Chapter 2

Meanings of scientific unity

The law, the orchestra, the pyramid, the quilt and the ring

Peter Galison

Contrary to its almost constant invocation in the Sunday sermonising of science and philosophy of science, unity is not an invariable part of science.[1] There is no single strand of unity talk, no 'unity idea' passed down across the ages from Thales to the modern syntheses of biology or physics. Instead, the unity of science – as a regulative part of scientific theorising – is a relatively modern phenomenon, one that came to widespread celebration to a very large extent in Germany around the middle of the nineteenth century. This modern unification enthusiasm drew its strength from the idealist philosophers, but gained real force as a scientific, metaphysical and political programme around the German 'Professors' Revolution' of 1848. Since that time, to be sure, unity has come to mean different things at different times at different places – there is a *dis*-unity to the genealogy of unity. But in writing a history of our scientific present, our starting point lies more in Bismarck's Berlin than in Anaximander's Athens.

On the occasion of the fascinating collection of essays assembled by the editors of this volume, it is perhaps worth stepping back to sketch out the larger contours of these diverse unities. Such an overview might help situate some of the specific movements for the unity of science; more proximately it might shed some light on our current situation, in which science seems to many scientists to be more quilt than pyramid. And it may be that the image of a ring will prove of more use than either. But this is truly a sketch, a view more from 30,000 feet than through the jeweller's loupe of case studies.

The law

The liberal nationalist German scientists of the nineteenth century cut a large swath through organised knowledge, not least those young medical scientists

1 Portions of this chapter are drawn from Peter Galison, 'Introduction: The context of disunity', in Peter Galison and David J. Stump (eds), *The Disunity of Science: Boundaries, Contexts, and Power* (Stanford, 1992), 1–33; idem, 'Constructing Modernism: The Cultural Location of *Aufbau*', in Ronald N. Giere and Alan W. Richardson (eds), *Origins of Logical Empiricism* (Minneapolis, 1996), 17–44; and idem, 'The Americanization of unity', *Daedalus* 127 (1998), 45–71.

who, around the attempted revolutions of 1848, strove simultaneously for a new physiology unified with physics and for a unified German nation. Among the key figures were Emil Du Bois-Reymond, Hermann Helmholtz and Ernst Brücke, who – in close association with Karl Ludwig in Marburg – were instrumental in forming the 'school of 1847', which sought to ground physiology in Newtonian physics. The three had much in common: Prussian-born and middle-class, similar in age, they came through the University of Berlin together and had all studied under Johannes Müller, the Professor of anatomy and physiology.

At the time of the 1848 uprisings, fought under the banner of 'Unity and Freedom', these physiologists were politically active liberals supporting the calls for a unified German nation and a constitutional assembly. When even the moderate reforms gained in 1848 were reversed already in 1849 and Prussian hegemony was consolidated, they mostly turned away from overt politics and focussed on building their scientific careers. They did maintain their ideal of a unified nation as espoused by the liberal nationalists, who aimed for a constitutional monarchy through moderate political reform of existing bureaucracies. The unification eventually achieved under Bismarck, in the form of a nation ruled centrally from Berlin, suited their purposes as members of the professional middle-class establishment.

Emil Du Bois-Reymond was born of a French-Swiss immigrant father and the daughter of a minister serving the French colony in Berlin. He studied philosophy, theology, psychology, logic, metaphysics, anthropology, botany, geography and meteorology; to boot he was a student of Müller. After Müller's death in 1858, his Chair was split into two and Du Bois-Reymond was elected to the Chair of Physiology. Among Du Bois's allies was Karl Ludwig, the foremost practitioner of physiology in Germany, training a generation of the leading figures in the field at his institute in Leipzig. Hermann Helmholtz, too, counted among Du Bois's friends and he, too, famously ranged widely and broadly – from fundamental studies on thermodynamics, including his crucial work on the conservation of energy, to the physiology of the senses. He invented the ophthalmoscope, contributed importantly to electrodynamics, reconsidered the foundations of geometry and grappled seriously with the philosophical meaning of science. The empirically oriented physiologist, Ernst Brücke, who was driven by politics to Zürich after 1848, led a generation to the study of physical physiology.[2] Rudolf Virchow, who went on to create 'cellular

[2] The literature on the relevant parts of late nineteenth-century German science is vast. The following works contain extensive bibliographies and I refer the reader to them: David Cahan, *Hermann von Helmholtz* (Berkeley, 1993); Klaus Christian Koehnke, *The Rise of Neo-Kantianism*, trans. R.J. Hollingdale (Cambridge, 1991); Timothy Lenoir, *The Strategy of Life* (Chicago, 1989); idem, *Instituting Science: The Cultural Production of Scientific Disciplines* (Stanford, 1997); Kathryn M. Olesko, *Physics as a Calling* (Ithaca, 1988). Particularly relevant are also: Sven Dierig, *Wissenschaft in der Maschinenstadt: Emil Du Bois-Reymond und seine Laboratorien in Berlin* (Chicago, 2008); Laura Otis, *Müller's*

pathology' and strove to unite medicine and society through scientific endeavour, was also associated with them and sympathetic on many broader issues. Politically more radical than the 1847 group, Virchow was forced to resign his post and leave Berlin after 1848. He joined the democratic *Volkspartei* which, unlike the liberals, aimed for the overthrow of existing political structures and for the establishment of a German republic.

