The face of a metal and the skin of a bomb

Jenny Bulstrode

ABSTRACT 'A solid with a Fermi surface', according to the Cambridge tradition of condensed matter physics, is 'the most meaningful definition of a metal that one can give'. The Fermi surface itself is defined as a skin of constant energy: a skin made up of electrons in constant motion from which a metal derives its unique 'face', identification that serves as a 'visiting card'. The theoretical relation between skin, identity, metal and movement was first demonstrated materially in the 1950s, in the immediate aftermath of Hiroshima and Nagasaki, using a very particular copper imported from Arizona to the Mond Laboratory, Cambridge. Copper – its mobile skin, its face and its visiting card – became the basis for linking the study of spectra to the physical structure of metals. This paper is concerned with an argument that also emerged among Cambridge physicists in the late 1950s: that there were 'two cultures', art and science, split by an apparently unbridgeable divide. In tracing the migrations of copper, crossing borders between traditions as between art, industry and science, this paper reverses the relation whereby the study of spectra and its concomitant condensed matter cosmology has been brought to bear on the physical structure of art. Among ethnographic collections in particular, forensic tests are used to precisely locate art materials in specific contexts, not least to assess the isolation and supposed purity of diverse material cultures. Instead, this paper uses the copper itself as an instrument to bring a cannibal metaphysics known as 'perspectivism' to bear on the heroic age of nuclear physics from Faraday to Fermi.

The fantasies of a modern artist

Within the Cavendish Laboratory of the University of Cambridge lie a number of strange and otherworldly forms, designed and made to convey worlds one can barely articulate, let alone see. Of these fantastical forms, P2049 (Figure 1) is the first. It is the definition of copper. Not in the sense that it is made of copper – it is not. Indeed, it is not even what one might think of as the colour of copper: somewhere between salmon pink and deep oak brown. It is the definition of copper because this model represents the 'Fermi surface of copper': a three-dimensional layer of electrons in ceaseless movement, the technical term for which is 'a skin'. In the canon of condensed matter physics, a solid with a Fermi surface, with this skin of constant energy, is considered 'the most meaningful definition of a metal that one can give' (Mackintosh 1963: 110). In the language of this hard science, it is understood that 'one of the main achievements of the modern electron theory of metals' is that 'each metal acquired its own "face"'. And this face became 'a "visiting card"' for the metal, a skin of energy in constant motion 'so diverse in form that one might think they are the fantasies of a modern artist' (Lifshitz and Kaganov 1980: 4).

The Fermi surface of copper (Figure 1) was modelled in the Cambridge Mond Laboratory using equipment built and designed by Russian-born physicist Piotr Kapitza, equipment he was forced to leave behind when he was detained in Soviet Moscow in 1934.[1] Famous for his work on low-temperature physics, Kapitza is also renowned as the scientist who spoke back to Stalin and openly fought with Lavrenti Beria, the head of the Soviet secret police. In one heated exchange, Kapitza shouted at Beria that he did not understand physics, P2049, Pippard's model of the Fermi surface of copper (The Cavendish Museum: copyright and courtesy of the Cavendish Laboratory, University of Cambridge).

to which the man in charge of the gulags replied that the physicist knew nothing about people (Kapitza 1990: 29).

The Mond Laboratory building now houses research in the arts, humanities and social sciences. Its architecture intimately links two apparently alien traditions notoriously described as 'two cultures' in 1959 by Cambridge physicist C.P. Snow in trying to account for why his scientist friends did not get on with his literary friends at parties:

> Instead of going from Burlington House or South Kensington to Chelsea one might have crossed an ocean. In fact, one had travelled much further than across an ocean – because after a few thousand Atlantic miles one found Greenwich Village talking precisely the same language as Chelsea, and both having about as much in communication with M.I.T. as though the scientists spoke nothing but Tibetan (Snow 2000: 112).

What for Snow was an awkward dinner party, his 'two cultures', would become a war when, in the final years of the twentieth century, two physics professors, Alan Sokal and Jean Bricmont, claimed to have unmasked social theorists as intellectual imposters, and called for their '*hara-kiri*' (Sturrock 1998: 8–9). My work as a historian of science is interested in what attending to materials can offer toward understanding the encounter between traditions. If something was lost in translation between Snow's scientific and literary friends, this paper would like to offer copper, not as a 'babel fish' – a natural or god-made solution to moving between languages – but a different kettle of fish altogether. While Snow imagined two distinct worlds, this essay considers their shared culture of copper as an instrument that, made and remade by man (Wilner 2018: 28–9), changes its skin to move between worlds. Not translation but transmutation. Of all materials, metals are identified by a 'visiting card' because they have faces and skins in constant movement, and of all metals, copper is a migrant.

