CHAPTER 11

THE ADVENT OF SCIENCE

Why, when science finally arrived, it was in Western Europe and not some other place and in the seventeenth century and not some other time

WRAP YOUR FINGERS AROUND an Acheulean hand ax, and you are holding one of the oldest of all human technologies (Figure 11.1). For over a million years, *Homo erectus* and its progeny used these tools to butcher animals, scrape and slice their hides, cut wood, dig roots, and much more.

Anthropologists from another star system visiting this planet not so long ago might have supposed that the human lineage would never change its ways. What had worked for a million years would work for a million more: the Acheulean axes would be standard equipment for intelligent life on earth forever.

Not so. Around 300,000 years ago, a dramatically superior stone technology appeared in Europe—what are called Mousterian axes, scrapers, and spearpoints (Figure 11.2). What was responsible for this sudden innovation? Was there a Newton of stone, a reclusive, cave-dwelling genius who saw the way to make the leap from the Acheulean to the Mousterian way of hammering and flaking flint after interminable iterations of the same old thing?

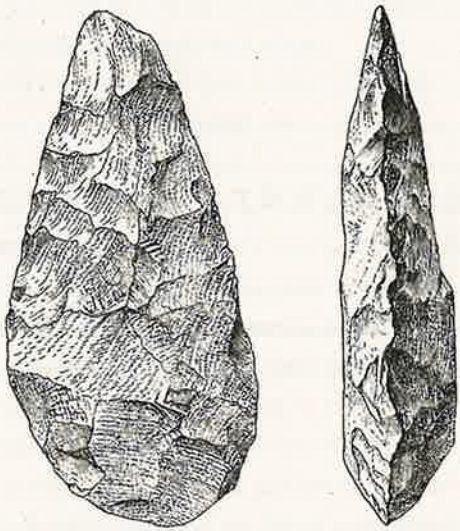

Figure 11.1. Acheulean hand ax (front and side).

The archaeological evidence suggests a rather different answer: Mousterian technology appeared with the evolution of a wholly new species—the Neanderthals. These low-slung, craggy-browed individuals were long treated as the archetypal cave people—mute, simpleminded, unreflective club bearers. The more we learn about them, however, the less accurate this picture turns out to be. The Neanderthals shared something like 99.7 percent of their DNA with modern humans, and they were human in many far more meaningful ways: they were not mute, but had language after all, along with art, ritual, and complex hunting techniques. The transition from *Homo erectus* to *Homo neanderthalensis* seems to have hinged on the evolution of a new kind of mind. It was the superior power of these enhanced organs of thought, perhaps, that enabled the invention of Mousterian tools. At any rate, after this great cognitive leap forward, Stone Age technology began to evolve at a newly

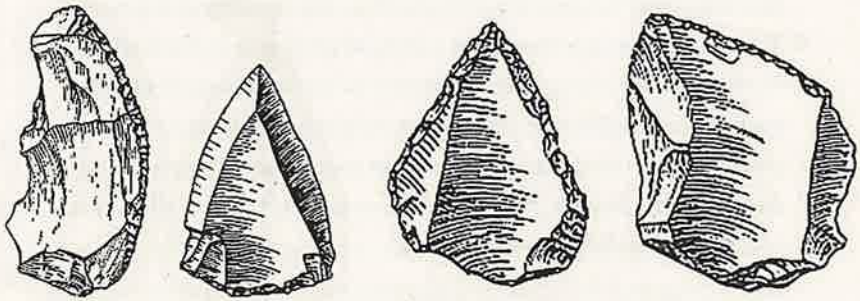

Figure 11.2. Mousterian tools: from left, a convex sidescraper, a Levallois spearpoint, a Mousterian spearpoint, a canted scraper.

rapid pace: gaps between innovations were measured not in millions of years but in tens of thousands of years, with tools becoming ever lighter, sharper, and more incisive.

Mousterian tools first appear in the archaeological record 300 millennia ago. Humanity's keenest, subtlest, most sophisticated tool of all—modern science—first appeared just over 300 years ago. Its belated debut poses the same question as the Mousterian explosion: why, after such prolonged stasis, so sudden a breakthrough?

Evolution, in the case of science, is certainly not the answer. Natural selection made no biological breakthroughs in the seventeenth century. However modern science was made, it was done with the same brains that the human race had been wielding for tens of thousands of years. Likewise, it was done with cultural tools that had been part of the human kit for many centuries before science: philosophy, logic and mathematics, systems of weights and measures, the rule of law and the division of labor. None of this, evidently, was sufficient in itself to set off the Scientific Revolution. Something else must have sparked the fire.