Du Bois-Reymond was to become in many ways the epitome of the German academic establishment, and he worked hard, over a lifetime, to join up the historical, political and moral functions of science. At the University of Berlin he was rector in 1869–70 and in 1882–83. He was a member of the Prussian Academy of Sciences and became one of its permanent secretaries in 1876; in this capacity he had a great deal of political influence. As his career flourished, Du Bois increasingly promoted the development of pure science for the sake of a greater German culture. He also articulated the fundamental questions that science could and could not expect to solve. His famous 1872 *Ignorabimus* speech, insisting that some questions are unknowable, was hailed and derided on presentation and remembered for its slogan 'we cannot know', proclaiming the limits of science.[3] Some took Du Bois's placement of science to put up defensible borders within which science could be practised freely; others argued, on the contrary, that such limits left space to religious knowledge.

Du Bois's 1872 speech took the aim of all knowledge to be its grounding in the 'mechanics of atoms' – it was a belief that he and his circle held deeply. Newtonian *law* lay at the foundation of all science. According to Du Bois, what was needed was the explanation of sensory impressions in terms of central forces alone. And this would require a dramatic reform of medicine, pathology and physiology, unifying the whole under the banner of the physical sciences. Du Bois asked: what is the ultimate nature of matter? We cannot know. That is the lower limit of science. What is consciousness? We cannot know that either – that is the upper limit of science. Science, therefore, existed as a

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Lab (Oxford, 2001); David Cahan, *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science* (Berkeley, 1993); Richard Kremer, *The Thermodynamics of Life and Experimental Physiology, 1770–1880* (New York, 1990); and Henning Schmidgen, *Die Helmholtz-Kurven. Auf der Spur der verlorenen Zeit* (Berlin, 2010). On contemporary projects to collectively unify knowledge, see Peter Galison and Lorraine Daston, 'Scientific Coordination as Ethos and Epistemology', in Helmar Schramm, Ludger Schwarte and Jan Lazardzig (eds), *Instruments in Art and Science. On the Architectonics of Cultural Boundaries in the 17th Century* (Berlin, 2008), 296–333; and Peter Galison, *Einstein's Clocks, Poincaré's Maps* (London, 2003).

3 What I say about this draws much from the remarkable but unfortunately still unpublished work of Keith Anderton, 'The Limits of Science: A Social, Political, and Moral Agenda for Epistemology in Nineteenth-Century Germany' (PhD diss., Harvard University, 1993).

unified, safe region between these two seas of the unknowable. Such a safe middle landscape was central to liberalism as it was understood by the stalwarts of 1848. These bourgeois revolutionaries aimed for freedom of conscience, expression and questioning; a freeing up of the economy, industry and education. They sought a system of belief and of knowledge building that was, by its very nature, pitted against feudalism, absolutism and religious orthodoxy. German liberals wanted a unified *Rechtstaat* in politics, a constitution of fixed laws and they wanted a fixed grounding of laws for science. Among the German nationalist liberals, unity oscillated easily and often from politics to scientific culture to philosophy.

As a vehicle for their unity aspirations, the liberal nationalists saw none better than the *Gesellschaft Deutscher Naturforscher und Ärzte* (Convention of German Scientists and Doctors). It was a perfect symbol of scientific and political drawing together, shifting, like a movable feast, among the German states. For years after 1848, the language of science and cultural unity self-consciously replaced that of political unity in public, at least until the 1860s.

The rule of law in science stood for constitutionalism for the nation – and the liberals understood their science to signify a particularly German-inflected form of free society. They argued that science instantiated freedom, but freedom under law, not the lawless, 'mechanical' (as opposed to the German 'organic') form of French freedom with its echoes of revolutionary anarchy. Benjamin Theodor Thierfelder opened the Convention of German Scientists and Doctors in Rostock in 1872 with the rallying cry: 'The victory of German weapons is a victory of the German spirit'.[4] According to Anderton, it was widely held among the liberal scientists that the Convention had been of key importance in keeping the ideal of unity alive in German hearts for decades. Helmholtz, ending the Innsbruck Convention of 1869 on the verge of German unification, took the aim of science to be the demonstration that all of nature would be unified around the basic laws of mechanics. Politics was not far away: the 'cardinal virtues of German science' could provide 'a means of deepening the sense of unity throughout our country'. In the same year, Du Bois concluded, 'The German unity which is finally nearing completion was first conceived in the German universities'.[5] Just after the rise of the German nation, Virchow looked back in a Convention address entitled 'On the Tasks of the Natural Sciences in the New National Life of Germany', where he contended that 'the

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4 Anderton, 'Limits of Science' (n. 3), 201, who draws it from Heinrich Schipperges, *Weltbild und Wissenschaft: Eroeffnungsreden zu den Naturforscherversammlungen 1822–1972*, Schriftenreihe zur Geschichte der Versammlungen deutscher Naturforscher und Aerzte, vol. 3 (Hildesheim, 1976), 46–7.

5 Anderton, 'Limits of Science' (n. 3), 203–4. Quoted from H. von Helmholtz, 'Aim and Progress', in *Popular Lectures on Scientific Subjects*, trans. E. Atkinson (New York, 1873), 397, and from E. Du Bois-Reymond, 'Ueber Universitaetseinrichtungen', in *Reden*, vol. 1 (Leipzig, 1912), 368.

present glory of the German nation would have been impossible if, in loyal, untiring work, the German universities had not been at their posts, if within the circle of the universities the national idea had not been fostered again and again, until it went out to all the world'.[6]