Made to move

From 1815, Cornwall's population of celebrated copper miners began to leave in vast numbers. In the second half of the nineteenth century alone, subsidised by the British government and international mining companies, over a quarter of a million emigrated overseas in an exodus of skilled mining

Figure 2 Maori *hei-tiki*, presented to Captain Cook by the Maori of Tōtaranui October 1769 (Royal Collection Trust/© Her Majesty Queen Elizabeth II 2019, RCIN 69263).

culture that followed global trade routes first gilt in Cornish copper (Payton 1999: 106–7).[2] Before the copper miners crossed oceans and before this mass migration of metal-extracting skill, the way was paved in Cornish copper coin, struck by the industrialist Matthew Boulton, from metal raised using the steam engines over which he and James Watt held a monopoly. For colonial governments, and the East India Company in particular, establishing currency, specifically small denomination currency coined in Cornish copper, was formal policy (R.S. 1877). From Hudson's Bay to Sumatra, coin was regarded as the first step in the subjugation of existing markets and the creation of new (Eagleton 2016). How Boulton came to be involved in this coining – making money to make a market of the world – begins, strangely, with the art of Aotearoa.

In October 1769 Captain James Cook, in charge of a Royal Society expedition to the South Pacific that wedded scientific vision to the East India Company's commercial interests, received from the Maori of Tōtaranui, a *hei-tiki* (Figure 2). Carved from *pounamu*, or jade, and worn close to the throat by persons of status, the *hei tiki* was understood by Cook as a god. He returned to Britain in the summer of 1771 and spent the subsequent 12 months in preparation for the next voyage. For this second expedition gentleman naturalist, traveller, and advisor to the East India Company, Joseph Banks, ordered three metal replicas of the *hei-tiki* to be cast in bronze by Boulton (Westwood 1926: 8; Coote 2008: 53–4). In April 1772, Boulton wrote to Banks: '1 Green God w'ch is all we can send of them, as 3 were done but crack'd in the cooling … 3 shillings' (Westwood 1926: 8). While not a complex shape to cast, the impure heterogeneous Cornish copper of this bronze pulled apart as it changed state. Banks ordered the replicas together with a number of other copies, cast in bronze, of earrings, wristlets and beads, imitations in metal commissioned to be used as gifts or presentation items to mediate encounters between traditions and to transform rich existing traditions into markets for Cornish copper. In addition, Banks ordered some 2000 medals from Boulton for distribution on the voyage (Figure 3) (Westwood 1926: 3–4; Tungate 2010: 30, 74).

Cook's celebrated voyages launched into the Pacific and the Arctic what would become a flood. His coins appear from Wairau Bar to Nootka Sound (Lane 2009: 7, 9), their surface transformed by oceans at opposite ends of the world. These were Boulton's first attempts at coining and his innovative techniques pioneered a ground-breaking level of detail and sophistication in design that would transform numismatic arts. As with the *hei-tiki*, the earrings and bracelets, the bronze from which the medals were cast used Cornish copper: a brittle, impure and poor quality copper. To make it workable at all it had to be rolled hot, but for the crisp image he sought the surface had to be struck cold, risking fracture of the valuable dyes. Attempting to find the balance between hot and cold caused Boulton a wealth of problems, as the coins themselves testify. While the first strike of coins were perfect (Figure 3), on 10 March 1772 the dye

Figure 3 Medal commemorating the second voyage of Captain James Cook, 1772 (© National Maritime Museum, Greenwich, London, MEC1384).

Figure 4 Matthew Boulton, Venus Vase Ormolu Parfumerie, *c*.1775 (private collection: image copyright © 2018 Online Galleries).

cracked and the coins struck thereafter bear the wound in a scar that slices from the L in SAILED cutting between the R and C in MARCH right to the edge of the reverse face (Westwood 1926: 3).

In 1773, just a year later, Boulton's experience of making money and making gods saw him appointed by the Treasury as the agent for the receipt of worn-out coin (Powell 1993), a post he made profitable by rendering down the Cornish copper to make three forms in particular: new coin, which large-scale industrialists used to pay their workers pittance wages; sheathing used first and foremost by British slavers to protect their wooden hulls from devastation by tropical worm thereby making exceptional gains on their obscene profits (Solar and Rönnbäck 2015); and ormolu mouldings, such as his 1775 Venus vase (Figure 4), a goddess made from melted down small change. Boulton's copper that could look like gold not only fashioned his fortune but, just as his coin had conquered colonial markets and caught new commercial captives, his ormolu created vast new markets for the consumption of art (Quickendon *et al.* 2013; Northover and Wilcox 2013: 109). In the late 1790s, and with the backing of Banks, Boulton won the hard-fought royal contract for legal tender and began to use copper recovered from ships' hulls, rendered down and struck with his innovative techniques to produce official coinage, with ingenious designs to protect against forgery (Doty 1990: 179).

