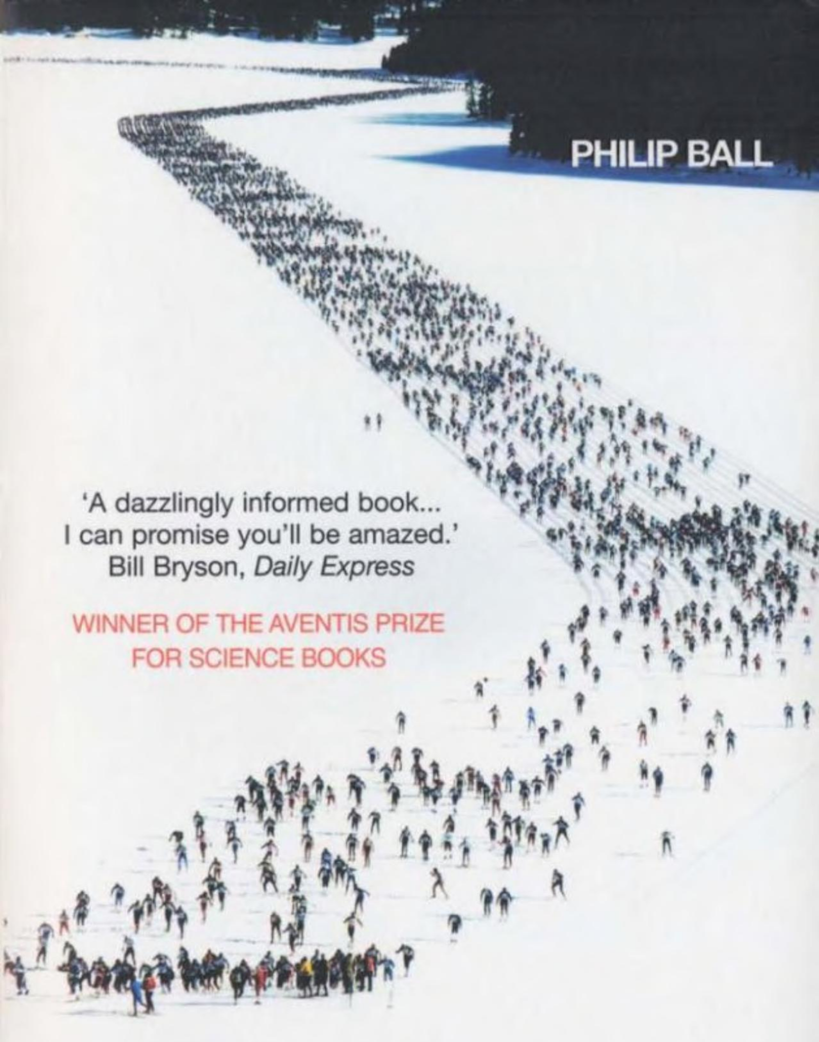
PHILIP BALL



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Critical Mass

HOW ONE THING LEADS TO ANOTHER

Being an enquiry into the interplay of chance and necessity in the way that human culture, customs, institutions, cooperation and conflict arise

PHILIP BALL

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Philip Ball
London, October 2003

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Note on trademarks

Introduction

Political Arithmetick

On the 7th of November 1690 a manuscript was delivered to England's new king, William III. William, the Prince of Orange, had only the previous year deposed the unpopular, Catholic James II in a bloodless coup; and in that time of turmoil the book's message might have provided some solace to the monarch, for it set out to show that England was a solid and secure force in the world.

The book's author was Sir William Petty, once a professor of anatomy at Oxford University and physician general to the English army in Ireland. He had died in 1687, but his work was delivered to the royal court by his son, the Earl of Shelburne. Petty claimed to prove:

> That a small Country, and few People, may by their Situation, Trade, and Policy, be equivalent in Wealth and Strength, to afar greater People, and Territory . . .
>
> That France cannot by reason of Natural and Perpetual Impediments, be more powerful at Sea, than the English, or Hollanders.
>
> That the People, and Territories of the King of England, are Naturally near as considerable, for Wealth, and Strength, as those of France.
>
> That the Impediments of England's Greatness, are but contingent and removeable.

That the Power and Wealth of England, hath increased above this forty years.

That one tenth part, of the whole Expence, of the King of England's Subjects; is sufficient to maintain one hundred thousand Foot, thirty thousand Horse, and forty thousand Men at Sea, and to defray all other Charges, of the Government: both Ordinary and Extraordinary, if the same were regularly Taxed and Raised.