It should be noted that physicists – even when they believed that Newton's laws would serve as the unifying basis for all science – had in mind different pictures of what mechanics was. Some chose to emphasise energy over forces (as did Helmholtz himself) and others fastened on most to the least action principle (as did late Helmholtz and Max Planck). But the most remarkable shift took place with the spectacular reversal articulated by Wilhelm Wien in 1900. Wien began arguing at that moment that the unification of all things scientific was to be predicated not in terms of mechanics, but even mechanics itself was to be accounted for in terms of the underlying theory of electricity and magnetism. But these unification strategies cannot be read in isolation from the changing world around them. In the unification of science, the construction of the vast unified mechanical *Weltanschauungen* paints a picture in which all is gears, pulleys, heat, engines – an imprinted vision of the mechanical, productive force of mid-nineteenth-century Germany and Britain. It was then displaced in 1900 by the electrodynamic world picture: a world in which all was electrons and their fields. Here we ought to see not the gears and steam engines of Victorian England, but Prussian dynamo halls and power transmission lines. We should see lamps torn from the walls so electric lights could take their place; carriage roads ripped up end to end to make way for electric trams. This was the street scene correlate of the electromagnetic world picture.[7]

But whether unified science was based in energy, in least action or in central forces, whether it began with charged electrons or inert mass, the great aspiration of the late nineteenth century, in the view from Berlin, was for a science that was unified under the law. The Prussians' goal was to understand the nature of that law, grappling with what we could know a priori and inserting what we could not know in advance by scrupulous experimental inquiry into everything from the outside world to our innermost senses. It was a task that all at once was of central importance to philosophy, to science and to the politics of a law-bound freedom for a united Germany.

The orchestra

Our overflight continues. In a second period, roughly from 1918 to 1939, the most widespread talk of unity of science came from another quarter altogether.

6 Cited in Anderton, 'Limits of Science' (n. 3), 205. Quoted from R. Virchow, 'Aufgaben der Naturwissenschaft', in Karl Sudhoff (ed.), *Rudof Virchow und die Deutschen Naturforscherversammlungen* (Leipzig, 1922), 108–9.

7 See Dierig, *Wissenschaft*, (n. 2).

Based in Vienna, not Berlin, unity stood for something quite different from the drawing together of previously separated German states, the elimination of tariffs or the establishment of a nation. Instead, unity of science resonated with a kind of high modernist construction, a resolutely *international* form of political ideal, one predicated on a shared language of scientific reasoning. Scientists hailed their own unification across domains as the very instantiation of rationality: beyond nation, race, or partisan political squabbling. In the hands of the largely (but not exclusively) socialist-leaning philosophers of science and their scientist allies, unification of science formed a bulwark against fascism, nationalism, clericalism and mysticism.

Undoubtedly the new and restless science-inflected philosophy was important for early twentieth-century unity talk. But intellectual – even political – rebellion was dwarfed by the awfulness of the First World War. The mechanised destruction of millions of lives put talk of rationality, science and unity under an intense spotlight. One of the responses to slaughter by machine-gun and gas was a drive to create a new society, or, more specifically, to harness the mechano-rational to a new, more rational, more scientific way of living. One indicator of this self-consciously modernist desire was a burst of post-war German-language journals with '*Aufbau*' in the title. The word is of course familiar from construction sites on every street corner of the German-speaking world. (In the late twentieth century there was even a shampoo called 'Aufbau' to convey its building-up power for lacklustre hair.) But back in the years following the European war, *Aufbau* stood neither for everyday construction nor for the frivolity of cosmetics.

Aufbau conjured up a building up anew. Not *re*-construction, but making anew. Here was a conjoint effort in knowledge, in city planning and in economy. Among the dozens of journals and tracts bearing that name, one (*Der Aufbau: Flugblätter an Jugend*) began in 1921: 'What is *Aufbau*? Is *Aufbau* "changing the world"? Evidently not! For what changes the world more than revolution? And yet we say: a revolution creates only the conditions for an *Aufbau*. Change is attached to the given, to the substantial; it is a redirection, a shifting of forces; it is the technical'.[8] Another (*Umsturz und Aufbau*) stated in 1919:

> We have lived through the most unheard of catastrophe that a people has ever encountered. In need and death, in blood and tears there has been only one asset . . . the spirit. To make the spirit fruitful for the renewal of our people is the goal of our series *Umsturz und Aufbau*. . . . We want to remove the rubble of the European killing fields and with heart and head to prepare for the erection of a new humanity.[9]

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[8] H. Schüller, 'Revolution-Aufbau', *Der Aufbau; Flugblätter an Jugend* 1 (1921), 2–7: 5.

[9] *Umsturz und Aufbau* 3 (1919; reprinted in 1974), 22–3.

Yet a third (*Der Aufbau*) – this one co-edited by some of the leading architects and city planners of Red Vienna alongside the polymath sociologist Otto Neurath – insisted in 1926: 'We want to work together on the cultural, social and economic *Aufbau* of society, which is striving from the present unclarity, disorder and chaotic confusion toward clarity and order'.[10] Neurath moved easily back and forth between politics, aesthetics and philosophy of science. At the root of all three, he was sure, lay a rational, rationalised life, engineering efficiency and the coordination of the different special sciences. Neurath likened scientific unification not so much to obedient subjects of a divine (or Newtonian) law, but rather to the harmonious combined playing of the various instruments of an orchestra.[11]

Neurath was one of the founders of what became known as the Vienna Circle – which to many philosophers stands at the beginning of the whole of modern philosophy of science. Along with physicists-turned-philosophers Philipp Frank and Rudolf Carnap, and led by the charismatic Moritz Schlick (the only card-carrying philosopher among them), this small group and a handful of others struggled to strip speech to its logical and empirical foundations and to build knowledge anew from clear, well-founded first principles. This building-up would have a rigorous structural integrity that could be shared beyond the particulars of one person or another – an *Aufbau*.