In the wake of Captain Cook, Boulton's coins and sheathing – and coins that *were* sheathing – were distributed along the Northwest Coasts of America in vast quantities, flooding these regions with the product of what were then the world's deepest mines, permanently inundated with water. From these Cornish depths, rocky masses were raised and smelted into Boulton's brittle manufactures designed to create and capture markets. On the Northwest Coasts in particular, Europeans plied this trade copper to swamp the 'native' metal in circulation (Thompson and Doonan 2018), that is, extremely pure, naturally occurring dendrites of copper which grew, almost frond-like, along the banks of the Coppermine, in Nunavut or the Skeena river in British Colombia. This copper had been traded and worked the length of the Northwest Coasts for almost a thousand years before Cook's arrival (Cooper 2012: 565–90), not as 'native' metal but as 'living copper'. According to the nineteenth-century

Figure 5 Tsimshian mask from the Northwest Coast (reproduced by permission of the University of Cambridge Museum of Archaeology and Anthropology, 1886.66.7).

Tsimshian oral history published by anthropologist Franz Boas in 1912:

> spring salmon went up the river; and when they reached the deep water at the upper part of the river, the salmon became copper. Therefore the Indians know that there was live copper in this brook or river (Boas 1912: 301).

This copper was living because it was a shape-shifter, a material of transmutation made and defined through migration: a skin to mediate between skins (Wilner 2018: 9, 28–9).

A Tsimshian mask (Figure 5) held by the Museum of Archaeology and Anthropology, Cambridge, is one face of the cosmology described by Boas. In this artwork copper and leather patches cover the painted wood of the base to make up the skin, but copper alone forms its identifying features. The lips, the nose bridge and the brows are all copper, as are the two sets of figurative eyes: almond-shaped slivers of copper either side of the nose and above the brows. For the life-like central set of eyes, the eyeballs rotate: on one side the iris is painted black as shown in Figure 5, on the other they are red, with bands of copper. The mask is the extension of Tsimshian cosmology and the copper is its identifying skin, the eyes that mediate between people and the eyes that move between worlds (Halpin 1984: 299; Wilner 2018: 9).

In comparison to brittle trade copper, living copper was qualitatively different and much softer, requiring particular ingenious techniques whereby through cold working with stone and antler tools, the dendritic frond-like structures of the living copper were almost matted together as if a felt textile, before coating with fish oil to preserve the surface (Witthoft and Eyman 1969: 15). The introduction of huge quantities of trade copper, in the form of coin and ship's sheathing, led to a confluence and progressive displacement of living copper by the cheap and plentiful alternative, and a concomitant impact on metal-working techniques. As Boulton himself had discovered, the brittle smelted Cornish copper required hot working and metal tools (Tungate 2010: 134), which in turn forged new dependence on European trade and displaced traditional skills (Thompson and Doonan 2018). As with the Maori *hei-tiki* and the ormolu Venus, the superfluity of cheap trade copper led to a proliferation of copper art and culture.

When, in the nineteenth century, naval officers self-consciously re-enacted the celebrated accounts of Cook's voyages, gave gifts in return for the gift of information (Bravo 1999), and collected the copper art of the Northwest Coasts, the art they brought to museums such as that in Cambridge had, almost without exception, already performed spectacular feats of migration and transformation: from Cornish mines and Birmingham manufactures through ships, gods and coin, to other worlds at either end of the world. The Tsimshian mask was collected in the mid-nineteenth century. Scrutinise the skin and no trace of living copper dendrites in its surface will be seen – it is made of trade copper. This mask is an instrument for moving between new collisions of worlds (Wilner 2018: 12, 17).

A penny for your thoughts

Boulton's problems with the brittleness and poor quality of the copper over which he held the monopoly were not restricted to coining. From the late

1770s he was heavily invested in intensive experiments with industrial chemists to transform Cornish copper into a hull-sheathing material that might hold without breaking or succumbing to corrosion (Harris 1966), as the same copper sheathing that protected ships' timbers became an electrical circuit in salt water, like a giant galvanic battery (Knight 1973: 300). In the summer of 1812 a bookbinder's apprentice, not quite 21, took up these 'old and obvious' experiments (Faraday quoted in James 1991: 1–3). He had been attending lectures by the celebrated Cornish chemist Humphry Davy and, following both his lecturer and Boulton before him, chose to use copper sheathing and pennies (Faraday quoted in James 1991: 3–7). In doing these experiments he became fascinated by the relation between copper and electricity. The bookbinder's apprentice was Michael Faraday. A few months later he would apply to work as Davy's assistant, and after initially being dismissed and told to 'attend to the book binding' was recalled within days when an explosion caused the Cornishman to lose the use of his eyes temporarily. Faraday's career would burgeon from this initial interest in copper and electricity. Among physicists, he is famous above all for being the first to articulate the field concept of electromagnetism during his public lectures at the Royal Institution in the late 1840s (Gooding 1989: 188). One noteworthy fan, then-journalist Charles Dickens, wrote to Faraday in May 1850, requesting the lecture notes in which he took copper circuits and wove their lines of force into fields of power (Dickens quoted in James 1999: 154–6). Six months later Dickens thanked Davy's onetime student, copper chemist and the author of field theory, by presenting him with a copy of his latest book, *David Copperfield* (Dickens quoted in James 1999: 218). The vignette on the title page of the first edition referred to a scene in Chapter 3 of the first instalment, titled 'I Observe', where David Copperfield – called Davy throughout – describes his childhood with little Emily, living in a house made from the wreck of a boat (Dickens 1850).