That there are spare Hands enough among the King of England's Subjects, to earn two Millions per annum, more than they now do, and there are Employments, ready, proper, and sufficient, for that purpose.

That there is Mony sufficient to drive the Trade of the Nation.

That the King of England's Subjects, have Stock, competent, and convenient to drive the Trade of the whole Commercial World.[1]

England, in other words, was styled for greatness. On what grounds did Petty make these bold assertions? The book was called *Political Arithmetick*, and it claimed to make a science of politics. Just as Isaac Newton's law of gravity ultimately rested on the quantitative measurements and deductions of the astronomers Tycho Brahe and Johannes Kepler, so Petty used numbers to derive proofs of the healthy state of English society.

'The Method I take to do this', he explained,

is not yet very usual; for instead of using only comparative and superlative Words, and intellectual Arguments, I have taken the course (as a Specimen of the Political Arithmetick I have long aimed at) to express my self in Terms of Number, Weight, or Measure; to use only Arguments of Sense, and to consider only such Causes, as have visible Foundations in Nature; leaving those that depend upon the mutable Minds, Opinions, Appetites, and Passions of particular Men, to the Consideration of others: Really professing my self as unable to speak satisfactorily upon those Grounds (if they may be call'd Grounds), as to foretel the cast of a Dye; to play well at Tennis, Billiards, or Bowles, (without long practice,) by virtue of the most elaborate Conceptions that ever have been written *De Projectilibus & Missilibus*, or of the Angles of Incidence and Reflection.[2]

In other words, while Petty professed to know little about mutable human nature, he believed that society could be understood to the extent that it could be measured and quantified. The science of political arithmetic, he argued, could free a nation's leaders from man's irrationality, and be used to fashion sound and verifiable principles of governance.

How dismayed Petty would have been to find that, three hundred years later, political scientists were still lamenting the fact that human affairs are dominated by whim and prejudice rather than being led by reason and logic. In *Man, the State, and War* (1954), Kenneth Waltz voices the hope that dealings between nations might one day be conducted by the use of rational theory rather than by dogma and polemic. 'In the absence of an elaborated theory of international politics,' he says, 'the causes one finds and the remedies one proposes are often more closely related to temper and training than to the objects and events of the world about us.'[3]

Waltz certainly does not envisage anything as simple as what Petty had in mind – a kind of Newtonian physics of society. But Petty's efforts, which now look woefully naive, nevertheless find an echo in contemporary physics. Over the past two decades, something extraordinary has been happening in this field of science. Tools, methods and ideas developed to understand how the blind material fabric of the universe behaves are finding application in arenas for which they were never designed, and for which they might at first glance appear ridiculously inappropriate. Physics is finding its place in a science of society.

This book is all about how that happened, why it is worth taking seriously and where it might lead. It is also about the limits and caveats of a physics of society, whose potential for misapplication is considerable.

We have been here before. In the 1970s, the catastrophe theory of René Thom seemed to promise an understanding of how sudden changes in society might be provoked by small effects. This initiative atrophied rather quickly, since Thom's phenomenological and qualitative theory did not really offer fundamental explanations and mechanisms for the processes it described. Chaos theory, which matured in the 1980s, has so far proved rather more robust, supplying insights into how complicated and ever-shifting ('dynamical') systems rapidly cease to be precisely predictable even if their initial states are known in great detail. Chaos theory has been advocated as a model for market economics, and its notion of stable dynamical states, called attractors, seemed to provide some explanation for why certain modes of social behaviour or organization remain immune to small perturbations. But this theory has not delivered anything remotely resembling a science of society.

The current vogue is for the third of these three C's: complexity. The buzzwords are now 'emergence' and 'self-organization', as complexity theory seeks to understand how order and stability arise from the interactions of many agents according to a few simple rules.

The physics I shall discuss in this book is not unrelated to the idea of complexity – indeed, the two often overlap. But very often what passes today for 'complexity science' is really something much older, dressed up in fashionable apparel. The main themes in complexity theory have been studied by physicists for over a hundred years, and these scientists have evolved a toolkit of concepts and techniques to which complexity studies have added barely a handful of new items. At the root of this sort of physics is a phenomenon which immediately explains why the discipline may have something to say about society: it is a science of *collective behaviour*. At face value it is not obvious how the bulk properties of insensate particles of matter should bear any relation to how humans behave en masse. Yet physicists have discovered that systems whose component parts have a capacity to act collectively often show recurrent features, even though they might seem to have nothing at all in common with one another.