If *The Knowledge Machine*'s explanation of how modern science works is on the right track, then the decisive innovation of the Scientific

Revolution was the iron rule of explanation. The narrowing of discourse required by the rule amounted to a demand for flagrant irrationality—a demand that for a long time constituted an immovable mental block to humanity's willingness to take the iron rule to heart. There is, then, one question about the appearance of modern science that is more important than any other: how did the iron rule's irrationality become, all of a sudden, unobjectionable, even enchanting?

In 1517, Martin Luther planted his "Ninety-Five Theses" on the door of a church in Wittenberg, Germany, precipitating a decisive break with the Catholic Church, the institution that had for one thousand years ruled religious life in Western Europe. In Italy, meanwhile, artists such as Piero della Francesca and Leonardo da Vinci developed the technology of perspective and depicted the human form in novel and more naturalistic ways, while across Europe scholars, builders, and writers rejected medieval models in favor of the literature and architecture of the classical world of Greece and Rome.

Perhaps the most radical of all these attempts to rebuild and rethink the highest forms of human activity were the efforts of the philosophers. To put human knowledge on a solid footing, René Descartes wrote, "I realized that it was necessary . . . to demolish everything completely and start again right from the foundations." With these words he exemplifies what is most exhilarating about Renaissance and early modern thought: the rejection of prevailing intellectual authority, above all the authority of the Catholic Church and its official philosopher, Aristotle, and a subsequent determination to construct everything from scratch and on its intrinsic merits, giving no hypothesis special consideration merely on the grounds of longevity, eminence, or religious orthodoxy. Not only Descartes, but all the great seventeenth-

century philosophers—among them, Thomas Hobbes, G. W. Leibniz, and Baruch Spinoza—gave over their lives to the creation of new philosophical systems.

One of those systems rejected philosophy itself. By the seventeenth century, natural philosophers had been wrestling with the problem of the world's unobservable structure for two thousand years, with rather limited success. Figuring that it was time for something utterly different, a small group of thinkers placed a bold wager on a narrowly empirical form of inquiry. I am referring, of course, to writers such as Galileo Galilei, Robert Boyle, and Isaac Newton—and leading the charge Francis Bacon, who in 1620 so forcefully repudiated Aristotle's metaphysics in favor of the strategy of judging a theory entirely by its ability to explain the observed facts: "A new beginning has to be made from the most basic foundations."

This, then, is how the notion that "only empirical evidence counts" found its way into the heady seventeenth-century mix: not because the times especially favored empiricism and certainly not because they were hostile to philosophical or theological argumentation—nothing could be further from the truth—but because they were unusually fertile for bold thinking of every sort. The garden of the human intellect exploded in a profusion of ideas without precedent in human history. In the midst of such tremendous variety, something like the iron rule of explanation might be expected, if only for a season, to flower.

At this point, finding the principal elements of the iron rule spelled out in the writings of Bacon or Boyle, you might suppose that the advent of science is explained. In fact, the explanation has barely begun. The dominance of the iron rule, even once formulated, was hardly preordained; there was little reason to think that it would take over the garden. It is one thing to flower, quite another to flourish. Bacon laid out some of the principles of iron rule–governed science, but he did not put

them to work in a concerted way. Galileo and Boyle did better, generating and explaining great amounts of quantitative data. Yet ideologically, they belong with Descartes as much as with Newton. Boyle wrote a great deal reporting his experimental investigations, but he wrote more still arguing like Descartes that all scientific explanation must proceed on the atomistic model, accounting for every observable fact in terms of "little bodies variously figured and moved." Rival styles of explanation, most of all the Aristotelian philosopher's appeal to "occult qualities," were, according to Boyle, "unintelligible." Boyle was not a systematic philosopher, but he used philosophical argument to promote what he considered to be a single legitimate explanatory style. We are still very far from Newton's explanatory permissiveness.

Deprive yourself of hindsight, and it is easy to imagine natural philosophy returning, by the late seventeenth century, to a status quo not so different from Aristotle's or Descartes's ideal, a theory of nature explaining the qualitative and some quantitative facts but always within a carefully reasoned philosophical framework.

Why did it not? If I were permitted only a one-word answer, I would say: Newton. It was he who demonstrated the full potential of iron rule–governed science with a sweep and force that his contemporaries could not ignore.