If Faraday first articulated the field, it was James Clerk Maxwell who defined it: first in his correspondence with William Thompson and Faraday in the late 1850s (Gooding 1989: 188; Maxwell quoted in James 2008: 301–3), then in a series of studies in the 1860s that extended Faraday's work on the dynamic behaviour of insulated copper circuits to a system of energetic interconnectedness between all things. Not instant action across empty space, as continental models had it, but a shifting medium whose tension and stress transmitted action and constituted the cutting-edge materialisation of communication: the new Victorian system of telegraphy (Schaffer 2011). According to the author of the two cultures, C.P. Snow, Faraday was 'the greatest of experimental physicists' (Snow 1982: 22). It is with Faraday, and field theory, that Snow began his heroic account of the 'golden age of physics' that would generate atomic weapons. Maxwell, however, he singled out as something else. Referring to the prodigy physicist, founding professor of the Cavendish Laboratory in Cambridge, Snow wrote 'perhaps one in a hundred million is born with the potential to be something like Maxwell and even that guess may be over-optimistic' (Snow 1982: 50).

When, in 1873, Maxwell was invited to join a 'physical society considered an instrument for the improvement of natural knowledge', he expressed his disapproval of the learned society as the best physical structure for the job, using his physics to explain his reticence.

> The gaseous condition is exemplified in the *soirée*, where the members rush about confusedly, and the only communication is during a collision, which in some instances may be prolonged by button-holing.
>
> The opposite condition, the crystalline, is shown in the lecture, where the members sit in rows, while science flows in an uninterrupted stream from a source which we take as the origin. This is the radiation of science.
>
> Conduction takes place along the series of members seated round a dinner table, and fixed there for several hours, with flowers in the middle to prevent any cross currents (Maxwell quoted in Campbell and Garnett 1882: 385).

Proposing 'an intermediate plastic or colloidal condition' as more favourable than the structure offered by a typical learned society, he recommended 'some London district where there happen to be several clubbable senior men who could attract the juniors from a distance' (Maxwell quoted in Campbell and Garnett 1882: 385). Maxwell's theory of particle distribution, and indeed much of his science, was also an articulation of how he saw himself in interaction with other inhabitants of his social world, in relation to patrons, family, colleagues and friends; and as for Faraday these were relations often mediated in copper. In October 1844, aged 13, writing to his father from Edinburgh Academy just a few months before he authored his first scientific paper, the young Maxwell fixed his letter with a copper seal made from an unfortunate beetle, plated using his uncle's new electrotype machine (Maxwell quoted in Campbell and Garnett 1882: 67). It was the beginning of a delight in sealing in copper he continued for years, beetle included (Maxwell quoted in Campbell and Garnett 1882: 116–20).

Nuclear physics would be built from Maxwell's development of Faraday's copper field theory, and in particular his accounts of atoms and particle bombardment. The draft manuscript of his 1874 article *The Atom* offers some glimpse into the basis of his thinking. In order to estimate the energy of a corpuscular bombardment, he used the circumference and thickness of a penny coin to bound the area of the moving system to be estimated, then extrapolated from this bounded system by comparing the dimensions of the penny with those of the earth. To extend the complexity of the system he then considered the bombard, if the penny were falling freely (Maxwell quoted in Harman 2002: 124).

Throughout the long history of encounter and exchange, copper pennies were deployed as one important way of knowing the world. In 1814, 17 years before Maxwell was even born, Faraday and Davy joined the hordes of well-to-do Brits who travelled to Mount Vesuvius (Pyle 2017: 7) and, with utmost care, used a stick to poke Cornish copper pennies into the cooling lava, see the copper flash green and imagine 'that as armour was forged by the Cyclops in Etna, the King of Naples had established a mint in Vesuvius' (Waldie 1820: 166–7). Well over a hundred years later, through the early decades of the twentieth century, the desire to make nature speak for a penny continued, but the coin and most crucially the copper itself had changed. Now the coins apparently minted from the molten rock of the mountain were those of the fascist regime that rose to power in Italy in 1922 (De Lucia and Russo 2011). The regime's immediate desire to militarise and the subsequent demands of war created a rapacious hunger for copper: a hunger which the United States supplied, now responsible for over 50 percent of the copper produced and exported globally (United States Tariff Commission 1941: 140). Between 1922 and 1930 the copper mines of Arizona and New Mexico provided nearly 70 percent of all the copper, raw and processed, that was suddenly rolled out across Italy with the rise of fascism (United States Tariff Commission 1941: 187).