In the early Vienna Circle meetings, much like Berlin in the 1840s, boosters of unity of science often held back from talking explicitly about governments. Peter Hempel, a participant in some of the logical positivists' assemblies, once told me that there was a rather explicit agreement to 'leave politics at the door'. But if politics stood outside, its terrifying presence hovered like a spectre over the table, only occasionally calling to the assembled.

Neurath, with Carnap and Charles Morris, edited the *Encyclopedia of Unified Science*, where the eminent American philosopher John Dewey contributed a rousing defence of the unity of method, a 'scientific attitude' *(wissenschaftliche Weltauffassung* to the Vienna Circle) that brought disparate specialties together. But Dewey wanted more than scientific results alone: '[T]here is also a human, a cultural meaning of the unity of science'. Beyond the reformation of one's own individual stance towards the scientific method, one's 'efforts are

10 'Unser Wollen', *Der Aufbau. Österreichische Monatshefte für Siedlung und Städtebau* 1 (1926), 1.

11 Here and in the following discussion I draw on Peter Galison, 'Aufbau/Bauhaus: Logical Positivism and Architectural Modernism', *Critical Inquiry* 16 (1990), 709–52; and idem, 'Constructing Modernism' (n. 1). On Neurath and political unification, see Nancy Cartwright, Jordi Cat, Lola Fleck and Thomas E. Uebel, *Otto Neurath: Philosophy Between Science and Politics* (Cambridge, 1996). See also John Symons, Olga Pombo and Juan Manuel Torres (eds), *Otto Neurath and the Unity of Science* (Dordrecht, 2011).

hampered, often times defeated, by obstructions due not merely to ignorance but to active opposition to the scientific attitude on the part of those influenced by prejudice, dogma, class interest, external authority, nationalistic and racial sentiment and other powerful agencies'.[12] There were evils afoot, real evils that could be fought only through the adoption of a scientific attitude promulgated through education.

It was relatively easy to agree that unification was good. What unification *meant* was entirely less unanimous. For Rudolf Carnap, the engineering physicist-turned-philosopher, unity of science carried with it a sense rather different from that of Dewey. For Carnap, to demonstrate unity was to exhibit what he called the common 'reduction basis' of different branches of science, such as biology and physics. By this he never meant that biological laws could be replaced by physical laws. Carnap considered that an entirely open scientific question. Nor did Carnap consider the reduction project to be an ontological one in which the entities of biology, say, would turn out to be nothing but the entities of physics suitably arranged. Instead, he argued that *both* biological and physical laws could be expressed in terms of everyday physical terms and procedures. There was therefore, for Carnap, a reduction of *language* quite distinct from a reduction of *laws* or *ontology*. Linguistic reduction was central.

Despite their occasional clashes, Neurath's 'unification' was not so terribly far from Carnap's. Finding a linguistic unity involved the deployment of a common language of everyday terms, the adoption of a system of universally recognisable icons and most importantly an 'encyclopaedic' assemblage of scientific subjects without forcing them into a suprascientific philosophical 'system' such as Kantianism. For Victor Lenzen, the reduction was more explicitly nomological:

> In the face of apparent disunity, developments in contemporary physics inspire the hope that quantum mechanics and the theory of relativity may be united in a single theory. And because of the basic function of generalised physics and the ever increasing development and adaptation of the techniques of specialised physics, the progress of physics augurs well for the unity of all empirical science.[13]

Insofar as quantum electrodynamics represented the prototypical unification then, at least for Lenzen, unification meant precisely the creation of integrated laws.[14] As in science, so in society: coordination through language,

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[12] John Dewey, 'Unity of science as a social problem', in R. Carnap, O. Neurath and C.W. Morris (eds), *Encyclopedia of Unified Science*, vol. 1 (Chicago, 1955 [1938]), 29–38: 32–3.

[13] Victor Lenzen, 'Procedures of Empirical Science', in Carnap, Neurath and Morris, *Encyclopedia of Unified Science* (n. 12), 338.

[14] On the meaning of unification for Lenzen, Carnap and Neurath, see Galison, 'Introduction: The Context of Disunity' in Galison and Stump, *Disunity of Science* (n. 1).

method, laws – these were the ways of holding the whole together against disintegration.

But as with their predecessors Helmholtz, Virchow, Ludwig and Du Bois-Reymond, there was no way of entirely avoiding political power, classically conceived, when we turn to post–World War I Vienna, where unified science took the form so well known in philosophy of science. Surely no one lived the question of unity with the urgency of the sociologist-philosopher-cultural critic Otto Neurath. For Neurath's Austro-Marxism, it was planning, not nation building and ideology, that was important. He wanted a rationalised and coordinated distribution of goods, farming, production and currency. Soon after the foundation of the Bavarian Republic by the socialist leader Kurt Eisner in November 1918, Neurath came to Munich to urge his thoughts about central planning on Eisner and on the Munich Workers' and Soldiers' Council. After the violent suppression of the Bavarian Republic by the *Freikorps* in May 1919, Neurath was arrested, tried and sentenced, only to be rescued before he landed behind bars – his saviour was an old friend and ally, Otto Bauer, the Austrian Minister of Foreign Affairs. In this political history, as we know from Cartwright, Cat, Chang, Fleck and Uebel, we find an important wellspring for Neurath's outlook on unified knowledge. The virtues of centralisation and unification seemed as apposite in matters of state as in matters of science. But more subtly, Cat, Cartwright and Chang point out that Neurath's political sense of unification never involved a homogenisation or radical hierarchy. Quite the contrary, his vision in the Bavarian Socialist Republic was always of a *coordinated* economy, left substantially in private hands and synchronised rather than brutally assembled into a vertically integrated whole. In science, Neurath's vision of 'orchestration' similarly avoided the coercive implications of science structured from one 'master law' all the way down through the nitty-gritty of applications. Neurath never believed that science would amount to a small set of microphysical equations from which the laws of ecology, economics and psychology might be derived.[15] (Though, as I will point out in a moment, that *was* a goal for one strand of post–World War II nuclear and particle physics.)

