHANICS

Rupture: Two World Wars Against the Grain of a Scientific Europe

The conversation was violently interrupted twice — and how it broke is as instructive as the conversation itself.

5.4 · WORLD WAR I: A BREACH THAT LASTED A DECADE

From manifesto to boycott to reconciliation



The Solway Conferences, privately funded and Belgian rather than intergovernmental, were not bound by the Council's rule — but were not immune to its climate either.

5.4 · WORLD WAR II: THE RUPTURE RAN THROUGH THE COMMUNITY ITSELF

1933 onward

- **1933 Law for the Restoration of the Professional Civil Service** expelled Jewish and politically suspect academics from German universities and research institutes.
- **“Deutsche Physik”** a parallel movement denounced relativity and quantum mechanics as symptoms of a supposedly alien “Jewish physics.”
- **Who left** Einstein (already abroad, did not return); Max Born (Britain); James Franck; Erwin Schrödinger (left in protest, though not himself Jewish); and, in 1938, Lise Meitner (see below).
- **Academic Assistance Council, 1933** founded by the economist William Beveridge with Ernest Rutherford's backing, it mobilised the pre-war scientific network to find British posts for hundreds of displaced scholars — it still operates today as the Council for At-Risk Academics.
- **Bohr's Copenhagen institute** served as a way station for refugee physicists, until Bohr himself had to flee — first to Sweden, then to Britain and the United States — in 1943.

5.4 • BY 1945: SCATTERED ACROSS THREE CONTINENTS

Not continued cooperation

The network's wartime fate was not, in the end, one of continued cooperation: many of the same physicists who had debated together at Solvay for two decades spent the war years on opposite, mutually secret sides.

The Allied side

The atomic bomb project centred at Los Alamos, in which Niels Bohr, among many European émigrés, took part.

The German side

A much smaller nuclear research effort, in which Werner Heisenberg played the leading role.

By 1945, the prewar continental conversation was scattered across three continents, several of its members were dead, and Europe's physics laboratories, like so much else on the continent, lay in ruins.

5.4 • LISE MEITNER: A CAREER BUILT AGAINST THE CURRENT

Vienna, Berlin, Sweden



Lise Meitner (1878–1968).

- **Vienna, 1906** earned her doctorate in physics — only the second woman to do so.
- **Berlin, 1907** began a 30-year partnership with the chemist Otto Hahn: co-discovery of protactinium (1917–18); description of the Auger effect (1922, independently of and slightly before Pierre Auger).
- **Barred, then first** for a period required to use a separate entrance, Prussian rules then barring women from the main laboratory; became, in 1926, the first woman to hold a full physics professorship in Germany.
- **1938: a flight across a border** the Anschluss made her, overnight, a German Jew in Nazi law. The Dutch physicist Dirk Coster smuggled her into the Netherlands, then Sweden — with only summer clothing, ten marks, and a diamond ring from Hahn.
- **Fission, worked out by post** from Sweden, with her nephew Otto Frisch, she used Bohr's liquid-drop model to explain Hahn and Strassmann's puzzling Berlin finding (uranium plus neutrons yields barium): the nucleus splits, releasing energy consistent with $E=mc^2$. Frisch coined “fission”; published in *Nature*, February 1939.

5.4 • THE NOBEL PRIZE THAT DID NOT FOLLOW

Recognition that failed to keep pace

1945: Otto Hahn alone received the 1944 Nobel Prize in Chemistry, “for his discovery of the fission of heavy nuclei.” Meitner, despite forty-nine nominations across her career, never received one.

“...because the structure of the Nobel committees was ill-suited to assess interdisciplinary work; because the members of the chemistry committee were unable or unwilling to judge her contribution fairly; and because during the war the Swedish scientists relied on their own limited expertise.”

— Ruth Lewin Sime et al., *Physics Today*, 1997.

“An unjust award.”

— Max Perutz, chemist and Nobel laureate, reviewing the same evidence.

“I believe that Frisch and I contributed something not insignificant to the clarification of the process of uranium fission.”

— Lise Meitner, on her own contribution.

Meitner herself declined any part in the Allied atomic bomb project her own theoretical work had helped make conceivable: she would, she said flatly, “have nothing to do with a bomb.”

5.5
CHAPTER 5 · A EUROPEAN SCIENCE & QUANTUM MECHANICS

Reconstruction: Shared Laboratories for a Shared Continent

Out of the wreckage, Europe's physicists rebuilt — this time by treaty, not just by letter.

5.5 · CERN: A LABORATORY NO SINGLE COUNTRY COULD AFFORD

1949–1954



The CERN site, straddling the Franco-Swiss border near Geneva.