The boundaries of knowledge

In the heart of this, in the mid-1920s, physicist Enrico Fermi – according to C.P. Snow the first to take the step toward the nuclear age (Snow 1982: 109) – taught the work of Faraday and Maxwell to his students at the University of Rome, beginning with a playful question: 'As you know the boiling point of olive oil is higher than the melting point of tin. How can you explain that it is possible to fry in olive oil inside a tinned skillet?' when it is well known that 'Italian skillets are made of tin-lined copper' (Fermi 1961: 45). The answer he sought – that the water in the food boils before the oil – was significant: the lesson of Fermi's frying pan was that all the energy and movement take place in the fine film layer at the surface of the metal. At the same time as he teased his students with this question, he developed Maxwell's theories of particle distribution, pennies and party etiquette into a statistical relationship that would become the basis of the characterisation of the Fermi surface: that three-dimensional layer of electrons in ceaseless movement, that *skin* of constant energy. As fascist Italy lined itself in US copper, Fermi along with his Jewish wife, colleagues and students, found their skins gravely under threat and looked to move. As American copper continued to flood in, they left for the States. Arriving early in 1939, Fermi joined the physicists working on nuclear fission in Los Alamos, New Mexico. On his arrival, Herbert Anderson, one of the project leaders, greeted him with advice about changing skin with copper. That evening as they tried to come to terms with so much change, Fermi told his wife 'Anderson says we should hire our neighbours' children and pay them a penny for each of our English mistakes they correct. He says it is the only way of learning the language' (Fermi 1961: 150).

The desert town of Los Alamos was itself the product of colonisation that had long since displaced or dispossessed the indigenous Native Americans of the Pajarito plateau. Here brilliant physicists, themselves forced to become migrants, would use Fermi physics, built on Faraday copper, to become god-like architects of mass destruction, destroyers of worlds and give birth to the atomic bomb at the end of a war that saw some 50 million displaced people globally.[3] Within a year of Fermi's arrival, the United States launched its alien registration permit that made the right to live and earn not, as it was for Fermi, an exchange of copper, but a flash of green. Since 1861 federal government currency had been backed in patent green ink, originally a calcined green oxide of chromium, as a measure against counterfeit. The green of the 1940 alien receipt, the green card as it is now known, was to match the 'institutional green' of the dollar to which it gave access. With currency backed not by gold but by green, the colour had, over nearly a century, come to represent the stability and authority of the state.[4] While the American copper of fascist Italian coins was pressed into Vesuvian lava to be transformed in a green flash, across the Atlantic a flash of American institutional green won Italian émigrés the right to enter this new world, to waged labour's small change and to make change. With the detonation of nuclear weapons over Hiroshima and Nagasaki on 6 and 9 August 1945 respectively, the relation between physics and skin had become undeniably physical: hundreds of thousands dead; hundreds of thousands more, fatally poisoned. The day after Hiroshima the *Los Angeles Times* front page introduced what would become narrative convention in describing the sequence of total atomic devastation: a 'blinding flash' followed by a 'multi-coloured cloud … mushrooming' into the sky. Despite the US government's efforts to control emerging accounts of the bomb, within days the blinding flash was understood with burning flesh and, over time, the creeping shadow of radiation sickness (Sharp 2000: 441–2).

In the mid-1950s, in the wake of this global mass displacement and the immediate tensions that ushered in the Cold War, Alfred Brian Pippard, later professor at the Cavendish, would use instruments Piotr Kapitza had been forced to leave behind in Cambridge[5] to determine in practice the physical structure of Fermi's theoretical surface: the copper-tin skin below the oil in his pan. In 1938 as a Bristol grammar school boy, Pippard had come to Cambridge to study chemistry, but changed course when war broke out the following year and his tutor advised him that it was physicists the country needed, not chemists (Longair and Waldram 2009: 204). Pippard proved brilliant, and in spring of 1941, C.P. Snow interviewed him to judge his suitability for military research on microwave radar techniques (Longair and Waldram 2009: 205). These techniques, together with the Maxwell-Faraday tradition of his Cambridge training and Kapitza's equipment, he brought to bear on characterising Fermi's surface. Experimental and economic concerns combined in the choice of metal for finding this ferociously complex skin of constant movement. The metal had to be monovalent. Furthermore it had to be readily affordable and available in large quantities of extremely high purity, 'so that at low temperatures the free path of the electrons may rise to values much greater than the skin depth'. For all these reasons 'Copper was chosen' said Pippard, 'on account of its metallurgical convenience', and specifically copper supplied by the American Smelting and Refining Company from mines in Arizona and New Mexico, where just 10 years before Fermi's research had witnessed the birth of the bomb (Pippard 1957: 327).