I want to return to the fundamental point about this period leading up to the Second World War: unification was a form of cultural politics; both its supporters *and* its antagonists understood the link between scientific unification and international cooperation. So too in other domains of culture: there was a similar fierce attachment to systematicity, unification and removal of ambiguity among modernist architects. Hannes Meyer of the Bauhaus produced a League of Nations plan that would leave no back corridors for the diplomats' secret

15 Jordi Cat, Nancy Cartwright and Hasok Chang, 'Otto Neurath: Unification as the Way to Socialism', in J. Mittelstrass (ed.), *Einheit der Wissenschaften* (Berlin, 1991), 91–110; and Cartwright et al., *Otto Neurath* (n. 11).

deals that many believed had precipitated the Great War. Schlick, in 1928, persuaded Carnap to rename his magnum opus, dropping *Konstitutiontheorie* and taking on *Logische Aufbau der Welt* (logical construction of the world): an attempt to unify all knowledge into a vast structure embracing everything from auto-psychological experience to physics, chemistry and sociology. Carnap, as a good neo-Kantian, remained 'neutral' as to the proper starting point of this construction: his *Aufbau* (his construction) could start with an individual's experience; it could start with the collective. It was the systematic building up that mattered; the placing of all knowledge in a uniquely specified place, or absolute commitment to the launching point of knowledge, was far less significant.[16]

Keeping in mind the deep embedding of unity of science within culture and politics, listen to Carnap's own preface to his *Logische Aufbau der Welt*:

> We do not deceive ourselves about the fact that movements in metaphysical philosophy and religion which are critical of such [a scientific] orientation have again become very influential of late. Whence then our confidence that our call for clarity, for a science that is free from metaphysics, will be heard? It stems from the knowledge or, to put it somewhat more carefully, from the belief that these opposing powers belong to the past. We feel that there is an inner kinship between the attitude on which our philosophical work is founded and the intellectual attitude which presently manifests itself in entirely different walks of life; we feel this orientation in artistic movements, especially in architecture . . . of personal and collective life, of education and of external organisation in general. We feel all around us the same basic orientation, the same style of thinking and doing. Our work is carried on by the faith that this attitude will win the future.[17]

If cultural and political allies of the philosophers of science recognised this common form of life, so too was it a weapon-at-hand against the Nazi threat on every level: as a political organisation, as a model for rational decision making, as a unifying cultural apparatus across national boundaries.

Unity was at once political in its anti-fascist pronouncements and in the practices that made up everyday scientific life. This was certainly how the situation looked to the scientists and philosophers drawn to the *movement*: Unity of Science. Theirs was an international vision, a bulwark, its advocates hoped, for linking scientific fields, for forging a common scientific method, for coordinating international organisations and for building a shared scientific language. And perhaps most ambitiously of all, the interwar unifiers aimed to model a form of life around the persona of the rational, technically reasonable

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16 Michael Friedman, 'Carnap's *Aufbau* Reconsidered', *Noûs* 21 (1987), 521–45.

17 R. Carnap, *The Logical Structure of the World*, trans. R.A. George (Berkeley, 1967 [German edn, Berlin, 1928]), preface.

scientist – all against the powerful and rising enemy of racism, fascism, religious fanaticism, irrationalism and nationalism.

The pyramid and the quilt

Our final view down from our high-altitude flight is of the third period, the violent half century one might call the Long War (1939–89) in which unity of science took on a more imperial and centred quality. Nuclear science arose in strength with the discovery in the 1930s first of the neutron and then of nuclear fission. During and after the Second World War, Los Alamos accelerated this science with prestige, facilities and intellectual labour that only a centrepiece of a world war could provide. From humble, semi-empirical beginnings in radiochemistry, atomic physics and shoestring experiments, nuclear physics morphed again and again – into elementary particle physics with its international community of mobile physicists and city-spanning sites of accelerator laboratories.

During the Cold War particle physics accelerators became sites for symbolic East-West competition. Unity of science came to be a high-prestige search for the building blocks of all things and all sciences. This was by no means undisputed – and the struggle over the right way of understanding the relation of the special sciences to one another had much to say about how scientists saw the present ethos and the future structure of their discipline.

The experience of mass population displacements, mechanised mass death and redrawn political boundaries created the conditions under which *Aufbau*-style modernism took hold as the ideal of unity of science between the wars. To see how differently unity of science looked after the Second World War, recall the Vienna Circle's enemies. The Circle saw itself as fighting the forces of irrationality, forming alliances with modern architects, educators, city planners and at times Austro-Marxist politics.[18] Never politically powerful or even institutionally secure, as time went on their voices were increasingly drowned out by the array of nationalistic forces pitted against them. The drive to a 'Unity of Science Movement' was, for Neurath, Carnap, Philipp Frank and their many allies, part and parcel of a struggle to bring together a rationality and objectivity that would halt racial and nationalistic assaults from dominating the world. Their opponents were Austrian clericalism, entrenched traditional philosophy and later Nazism. Whether through an *Aufbau*, a physicalist thing language, protocol sentences or isotypic images, the Vienna Circle's goal was

18 Galison, 'Aufbau/Bauhaus' (n. 11); idem, 'Constructing modernism' (n. 1). The Vienna Circle's stance on metaphysics generated a fierce struggle between Carnap and the leading philosopher in interwar Germany, Martin Heidegger – see M. Friedman, 'Overcoming Metaphysics: Carnap and Heidegger', in R.N. Giere and A.W. Richardson, *Origins of Logical Empiricism* (Minneapolis, 1996), 45–79.

to extirpate irrational metaphysics out of the meaningful world. Metaphysics was not some supererogatory flourish, it was the motor behind the worst forms of mysticism and obscurantism that threatened civilisation.