- **De Broglie proposes, Lausanne, Dec 1949** the first public proposal for a joint European physics laboratory, at the European Cultural Conference.
- **Rabi carries it to UNESCO** the American physicist Isidor Rabi secured a UNESCO resolution at Florence, June 1950, backing regional research laboratories of this kind.
- **1952–1954** a provisional council (acronym CERN) in 1952; founding convention signed in Paris, 1953; formal existence on 29 September 1954.
- **Twelve founding states** Belgium, Denmark, France, West Germany, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, Yugoslavia.

5.5 · SAME LOGIC, SAME MOMENT — NOT THE SAME INSTITUTION

CERN and the founding of political Europe

CERN, 1954

West Germany a founding member, only nine years after the war's end, alongside France, Britain, and its other recent wartime adversaries — not an afterthought, but the explicit point: binding recent enemies into one shared, cooperative scientific undertaking.

Political Europe, 1950–51

The Schuman Declaration (1950) and the Treaty of Paris (1951), establishing the European Coal and Steel Community — the institutional seed of today's EU — pursued, at almost the same moment, an overlapping set of countries.

CERN did not cause the European Union

CERN is an intergovernmental scientific organisation, entirely distinct in law from the European Communities and later the EU; its membership has never mapped onto EU membership (Switzerland, a founding member, has never joined the EU; the UK's 2020 departure from the EU left its CERN membership unaffected; Norway and Israel are CERN members without being EU members). The defensible claim: CERN and the Coal and Steel Community were parallel, near-simultaneous responses to the identical postwar diagnosis — that binding recent enemies into shared technical institutions was how a continent that had just fought two catastrophic wars in one generation might make a third one harder to contemplate. The two projects reinforced, rather than caused, one another.

5.5 • THE TEMPLATE SPREADS: FROM TELESCOPES TO FUSION

ESO, ESA, Euratom, and JET

- **European Southern Observatory, 1962** founded by Belgium, France, West Germany, the Netherlands, and Sweden, giving European astronomers access to major southern-hemisphere telescopes — its convention explicitly modelled on CERN's.
- **European Space Agency, 1975** formed from the merger of two earlier, less successful bodies (the European Space Research Organisation and the European Launcher Development Organisation).
- **Euratom, Treaty of Rome, 25 March 1957** signed the very same day, in the very same ceremony, as the treaty founding the European Economic Community — here, uniquely, scientific and political Europe are literally the same treaty.
- **JET, approved 1978** built at Culham, Oxfordshire; first plasma June 1983; operated for four decades as the world's largest fusion experiment.



Interior of the JET tokamak vessel, Culham, United Kingdom.

JET's technical legacy fed directly into ITER, at Cadarache — Euratom's founding partnership widening into a genuinely planetary collaboration (below).

5.5 • WHAT DID IT ACTUALLY COST?

JET, the LHC, and ITER, side by side

Facility	Approved / operating	Approximate cost
JET (Culham, UK)	1978 / 1983–2024	≈ 200 million European Units of Account at the time (roughly \$440 million in 2014 dollars) — a single Euratom budget line.
LHC (CERN, Geneva)	1994 / 2008–	≈ \$4.75 billion for the accelerator alone; commonly cited near \$9 billion (≈ €7.5 billion) once detectors and first experiments are included; ≈ \$1 billion/year in running costs, separately.
ITER (Cadarache, France)	2006 / under construction	≈ €5.9 billion at the 2001 baseline; roughly €20 billion by 2016 estimates; a further ≥ €5 billion added, and first full-power operation pushed to 2039, at the Nov. 2024 rebaseline.

Headline costs are harder to compare, and harder to pin down, than the round numbers usually quoted suggest — each was financed differently, and first-of-a-kind scientific infrastructure routinely costs more than its original estimate.

Three very different accounting problems

Historiographical note

None of these three figures is a single, precise, audited total. JET's is the most tractable, a single, nationally hosted facility on one funding line. The LHC's depends entirely on where the boundary is drawn — the accelerator ring alone, the four detector experiments built and owned by separate international collaborations, or CERN's ordinary running costs — and different reputable sources reasonably draw that boundary differently. ITER's is harder still: the project is financed overwhelmingly through in-kind contributions — each of the seven partners builds an agreed share of components at home and ships them to Cadarache, rather than transferring cash into one common budget, a structure chosen precisely to let governments with no shared currency or single budget authority co-finance one reactor — a structure that has led ITER's own leadership to decline, in statements as recent as 2024, to state a single consolidated cost.