In that case, to what happy circumstances do we owe Newton? Was it simply good fortune that Newton came along when he did? Is it possible that in 1642, after millennia of untiring but fruitless play, Mother Nature's great genetic lottery hit the jackpot, assembling Newton's peerless genome like a row of bananas rewarding a last-gasp gamble on a Las Vegas slot machine—that by chance, at an exceptionally fortuitous historical moment, just the right sequence of nucleic acids was strung together to manufacture a mind capable of exploiting to its utmost the magic of the iron rule? Or perhaps more than genes are needed to make

a Newton; perhaps it takes the right mix of personal, educational, and social experiences. Either way, a stupendously lucky cosmic accident occurred in mid-seventeenth-century rural Lincolnshire to make the Scientific Revolution not only thinkable, but winnable.

That is intellectually thin gruel; luck is neither a nutritious nor a delicious explainer. There has got to be more to say. Something else was present in the seventeenth century besides Bacon's incipient methodological prescriptions and Newton's idiosyncratic intellect, something that made the irrationality of the iron rule—its rejection of all philosophical, theological, and aesthetic considerations in scientific argument—seem more tolerable, prudent, even civilized than it had ever appeared before. The key to explaining the advent of science, then, is to track down this neutralizer of the rule's intrinsically repellent nature.

EUROPE, once Luther's "Ninety-Five Theses" went out, was forever to be spiritually divided—the new Protestant versus the old Catholic faith; citizens, rulers, and territories of opposing religions living uneasily side by side. Violence followed soon enough: popular revolt in Germany in the 1520s; English dissidents burned at the stake in the 1550s; the desecration of churches in the Low Countries in the 1560s; full-scale war in France from then through the end of the century.

It was to get worse. In 1618, the Protestant nobles of Bohemia, rightly fearing for their religious freedom, spurned their Catholic king Ferdinand—famously by ejecting his representatives from an upper-floor window of Hradčany Castle in Prague—and appointed a Calvinist prince in his place. The deposed Ferdinand soon after assumed the station of Holy Roman Emperor, thereby becoming the ruler of a motley but powerful confederacy of Central European states, some Catholic and some Protestant. He marched on Bohemia to take his revenge.

These were the opening moves of the Thirty Years' War, the conflict that launched Descartes's short, uneventful military career and devastated Europe.

Although the war began over a matter of religious toleration, it soon grew into far more than that: a war between the Bourbon dynasty that ruled France and the Habsburg dynasty that ruled Spain and the Holy Roman Empire; a war by which the German princes asserted their rights against the Holy Roman Emperor; a war of territorial aggrandizement by mercenary captains and Scandinavian kings. Europe was decisively transformed. From a complex, shifting web of loosely affiliated fiefs connected by religious observance and dynastic alliance, it became a mosaic of nation-states held together by something quite new: patriotism and a national interest. As C. V. Wedgwood wrote in her classic history of the war:

> The terms Protestant and Catholic gradually [lost] their vigor, the terms German, Frenchman, Swede, [assumed] a gathering menace. The struggle between the Habsburg dynasty and its opponents ceased to be the conflict of two religions and became the struggle of nations for a balance of power.

Within these nation-states, religion was less and less a prime organizing principle:

> It was not that faith had grown [weaker] among the masses; even among the educated and the speculative it still maintained a rigid hold, but it had grown more personal, had become essentially a matter between the individual and his Creator.

For civic purposes, what mattered now was that you were English or French. That you were Anglican or Catholic was your private concern. When the Peace of Westphalia brought the war to an end in 1648, this