Twenty-one years on, a *Festschrift*, 'Electrons at the Fermi Surface', held in honour of Pippard's close colleague and Kapitza's former student, Cavendish Laboratory Professor David Schoenberg, invited leading Soviet physicists Ilya Lifshitz and Moisei Kaganov to summarise the contribution of Pippard's work following his choice of copper two decades previously. Although Lifshitz and Kaganov both trained and spent most their careers in Kharkov, they were the intellectual heirs to Kapitza and his renowned condensed matter cadre, Yakov Frenkel, Igor Tamm and Lev Landau. These greats developed Fermi's research to produce many of the models which underpinned solid state physics and, significantly, defined its terminology – not just within the Soviet Union but internationally (Kojevnikov 2004: 47–72). Like the poetry of Maxwell's conductive dinner parties before them or Geoffrey Chew's attempts to formulate a 'nuclear democracy' in US particle physics in the 1950s (Kaiser 2002), the models were developed in explicit dialogue with the political ideologies of the Soviet researchers: a complex relation that, whether patriotic or sceptical, articulated lived experience of loss of life and freedoms under totalitarian rule alongside high principles and ambitions for humanity. Electrons were the slaves of free atoms, but where atoms gave up freedoms to be packed in a tightly bound lattice structure of collective action, electrons would be liberated to a higher state. Such models emerged directly from the events of contemporary political life, describing the collectivist programme of the Soviet state, its brutal realities as much as its ideals, and making the building blocks of the natural world in its image (Kojevnikov 2004: 47–72, 245–75). Tellingly the Russian word, *reshetka,* described both the bars of a jail and the lattice of a crystal (Kojevnikov 2004: 54).

The position of individual physicists in relation to such accounts of the natural world differed. For Frenkel the terms 'free' and 'collectivised' were interchangeable. Others, living in fear – not least Landau, working on the Soviet atomic bomb project only in an attempt to gain some security after his release from prison (Kojevnikov 2004: 245) – expressed reservation at the all-too-salient limitations of the terms by placing them in quotation marks. In doing so they cautiously acknowledged the politics laden in Frenkel's application (Kojevnikov 2004: 250). Lifshitz and Kaganov were heirs to this intellectual legacy with Lifshitz taking Landau's place in 1968 as head of Moscow's prestigious 'P.L Kapitza Institute of Physical Problems' (Grosberg *et al*. 2017: 44). For Schoenberg's *Festschrift*, the two Soviet physicists wrote the quotation with which this paper opened. That, through Pippard,

> each metal acquired its own 'face' … its Fermi surface, a 'visiting card' describing the constant-energy surface … so diverse in form that one might think they are the fantasies of a modern artist (Lifshitz and Kaganov 1980: 4).

They recognised in Pippard's material demonstration of Fermi's surfaces the salient influence of state attacks on free movement – West and East. From their position, acutely aware of the politics in the language, Lifshitz and Kaganov followed Landau, and signalled the border checks of 'face' and the 'visiting card' concepts, with quotation marks.

Far from instances of false or bad science, polluted by a particularly notorious twentieth-century era of political intervention, here were the dominant models, internationally accepted across political divides (Kojevnikov 2004: 249). These laws of nature, these natural physical worlds, were built out of individual perspectives on lived social relations as they had been for Fermi, Maxwell and Faraday: not the socialisation of physics, but rather physics was socialisation that made physical worlds. Maxwell's successor and Kapitza's boss during his time at the Cavendish, Ernest Rutherford, made a pithy articulation of the relation. Responding to a comment on his good fortune, to be 'always on the crest of the wave', the man who oversaw the first successful attempt to split an atom by particle bombardment replied, 'Well, I made the wave, didn't I?' (Rutherford quoted in Snow 2000: 116).

Not fantasies but instruments

Speaking in Paris in 2009 on a cold morning in late January, the celebrated anthropologist Eduardo Viveiros de Castro unveiled what was in his words 'a bomb': his theory of 'perspectivism', with the power to explode the relativism that dominates current anthropological thought – and indeed the arts and humanities more generally (Latour 2009). This incendiary device proposed to blow apart a philosophy that supposes a diversity of subjective cultures, each producing representations that strive to grasp an external and unified nature, indifferent and independent of those same representations (Viveiros de Castro 1998: 478). His weapon was a 'cannibal metaphysics' that recognised a single culture – the perspective of one being in relation to another – and many natures: for every perspective new and diverse natures formed. In this explosive cosmology, derived from close study of shamanistic traditions among which studies of the Tsimshian have been an anthropological archetype, salmon may look to humans like salmon but 'salmon look to salmon as humans to humans', while humans look to salmon 'like spirits, or maybe bears' (Viveiros de Castro 1998: n. 10). The power of shamans, Viveiros de Castro observes, lies in their ability to move along these relations and to exchange perspective.

> The animal clothes that shamans use to travel the cosmos are not fantasies but instruments: they are akin to diving equipment, or space suits, and not

> to carnival masks. The intention when donning a wet suit is to be able to function like a fish, to breathe underwater, not to conceal oneself under a strange covering (Viveiros de Castro 1998: 482).