Now I ask you to move your mental image from the unity of science movements in the 1930s to 1947, not in Vienna, but in post-war Cambridge, Massachusetts. Here, the scientific banner flying overhead the newly founded Institute for the Unity of Science is not that of relativity and quantum mechanics, though these might occasionally be invoked by Philipp Frank. Instead, the newly rehoisted scientific flag announced the riveting new, war-boosted interdisciplines: cybernetics, computation, neutronics, operations research, pshycoacoustics, game theory, biophysics, electro-acoustics. The old enemies of interwar Vienna were gone or vanquished: Austrian clericalism and the hollow vestiges of the Habsburg empire did not figure very large in Cambridge, and fascism had been slain – in the scientists' eyes at least – in no small measure because of their intervention. Now these same tools that had won the war promised the world. Cybernetics with its nonlinear feedback was celebrated as offering a way to rewrite the social sciences as well as the natural sciences. The computer's logic was thought to be universal and capable of doing everything from weather forecasting and nuclear weapons design to the resolution of long-standing problems in number theory, to modelling the human mind.[19]

The unification these scientists had in mind was a unification through localised sets of common concepts (a kind of patchwork quilt), not through a global metaphysical reductionism (with the pyramid as model). Were the mathematical and technical features of feedback, control, black boxes, flow diagrams, or extensive forms of a game 'reducible' to nuclear physics? Hardly. Even posing that question about the kinds of problems facing the Institute seems hopelessly inappropriate. With the kind of power these scientists felt they had at war's end, fretting about ontological reductionism must have seemed almost beside the point. As the chemist E. Bright Wilson wrote in 1950 to Gerald Holton, the Institute Secretary: 'The phase of the Institute's work in which I am particularly interested is that which deals with scientific method in its most practical and least philosophical senses'.[20] The Americanisation of unity just after the Second World War was not sited around an isotypic picture language, a physical language, an *Aufbau*, or an orchestration. It was planted around the new sciences of Los Alamos, the Massachusetts Institute of Technology's Radiation Laboratory (the 'Rad Lab'), the stored-program computer of the Institute of Advanced Study in Princeton; this was to be a science unified in

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[19] See also Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago, 1997).

[20] E. Bright Wilson, Jr to Gerald Holton, 6 October 1950, folder 3, Gerald Holton, Private Papers.

pieces, grounded in common widely applicable concepts, and promising a power beyond dreams.

One last contrast: when the Vienna Circle faced off against theology in their manifesto, they saw mystic obscurantism as a rising threat; however misunderstood or powerless they were, the Vienna Circle aimed to cast millennia of such speculation to the winds. When the Institute for the Unity of Science sent out its first flyers, they made 'Science and Faith' and 'Science and Values' early and long-standing objects of study. In one of the first meetings of the Institute for the Unity of Science, a prominent participant probably spoke for many when he said the public now saw scientists as authorities comparable to the high priests of ancient cults. But the truly staggering feature is not the prominent positive role accorded truth and values, it is that in these first months of the *Pax Americana* this group of scientists, humanists and philosophers could take on God and morality as problems – and fully expect to solve them. There was a brief interregnum after the Second World War before the Cold War began in earnest; this is the period in which the new Institute for the Unity of Science began.

The Cold War brought with it a vastly expanded nuclear community, and the foregrounding of that community, though too long a story to tell here, is coincident with the vision of science as unified through a pyramidical structure in what its own practitioners came to call a *fundamentalist* programme grounded in the great synthesis of quantum mechanics and relativity. This, unlike Neurath's programme, was knowledge built on a base, a base where status, metaphysical primacy and vast scientific resources came to bear.

As Jordi Cat has effectively argued in his fine study of late twentieth-century unification debates, Victor Weisskopf (who participated in nuclear physics and quantum electrodynamics, and directed the European particle physics centre, CERN) was a staunch defender of this pyramidical view. In 1966–67 he put the position in stark terms: 'fundamentalism' was simply the view that 'all sciences are at the end a branch of physics'. 'The fact that everything can be reduced to the Dirac equation is a very important statement. It is the great fact on which science lives and develops. There are certainly more interesting developments in all sciences, but they all use the foundations which are laid by the fundamentalists'.[21]

The raw ambition of statements like Weisskopf's opened a rift. One opponent was Chew, who – as David Kaiser has so beautifully shown – advocated a conjoint effort. On the one side he set the agenda of a long and productive theoretical programme of 'nuclear democracy' that aimed to capture the relations of particle physics without making any entity more fundamental than the others. On the other side he worked hard, through small-group meetings

[21] Jordi Cat, 'The Physicists' Debates on Unification in Physics at the End of the 20th Century', *Historical Studies in the Physical and Biological Sciences* 28 (1998), 253–99: 262.

and through his macropolitical positions, for a political order opposed to that of McCarthyesque authoritarianism.[22] So it was that even *within* particle physics there was a split that divided a pyramidical notion of unity from that of a more egalitarian 'nuclear democracy'.