With that in mind, I hope to show that the new physics of society is able to accommodate just those characteristics of humankind that Petty felt it expedient to exclude: the 'mutable Minds, Opinions, Appetites, and Passions of particular Men'. I want to suggest that, even with our woeful ignorance of why humans behave the way they do, it is possible to make some predictions about how they behave collectively. That is to say, we can make predictions about society even in the face of individual free will, and perhaps even illuminate the limits of that free will.

William Petty thought that quantification alone was enough to qualify his Political Arithmetick as a science. But his contemporary Thomas Hobbes had a rather deeper appreciation of what a science of society should be about. It must look beyond mere numbers, Hobbes implied, and grapple with the difficult question of mechanism. We must ask not just *how* things happen in society, but *why*. In the first part of the book we shall see where Hobbes's mechanistic approach and Petty's arithmetic led in attempts to understand society, and how – most curiously – they fed back into physics itself in the nineteenth century. We shall see how physics deals with systems of many components, all interacting with one another at once, and why regular and predictable behaviour emerges in statistical form from such seeming chaos.

Treating people as though they were just so much insensate matter (or rather, *appearing* perhaps to do so) is a contentious business, which is why we shall approach the physics-based modelling of society with cautious steps, showing first why life (I am tempted to say 'mere life') need not in itself present a boundary to the application of statistical physics. First the bacterium; later the world.

Yet you should not expect to find a 'theory of society' expounded in this book. Indeed, the modern trend towards 'unified theories' – grand, over-arching frameworks – in science, while having its uses, is arguably unhealthy. If there is such a thing as a physics of society, it does not come in the form of some universal equation into which we feed numbers and out of which emerges a deterministic description of social behaviour. The case must be constructed by example, and the tools subtly adapted to each specific purpose. The survey presented in this book is by no means exhaustive; but we shall look at what physics has to say about how people move around in open spaces, how they make decisions and cast votes, and form alliances and groups and companies. We shall see physics used to understand some aspects of the behaviour of economic markets and to reveal the hidden structure in networks of social and business contacts. We shall uncover physics of a sort in the politics of conflict and cooperation.

Underlying all of this is a more difficult question: does physics simply help us to explain and understand, or can we use it to anticipate and thereby to avoid problems, to improve our societies, to make a better and safer world? Or is that merely another dream destined for the already overflowing graveyard of utopias past?

1

Raising Leviathan

The brutish world of Thomas Hobbes

A work on politics, on morals, a piece of criticism, even a manual on the art of public speaking would, other things being equal, be all the better for having been written by a geometrician.

Bernard Fontenelle, Secretary of the Académie Française (late seventeenth century)

'I perceive', says I, 'the world has become so mechanical that I fear we shall quickly become ashamed of it; they will have the world be in large what a watch is in small, which is very regular, and depends only on the just disposing of the several parts of the movement. But pray tell me, madame, had you not formerly a more sublime idea of the universe?'

Bernard Fontenelle (1686)

The most complete exposition of a social myth often comes when the myth itself is waning.

Robert M. MacIver (1947)

It is no longer very useful to ask the question, 'Who governs Britain?' Discuss.

Exercise in Stephen Cotgrove (1967)

*

Brothers will fight
And kill each other . . .
Men will know misery . . .
An axe-age, a sword-age,
Shields will be cloven,
A wind-age, a wolf-age,
Before the world ends.[1]

This is how the Norsemen envisaged Ragnarok, the Twilight of the Gods; but in political exile in France in 1651, Thomas Hobbes must have thought that he had lived through it already. At Naseby and Marston Moor, Newbury and Edgehill, the stout yeomanry of England had hacked one another to bloody ruin. Oliver Cromwell reigned as Lord Protector of a country shocked to find itself a republic, its line of monarchial succession severed by the executioner's axe.

The combatants in the English Civil War, unlike those in France's revolution or America's blood-soaked battle of North against South, had few clear ideological distinctions. The Royalists fought under the king's banner, but the Roundheads also claimed allegiance to 'King and Parliament'. For all his presumptuous arrogance, Charles I had no desire to live outside the constitution and laws of the land. Both sides were Anglican and wary of Papists. There were aristocrats in the Parliamentarian ranks and common folk among the Cavaliers. Many of those who slaughtered one another might have found little to dispute had they wielded words instead of swords.