So too, the heroes of physics' golden age donned copper to travel the cosmos. Lifshitz and Kaganov (1980: 4) saw in the Fermi surface of copper 'the fantasies of a modern artist', yet understood these surfaces as animal clothes are to shamans – as copper eyes to the Tsimshian (Wilner 2018: 9) – 'not fantasies but instruments' (Viveiros de Castro 1998: 482). Follow the copper in physic's golden age and one finds the social relations at the Fermi surface, the movement in the skin: not Snow's two cultures but one culture and many natures. Follow the copper through the history of nuclear physics, and one comes to Viveiros de Castro's bomb.

Acknowledgements

This research was funded by a Caird Research Fellowship, National Maritime Museum, Greenwich, London. I am grateful to Mikey McGovern, the two anonymous reviewers, and the editors for their encouraging and extremely helpful comments. Thanks are also due to Isobel Falconer and David Pyle for their generosity in sharing their respective expertise on the Cavendish models and on lava coins. In particular I am indebted to Simon Schaffer for an extraordinary education, and to Simon, Andrew Lacey and Siân Lewis for those conversations that go everywhere, shape-shift and trip between worlds.

Notes

1. The Museum at the Cavendish Laboratory, 'Models of Fermi surfaces'. Available at: http://www.cambridgephysics.org/museum/area7/cabinet2.htm (accessed 28 July 2019).
2. Four articles in *The West Briton and Cornwall Advertiser*: 'Emigration', 26 March 1824; 'Entirely free emigration', 1 May 1825; 'Free emigration', 7 May 1826; 'Free emigration' 23 March 1838;
3. World Refugee Day, UNHCR, 20 June 2014. See https://www.unhcr.org/uk/news/latest/2014/6/53a155bc6/world-refugee-day-global-forced-displacement-tops-50-million-first-time.html (accessed 28 July 2019).
4. 'Why is U.S. money green', 29 February 2016. Available at: http://www.todayifoundout.com/index.php/2016/02/u-s-paper-money-green/ (accessed 28 July 2019).
5. See note 1 above.

References

Boas, F. 1912. 'Tsimshian mythology: based on texts recorded by Henry W. Tate', *Thirty-First Annual Report of the Bureau of American Ethnology, 1909–1910*, 27–1037.

Bravo, M. 1999. 'Ethnographic navigation and the geographical gift,' in *Geography and Enlightenment*, D. Livingstone and C. Withers (eds). Chicago: University of Chicago Press, 199–235.

Campbell, L. and Garnett, W. 1882. *The Life of James Clerk Maxwell*. London: Macmillan and Co.

Cooper, H.K. 2012. 'Innovation and prestige among northern hunter-gatherers: late prehistoric native copper use in Alaska and Yukon', *American Antiquity* 77(3): 565–90.

Coote, J. 2008. 'Joseph Banks' forty brass patus', *Journal of Museum Ethnography* 20: 49–68.

De Lucia, M. and Russo, M. 2011. '120 years of Italian and Vesuvius history in the lava medals collection of the Osservatorio Vesuviano', in *Geoitalia 2011–VIII Forum Italiano di Scienze della Terra*, Epitome Vol. 4, 144.

Dickens, C. 1850. *The Personal History of David Copperfield; with illustrations by H.K. Browne*. London: Bradbury & Evans.

Doty, R. 1990. 'The world coin: Matthew Boulton and his industrialisation of coinage', *Interdisciplinary Science Reviews* 15(2): 177–86.

Eagleton, C. 2016. 'Sarah Sophia Banks, Adam Afzelius and a coin from Sierra Leone', in *The Material Cultures of Enlightenment Art and Sciences*, A. Craciun and S. Schaffer (eds). London: Palgrave Macmillan, 203–5.

Fermi, L. 1961. *Atoms in the Family: My Life with Enrico Fermi*. Chicago: University of Chicago Press.

Gooding, D. 1989. '"Magnetic curves" and the magnetic field: experimentation and representation in the history of a theory', in *The Uses of Experiment*, D. Gooding, T. Pinch and S. Schaffer (eds). Cambridge: Cambridge University Press, 183–223.

Grosberg, A., Halperin, B. and Singleton, J. 2017. 'In celebration of Ilya Liftshitz', *Physics Today* 70(11): 44–50.

Halpin, M. 1984. 'Seeing in stone: Tsimshian masking and the twin stone masks', in *The Tsimshian: Images of the Past, Views for the Present*, M. Seguin (ed.). Vancouver: UBC Press, 281–308.

Harman, P. (ed.) 2002. *The Scientific Letters and Papers of James Clerk Maxwell. Volume 3: 1874–1879*. Cambridge: Cambridge University Press.

Harris, J.R. 1966. 'Copper and shipping in the eighteenth century', *Economic History Review* 19(3): 550–68.

James, F. (ed.) 1991. *The Correspondence of Michael Faraday. Volume 1: 1811–1831*. London: Institute of Engineering and Technology.

James, F. (ed.) 1999. *The Correspondence of Michael Faraday. Volume 4: 1849–1855*. London: Institute of Engineering and Technology.

James, F. (ed.) 2008. *The Correspondence of Michael Faraday. Volume 5: 1855–1860*. London: Institute of Engineering and Technology.