But in the long run, it is not from inside particle physics that dissent about pyramid-style unification has been countered most strongly. For my money it is the condensed matter physicist Philip Anderson who best articulated a position against Weisskopfian fundamentalism. Given all that had been accomplished in physics through an understanding of collective phenomena involving many atoms and many electrons, Anderson simply found it an outrage that particle physics had so monopolised status, students and resources. This was not merely symbolic. Anderson was clear that with the attribution of symbolic centrality came quite material consequences: he believed that other domains, especially condensed matter, had suffered at the hands of the imperial grasp of the particle physicists.

Condensed matter physicists were not – in any case not directly – children of Los Alamos. They found their homes away from the massive government-funded laboratories like Brookhaven National Laboratory or Lawrence Berkeley Laboratory, Lawrence Livermore or the new Fermilab accelerator (that Anderson opposed) carved from Illinois farmland. Many, like Anderson, had worked during the war not on the bomb but on electronics projects, radar problems, antenna design. These experiences spoke to tools. But associated with these material practices were the phenomena, and Anderson insisted that the many-bodied world was altogether as compelling – altogether as *fundamental* – as the decay of a meson into two gamma rays or the discovery of a new strange particle. Superconductivity, spin glasses, optical pumping – these were aspects of the physical world that were not, he believed, any less novel, less conceptually novel than the particle physicist's 'elementary' interaction.

In 1967 Anderson replied to Weisskopf and his allies in the Regent's Lecture, republished (in 1972) as 'More is different'. There, he attacked the difference (insisted upon by Weisskopf) between 'intensive' and 'extensive' research: intensive research was supposed to hunt for fundamental laws (read: nuclear physics, particle physics) while extensive research (solid-state physics, plasma physics, most of biology) putatively sought explanations in terms of known fundamental laws. Angry as he was with the particle physicist fundamentalists, Anderson reserved scorn for defeatists from his own field who on the one hand ceded the non-existence of fundamental problems in condensed matter physics and on the other relegated all *other* problems to 'device engineering'. Anderson stated:

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[22] David Kaiser, 'Nuclear Democracy: Political Engagement, Pedagogical Reform, and Particle Physics in Postwar America', *Isis* 93 (2002), 229–68.

> The reductionist hypothesis does not by any means imply a 'constructionist' one: The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. In fact, the more the elementary particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science, much less to those of society . . . the behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other.[23]

Analysis was possible, synthesis – to the point of accounting for the properties of biological systems in terms of quantum electrodynamics – impossible. Lower level (more elementary) laws simply did not carry within their reach the properties of the interesting, macroscopic phenomena. In 1971 Anderson campaigned against big particle accelerators. Joining Anderson was James Krumhansl (blamed by Steve Weinberg as being a 'heavyweight' in opposition to the superconducting supercollider [SSC]): 'All men are created equal', he said, and, like the nation, physics should be built 'e pluribus unum'. The unity of physics resides in the 'effort to try to recognise and cross the bridges to colleagues in other areas'. As a nation 'we are still bound largely by the common language of mathematics and by a common approach in our scientific method – measure, analyse, generalise'. Unity 'exists in shared scientific concepts' like the soliton that occurs in many domains of physics. This is the 'nation' of physics.[24] Again – as we have seen so often – there was a swift oscillation between political, metaphysical and scientific reasoning. Unity talk rarely walks alone.

As Cat points out, for Weinberg there were no 'autonomous laws'. Instead Weinberg wanted the 'reductionist attitude [to provide] a useful filter that saves scientists in all fields from wasting their time on ideas that are not worth pursuing'.[25] But there was more to Weinberg's view. He insisted that the reason for hunting fundamental laws should not be sold short. It was *not* that there were great rewards to be had in hunting for the calculational or predictive payoff from quantum chromodynamics – no one was going to calculate in detail how a tomato seed grows from the QCD Lagrangian. Nor should the SSC be built *because* there would be great 'spin-offs' to be had, like Teflon from the atomic bomb project (first put to large-scale application as a sealant for uranium hexafluoride). More precisely, there might be spin-offs, but that was

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23 P.W. Anderson, 'More is Different', *Science* 177 (1972), 393–6: 393; reproduced in idem, *A Career in Theoretical Physics* (Singapore, 1994), 1.

24 Cat, 'Physicists' Debates' (n. 21), 279.

25 Ibid., 195 and 299.

beside the point. 'For me', Weinberg wrote, 'reductionism is not a guideline for research programs, but an attitude toward nature itself. It is nothing more or less than the perception that scientific principles are the way they are because of deeper scientific principles . . . and that all these principles can be traced to one simple connected set of laws'.[26]

All this captures very well Weinberg's view: his stance towards the fundamental does not *derive* from the political any more than Chew pulled his conception of bootstrapping from anti-McCarthyism or Helmholtz his unification from liberal nationalism. That said, the very idea category of the 'fundamental' carried with it more than meets the eye. Anderson wanted to rescue the concept from the hands of the particle physicists precisely because the seat explanation is not a throne to be given up lightly. Weinberg knows too that more rests with fundamentality than problem solving alone: 'The reason we give the impression that we think that elementary particle physics is more fundamental than other branches of physics is because it is. I do not know how to defend the amounts being spent on particle physics without being frank about this'.[27] Here is where metaphysics meets the national budget.

Both Long War visions – Anderson-Krumhansl and Weisskopf-Weinberg – carry a political resonance. Both stood for democracy. Weisskopf-Weinberg's pyramid aimed to make science and society proof against intrusion by the lawless and the irrational. Anderson-Krumhansl's linked patchwork aimed to leave room for diversity under a broader rubric of shared methods. Both raised the microcosm of physics into macrocosmic significance. Los Alamos had spawned the pyramid and the Rad Lab the quilt. The struggle for control lasted the whole of the half-century Cold War.