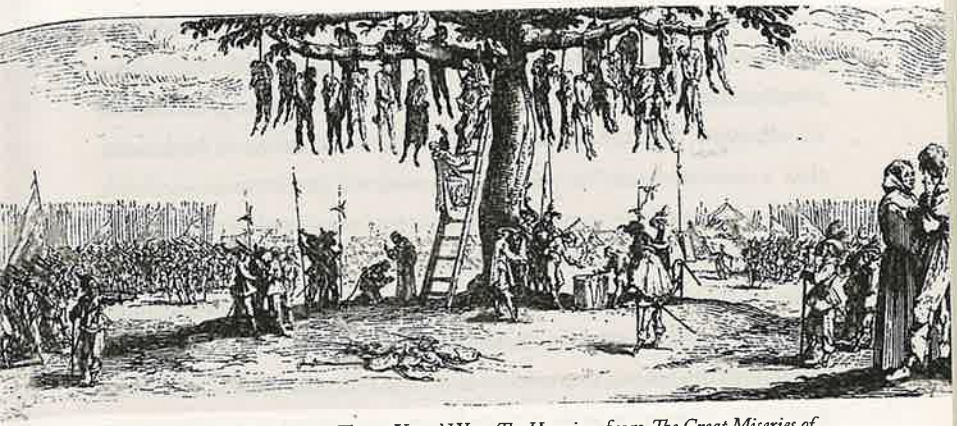

Figure 11.3. Life during the Thirty Years' War: *The Hanging*, from *The Great Miseries of War*, by Jacques Callot, 1633.

separation of political and religious identity was far from complete. But the new organizing principles were clear to, and eagerly debated by, the intelligentsia.

A citizen of a late seventeenth-century European nation-state had to live under two distinct regimes: the spiritual regime, within which they were subject to the will of God, and the civic regime, within which they were subject to the decrees of the monarch or the parliament. If a person cannot serve two masters, then these two roles—law-abiding citizen of the state and obedient servant of God—must not clash in what they require either in action or in thought. The law of the state ought not to prescribe religion, and God's law ought not to override the prerogatives of the state: coinage, taxation, public security, conscription. Or as Isaac Newton wrote, "The laws of God & the laws of man are to be kept distinct." The price of peace in Europe was a permanent bisection of the moral domain into nonoverlapping spheres of obligation, holy church and sovereign nation, each with its proprietary principles and its separate networks of duty and just desert.

To Aristotle, the iron rule's proscription of philosophical and theological argument would have seemed arbitrary and indefensible. To a seventeenth-century mind, by contrast, the rule was asking no more of its adherents than the contemporary political and religious settlement: that a dedicated intellectual space be reserved for its exercise, inside which only a strictly constrained set of principles would be allowed to govern the course of reasoning. Partition—civil and spiritual—was the order of the day. The iron rule's cognitive and logical partition might well have seemed distinctly, fashionably, glamorously, irresistibly "modern." Once the central characteristics of iron rule–governed science were put on the table by radicals such as Bacon, they stood to be taken more seriously than at any other time in human history.

Even after the glorious discoveries carved out by Newton's narrowly empirical method were published in the *Principia* in 1687, it was far from inevitable that his strategies would be universally adopted by other natural philosophers. In that case, the Newtonian opus might have stood alone, towering over the subsequent centuries as Aristotle's philosophy did for so long, admired but unparalleled. That is not what happened: thinkers took up Newton's project, continuing to deepen its fundamentals and to extend its range—developing theories of heat, light, electricity, and the structure of matter—within the same austere framework used by the master himself.

For Newton to be emulated so effectively, his successors had both to discern something like the iron rule at work in his research and to adopt it unreservedly in their own. The discerning was perhaps not too much trouble; Newton lent a hand by adding his famous methodological remarks—"I do not feign hypotheses"—to the second edition of the *Principia* in 1713.

For a thinker to commit to the iron rule in their own research, however—that required finding a way past the blatant irrationality of the rule, its exclusion of philosophical and theological reasoning regard-

less of merit. Even someone sincere in their intention to follow the rule might easily slip back into the forbidden modes of thought in those cases where they seemed relevant and compelling—as, for example, Boyle did advocating atomism in the years before Newton.

The morally compartmentalizing tenor of the times must have helped Newton's followers stick to their resolve. But even as Newton's work became an object of universal admiration, something else was emerging that was surely even more helpful: the recognition of a division between public argument in the official channels of scientific communication, properly policed by the iron rule, and private thought, in which philosophy, theology, and beauty are allowed free rein. The division is not there in Newton himself; as best we can tell, he applied the dictum that "only empirical evidence counts" to his inner thoughts about mathematical physics as much as to his published pronouncements—such were the workings of his theatrical psyche, separating and isolating methods like sparring characters in the great drama of inquiry. For those equipped with more ordinary minds, however, it would be far easier to commit to the iron rule if its application were required only in argument and not in thought. After Newton, then, the uptake of the iron rule was aided enormously by its confining the scope of its edicts against subjectivity and nonempirical argument to scientific journals and the like, leaving private reasoning unconstrained—a self-imposed limit to the power of the rule that is an essential part of modern science as we know it.