Kaiser, D. 2002. 'Nuclear democracy: political engagement, pedagogical reform, and particle physics in postwar America', *Isis* 93: 229–68.

Kapitza, P. 1990. 'Peter Kapitza: the scientist who talked back to Stalin', *Bulletin of Atomic Scientists* April: 26–33.

Knight, R.J.B. 1973. 'The introduction of copper sheathing into the Royal Navy', *The Mariner's Mirror* 59: 299–309.

Kojevnikov, A.B. 2004. *Stalin's Great Science: The Times and Adventures of Soviet Physicists*. London: Imperial College Press.

Lane, P. 2009. 'Captain Cook's exploration medals', *reCollections* 4(1): 1–12.

Latour, B. 2009. 'Perspectivism: '"type" or "bomb"'', *Anthropology Today* 25(2): 1–2.

Lifshitz, I.M. and Kaganov, M.I. 1980. 'Geometric concepts in the electron theory of metals', in *Electrons at the Fermi Surface*, M. Springfield (ed.). Cambridge: Cambridge University Press, 1–45.

Longair, M. and Waldram, J. 2009. 'Sir Alfred Brian Pippard', *Biographical Memoirs of Fellows of the Royal Society* 55: 201–20.

Mackintosh, A.R. 1963. 'The Fermi surface of metals', *Scientific American* 209: 110–20.

Northover, P. and Wilcox, N. 2013. 'Matthew Boulton's copper', in *Matthew Boulton: Enterprising Industrialist of the Enlightenment*, K. Quickenden, S. Baggott and M. Dick (eds). Aldershot: Ashgate, 101–10.

Payton, P. 1999. *The Cornish Overseas: A History of Cornwall's 'Great Emigration'*. Fowey: Alexander Associates.

Pippard, A.B. 1957, 'An experimental determination of the Fermi surface in copper', *Philosophical Transactions of the Royal Society of London* 250(979): 325–57.

Powell, J. 1993. 'The Birmingham coiners 1770–1816', *History Today* 43: 49–55.

Pyle, D. 2017. 'Visions of volcanoes', *19: Interdisciplinary Studies in the Long Nineteenth Century* 25: 1–30.

Quickenden, K., Baggott, S. and Dick, M. (eds) 2013. 'Introduction', in *Matthew Boulton: Enterprising Industrialist of the Enlightenment*. Aldershot: Ashgate, 1–18.

R.S. 1877. 'Coins of the English East India Company under Great Britain', *American Journal of Numismatics and Bulletin of the American Numismatic and Archaeological Society* 11(4): 90–92.

Schaffer, S. 2011. 'The laird of physics', *Nature* 471(17): 289–91.

Sharp, P. 2000. 'From yellow peril to Japanese wasteland: John Hersey's "Hiroshima"', *Twentieth Century Literature* 46(4): 434–52.

Snow, C.P. 1982. *The Physicists*. London: Papermac.

Snow, C.P. 2000. *The Two Cultures*. Cambridge: Cambridge University Press.

Solar, P.M. and Rönnbäck, K. 2015. 'Copper sheathing and the British slave trade', *Economic History Review* 68(3): 806–29.

Sturrock, J. 1998. 'Le pauvre Sokal: review of *Intellectual Impostures* by A. Sokal and J. Bricmont', *London Review of Books* 20(14): 8–9.

Thompson, L. and Doonan, R.C.P. 2018. 'Copper on the Northwest Coast: a biographical approach', *Journal of Archaeological Science* 24: 1102–12. Available at: https://doi.org/10.1016/j.jasrep.2018.06.009 (accessed 28 July 2019).

Tungate, S. 2010. *Matthew Boulton and the Soho Mint: Copper to Customer*, PhD thesis, University of Birmingham (unpublished).

United States Tariff Commission 1941. *Italian Commercial Policy and Foreign Trade, 1922–40. A Report on Recent Developments in the Foreign Trade of Italy with Special Reference to the Trade with the United States*. Washington DC: US Government.

Viveiros de Castro, E. 1998. 'Cosmological deixis and Amerindian perspectivism', *Journal of the Royal Anthropological Institute* 4(3): 469–88.

Waldie, J. 1820. *Sketches Descriptive of Italy in the Years 1816 and 1817, with a Brief Account of Travels in Various Parts of France and Switzerland in the Same Years*, vol. 3. London: Murray.

Westwood, A. 1926. *Matthew Boulton's Otaheite Medal*. Birmingham: Printed for the Assay Office.

Wilner, I.L. 2018. 'Transformation masks: recollecting the indigenous origin of global consciousness', in *Indigenous Visions: Rediscovering the World of Franz Boas*, N. Blackhawk and I. Wilner (eds). New Haven: Yale University Press, 3–43.

Witthoft, J. and Eyman, F. 1969. 'Metallurgy of the Tlingit, Dene and Eskimo', *Expedition* 11(3): 12–23.