The ring

Since the end of the Cold War in 1989–90, some features of the debate over unity continued unabated, and no doubt they will for a long time to come. But other forces began to act on the relationship of the sciences one to the other, and to the sciences in relation to both industry and the state. On the horizon we begin to glimpse new relationships among the sciences, in which there is neither a lead science (pyramid) nor a few hard-won passages between two at a time (quilt). For the period of the Long War from the early 1940s to the early 1990s, it may well help us to see as well a 50-year struggle between the centralising nuclear spirit of Los Alamos that culminated in two bombs on one side, and the

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[26] Cited in Peter Galison, 'Metaphysics and Texas', review of *Dreams of a Final Theory: The Search for the Fundamental Laws of Nature*, by Steven Weinberg, *The New Republic*, 6 September 1993, 40–43.

[27] Ibid.

offspring of many smaller groups that produced hundreds of different techniques and components at the Rad Lab on the other side. But now, on a much broader and deeper scale, scientists have reshuffled their disciplinary cards.

First, the pyramid is crumbling. There are no doubt many reasons for the cancellation of the SSC – there were budget overruns, there were management troubles, there were political miscalculations in the project's Congressional backers, there were disputes within the physics community. But looked at from our perch at 30,000 feet, I think none of these hold a candle to the double supernova that shook the whole of the physicists' contract with the state: the Cold War ended. Gone, in the unexpected flash of a mallet on the Berlin Wall, was the complex set of assumptions that had made political-symbolic sense of the progression from nuclear physics to weapons research to particle physics. Concomitantly, with its comet-like rise, was a worldwide boon in biomedicine, biotechnologies and more proximately the reach of the American National Institutes of Health and, internationally, the rise of multinational pharmaceuticals.

Indeed, the rise of biomedicine and the end of the Cold War hit particle physics at a vulnerable moment – vulnerable in part because of successes that reached an intellectual plateau in the mid-1970s with the establishment of the stubbornly unrevised Standard Model. Hit on all sides, students – and researchers too – began scrabbling for other ways to do physics, other fields to plough. It is instructive to see where they have gone. Some have headed to astrophysics and cosmology which, in part through new systems of land- and space-based instrumentation, has enjoyed some of its most generative years ever, from maps of the microwave background through programmatic searches for gravity waves, exoplanets and gamma-ray bursts. Detectors, modes of analysis, forms of simulation and theories criss-cross back and forth between the very small of particle physics and the very large of the astrophysical. Another site for joint work has been in the nanosciences where surface chemists, engineers, atomic physicists and biologists productively made common cause in hundreds of laboratories across the world. It is not just that they share a particular tool once in a while; no, the collaboration is much deeper. Experiments could not be done without the joint effort to produce certain macromolecules, instruments or systems, or to frame a problem in terms of one or another's discipline's standing intuitions. Even objects are shared: the nanotube to one collaborator is a molecule, to another a wire, to a third a switch.

String theory, in some ways the foster-child descendant of particle physics, no longer carries with it quite the same evangelical fervour of the 1980s. No longer do most practitioners imagine that one day soon someone will publish the one and true fundamental Lagrangian that will truly be a theory of everything. Instead, the field more and more carries its own weight in which mathematicians and physicists are making common cause, illuminating basic relations of algebraic geometry here and quantum field theory there. This is not a matter of passing a new hammer across the disciplinary divide; it is making a new and substantial field together – whether or not it eventuates in the final unification of all science.[28]

In domain after domain, the most generative parts of physics are forming alliances like those of astrophysics/cosmology, nanoscience and string theory. Our earlier sharply hierarchical or flat patchwork metaphors will not do. These are not 'applications' of a single governing law to the more applied domains. Nor are they quilt-like microexchanges with small border regions and stable centres. Instead, it seems to me that we are seeing a topological shift in the intellectual and cultural structure of physics, one that takes a pyramid into a ring: facing outwards everywhere but without a single, acknowledged centre.

My argument throughout this brief excursus has been this: at every stage of the century and a half of modern unity of science movements, science, metaphysics and politics have always been in play at once. It is that confluence that has made unity of science so important for us to understand both in our grasp of the past and our contemplation of the future. Now the physical sciences are in flux, spiralling on one side dramatically towards the marketplace in biophysics, bioinstrumentation, nanotechnology, computer science. By participating so directly in the flow of venture capital, start-up companies and multinationals, one new face of interdisciplinary, mobile and market-driven sciences has found a form of unification. But in the process of achieving such temporal success it is ever harder for science to provide the ideal representation of, or a philosophical argument for, a unified society toward which we might aim. On the other side, the string side, the physical sciences have advanced so dramatically, moving precisely in the opposite direction: by forming an alliance with the most *abstract* of mathematical disciplines. And there, too, for opposite reasons, because of the *dis*-association of string theory from the pragmatic, unification has also pulled away from providing anything like a model for civil society.

More indirectly there is a cultural-political lesson in these current, disorienting shifts. Appropriate to our world, in which the Cold War recedes into the past, we have produced a science that is both deeply and generatively connected – connected in unexpected, untraditional ways – and yet without, and without any prospect of, a single centre.

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28 Peter Galison, 'Theory Bound and Unbound: Superstrings and Experiment', in Friedel Weinert (ed.), *Laws of Nature: Essays on the Philosophic, Scientific, and Historical Dimensions* (Berlin, 1995), 369–408; idem, 'Mirror Symmetry: Persons, Values, and Objects', in M. Norton Wise (ed.), *Growing Explanations: Historical Perspectives on Recent Science* (Durham, NC, 2004), 23–66. On the rise of shared techniques in nanoscience, see e.g. Lorraine Daston and Peter Galison, *Objectivity* (Boston, 2007), ch. 7.