What is not in doubt is the direction of travel: all three projects, ITER most dramatically, have cost substantially more than their original approved estimate — a pattern common to first-of-a-kind scientific infrastructure everywhere, in the United States and Japan as much as in Europe, not a peculiarity of these particular projects.

5.5 · GRENOBLE I: THE INSTITUT LAUE-LANGEVIN

A neutron source neither country judged worth building alone



Inside the reactor hall of the Institut Laue-Langevin, Grenoble: the reactor core (rear) and the surrounding instrument floor, lined with the beamlines, shielding, and detectors used for neutron-scattering experiments.

- **Founded 1967** by France and West Germany, with the United Kingdom joining as a full partner a few years later.
- **Neutrons, not X-rays** far more sensitive than X-rays to light elements such as hydrogen, and to magnetic structure — a genuine complement, not a substitute.
- **Today** thirteen collaborating nations; ~1,800 visiting researchers a year; ~1,400 experiments on roughly forty instruments — the world's leading neutron-science facility, on its own and outside assessment alike.

5.5 · GRENOBLE II: THE ESRF AND THE EPN CAMPUS

A generation later, the same logic for synchrotron X-rays

The European Synchrotron Radiation Facility (ESRF), Grenoble, followed an identical logic to the ILL — a generation later, and for synchrotron X-rays rather than neutrons.

First proposed, 1975

its founding convention signed by eleven European governments in 1988.

First beam 1992, full operation 1994

fifteen X-ray beamlines at the outset.

Upgraded 2015–2022

≈ €150 million, into the world's first “fourth-generation” high-energy synchrotron light source; twenty-one European states now participate.

The EPN campus

ESRF, ILL, and a Grenoble outstation of the EMBL, deliberately co-located — turning separate national programmes into one shared European instrument.

Deliberately co-located with ILL, ESRF makes — in miniature, and in a different corner of physics — the same argument this chapter has already made about CERN.

The twenty-first-century instalments

European XFEL

Schenefeld, near Hamburg

Built 2009–2017; full user operation since 2019. $\approx$ €1.22 billion at 2005 prices; twelve partner countries, including Russia — a reminder that this scientific tissue does not map neatly onto today's EU boundaries. Its X-ray laser pulses are billions of times brighter than a conventional synchrotron's, and briefer than 100 femtoseconds — finer and faster windows onto matter than ESRF's.

European Spallation Source

Lund, Sweden

A thirteen-nation consortium, formally constituted in 2015. Construction and initial operation estimated at $\approx$ €3.13 billion (2013 prices) through 2027. As this course is written, in 2026, ESS is still advancing toward its first neutrons rather than yet open to users — the newest instalment of the same six-decade-old argument: some instruments are worth building only once, and only together.

CHAPTER SYNTHESIS

Two interleaved chronologies, 1911–2006

Schematic, not strictly to scale — evenly spaced in order, not by year.

SCIENCE



POLITICS



The Maastricht Treaty founding the European Union itself followed only in 1993 — after every scientific institution this chapter describes had already been built.

LOOKING AHEAD

One community, followed from conversation to reconstruction

This chapter followed a single scientific community — physicists studying matter, radiation, and the quantum — from an already-international conversation at the century's start, through two wars that scattered and, for a time, weaponised it against itself, to the deliberate, treaty-based reconstruction of shared European laboratories whose founding logic ran alongside, and at one point literally coincided with, the founding of political Europe.

A fuller course would ask:

how that same postwar logic of pooled infrastructure extended far beyond physics — into molecular biology, computing, and space science — and how the European Union itself, once founded, gradually took on a direct funding role, through its own framework programmes for research, that the founders of CERN, working before any such Union existed, could not yet have relied upon.

FURTHER READING

- Helge Kragh, *Quantum Generations: A History of Physics in the Twentieth Century* (1999)
- John Krige, *American Hegemony and the Postwar Reconstruction of Science in Europe* (2006)
- Armin Hermann et al., *History of CERN*, 3 vols. (1987–1996)
- Max Born (ed.), *The Born-Einstein Letters*, trans. Irene Born (1971)
- Ruth Lewin Sime, *Lise Meitner: A Life in Physics* (1996)
- Graham Farmelo, *The Strangest Man: The Hidden Life of Paul Dirac* (2009)
- Brigitte Schroeder-Gudehus, on the postwar boycott of German science
- Gustav Guthleben (ed.), *Neutrons for Society: The History of the Institut Laue-Langevin* (2016)

Chapter 5

Questions?

From Byblos's alphabet to CERN's accelerators, the same pattern recurs: knowledge travels, breaks, and rebuilds, across borders that mattered less to the people making it than to almost anyone else in their moment. That pattern closes this course's arc.