An explanation of science's advent must therefore account for the iron rule's restricting its attention to public argument alone. The full story is long and complex and is indeed still unfolding as standards for scientific objectivity and methods of "sterilization" evolve. That the Royal Society's members conceived of their house journal—founded in 1665, just as Newton began to think about the nature of gravity and light—as a repository of "naked fact" surely played a part. But that in itself does

not account for the carving out of a private space in the scientist's mind where the rules dare not intrude. It is possible to glimpse in a celebrated seventeenth-century crisis of conscience, however, the social conditions that favored this final step in the construction of the knowledge machine.

In 1675, Isaac Newton was facing social and professional disaster. Seven years earlier he had been elected a Fellow of Trinity College, and Fellows were required, within seven years of their election, to take holy orders—to be ordained as priests of the Anglican Church. That fate Newton could not contemplate with good conscience. His close study of scripture had convinced him that Jesus Christ was not equal in status to, but was rather created by, God the Father, a denial of the doctrine of the Holy Trinity, the three-in-one nature of the Christian God from which his own college took its name. He was, from the Church of England's point of view, an Arian, a heretic. From his own point of view, it was the church that was in error—an error that he traced back to fraudulent emendations of the scriptures in the fourth and fifth centuries. He could not sully his soul by becoming an agent of a perverted religion; he could not become an Anglican priest. But in that case he would have to relinquish his fellowship, something to which he seemed at one point in 1675 sadly resigned.

Not only would he lose his income; if the reason for his stepping down became known—if his colleagues at the university or in the Royal Society guessed, as well they might, that heresy lay behind his reluctance to take holy orders—then he would be ostracized, "branded a moral leper."

Newton was saved by King Charles II. In response to a plea by someone important at Cambridge—perhaps Isaac Barrow, Newton's predecessor in the Lucasian professorship—a royal dispensation was granted: no holder of the professorship would have to undergo ordination. Provided he was willing to remain silent about his beliefs, then, Newton

could continue in his position at Trinity as long as he wished. And so he did, leading two intellectual lives in parallel: one as an orthodox Fellow of Trinity College, publicly conforming to the precepts of the Church of England; one as an anti-trinitarian heretic, privately subscribing to beliefs that would outrage respectable society.

Newton's dilemma illustrates a conflict that arose repeatedly through the seventeenth century. Because the partition of civic and religious life brought by the wars was imperfect and incomplete, and because political and religious borders did not always coincide, it was common for the ambitious or successful to find themselves obliged to say or perform in public things that they privately disdained.

Secrecy and circumspection have, of course, always been useful for surviving despotism or fanaticism. Testaments to the importance of keeping your mouth shut abound:

> Do not befriend kings until you have trained yourself to obey them in matters that are reprehensible to you; to agree with them on matters that you disagree with; to appraise things according to their desires rather than to yours.

So advised the Egyptian civil servant Shibāb Al-Dīn Al-Nuwayrī in early fourteenth-century Islamic Cairo. What made seventeenth-century Europe different from other places at other times was that the divide between the public and private was to a great extent normalized, to a great extent socially accepted. Public speech codes were made very clear and strictly enforced, yet not seriously expected to constrain private thought. The alternative—perpetual religious conflict—was too awful to countenance.

This was the practical beginning of the modern liberal ideal of religious tolerance. It was not the ideal we have today: neither Trinity College nor English society tolerated Arian heresy. But the king's relaxation

of Newton's ordination requirement reflects an understanding that a certain degree of play is needed to ensure that the intellectually and spiritually diverse institutional components of the early modern state mesh smoothly, along with a willingness to accept outward conformance to the rules as a sufficient qualification for good citizenship. Thanks to its nascent liberalism, then, the European seventeenth century stands apart from other places in history in its explicitly discussing, regimenting, and occasionally celebrating the segregation of strictly policed outward expression and unfettered personal opinion. This goes some way toward explaining how those who built on Newton's science found it natural and easy to conform to the iron rule's strictures in public scientific debate, even as their minds trafficked in ideas they dared not speak aloud.

THE THINKERS WHO invented science were already experts, theoretically and often practically, in the subdivision of thought, both into autonomous domains—the political and the spiritual—and into the public and private spheres of expression. Such distinctions were hardly unknown in other parts of the world and in other times, but in seventeenth-century Europe they acquired an urgency and, far more important, a legitimacy among the privileged classes that was of historically unprecedented magnitude. The seventeenth century was ready for the iron rule, and when the rule appeared, it made the most of it—it made modern science.