Such a conflict could be nothing but a prescription for confusion, once the beheading of the king brought it to an end. Embarrassed by the power with which fate had invested him, Cromwell searched in vain for a constitutional solution that would guarantee stability. Such was the might the Ironsides gave him that as Lord Protector he could experiment more freely than any British ruler before or since – though this was a freedom Cromwell would happily have relinquished had he felt able. Time and again he created parliaments on which to shed some burden of authority, only to dissolve them once he found them unworthy of the responsibility.

In the turmoil of those times, none could be certain that friends would not become foes, or old opponents emerge as allies. The Presbyterian Scottish Parliament, whose fierce antagonism to Charles I had precipitated the conflict between Parliament and Crown in the 1630s, was by 1653 fighting against Cromwell with Charles II as its figurehead. Cromwell himself expelled from the House of Commons the Parliament he had fought to instate, and struggled to maintain control of the monstrous army he had created. After Cromwell's death in 1658 this militia restored Parliament and craved an end to the Protectorate. John Lambert led the troops to victory over a Royalist uprising in 1659 even as he plotted to restore Charles II to the throne (and conveniently make him brother-in-law to Lambert's daughter). Yet in the end it was by defeating Lambert that George Monk, a former Royalist, restored a Parliament in 1660 that he knew would crown the exiled king.

What could the common people have possibly craved more than stability? Twenty years of war and changing fortunes had convinced them that only a monarchy would supply it; and Charles II, who had narrowly escaped the tender mercies of the Ironsides just eight years previously, found a loyal army and a joyous population awaiting his return from France.

There is no way to understand the extraordinary quest on which Thomas Hobbes (1588–1679) embarked without acknowledging its historical setting. Centuries of monarchical rule over a hierarchical society had been graphically dismembered with the fall of the axe on

30 January 1649. A system of governance previously upheld by divine and moral imperatives had been revealed as arbitrary and contingent. Almost every political idea that was to follow in later centuries was voiced in seventeenth-century England, and many of them were put into practice. Soldiers and labourers became Levellers and Diggers, advocating socialist principles of equality and an end to individual ownership of land. Cromwell himself seems to have toyed with the notion of a freely elected democratic government, yet he spent much of his Protectorate heading a military dictatorship. Charles I dissolved Parliament and instigated an absolute monarchy in the years before the Civil War.

Which of these systems should a society adopt? The issue was a burning one. Although war between nations was regarded almost as a natural state of affairs, it might hardly pain the common person beyond the imposition of new taxes and levies. But internal strife was agonizing. The Civil War in England, conducted on the whole with restraint toward civilians, was bad enough; but the Thirty Years' War, which ravaged Europe from the early part of the century, killed one in every three of the inhabitants of many German states. For Hobbes and many of his contemporaries, civil peace was worth almost any price.

England's miseries were a symptom of broader changes in the Western world. The feudal system of the Middle Ages was waning before the rise of a prosperous middle class, and from the ranks of this vigorous and ambitious sector came many of the Parliamentarians who no longer felt obliged to submit to every royal whim. The monarchy, with its counsellors and Star Chamber, harked back to the medievalism of Elizabethan society, but the spirit of the age cleaved to something more democratic, however limited in scope. The Reformation of Luther and Calvin had split Europe asunder; no longer did a single Church rule all of Christendom. The backlash to the assault on ecclesiastical tradition – prompted not only by Luther's heresy but by the

Humanism of the Renaissance – gave birth to the Counter-Reformation, the Council of Trent, the Jesuits and the persecutory zeal of the Inquisition. The greater the religious diversity, it seemed, the greater the intolerance.

And emerging from this ferment were ideas about the nature of the world that were ultimately to prove as challenging as any of the proclamations that Luther nailed to the church door in Wittenberg. Copernicus had been fortunate to develop his heliocentric theory – the idea that the Earth revolves around the Sun – in the early sixteenth century, before the Counter-Reformation; his first manuscript, circulated around 1530, even received papal sanction. But by 1543, when the full treatise was published after his death, it was prefaced with a note through which the editor, Andreas Osiander, hoped to evade ecclesiastical condemnation by indicating that the new view of the celestial bodies should be regarded simply as a convenient mathematical fiction. How Galileo fared against papal authority when he placed the same idea on firmer footing is the stuff of legend. The Inquisition condemned him in 1616 and forced him to recant in 1633. But by the middle of the seventeenth century, with René Descartes revitalizing the ancient Greek atomic theory and Isaac Newton soon to be admitted to Trinity College in Cambridge, the banishment of magic and superstition by mechanistic science seems in retrospect inevitable.

Hobbes's masterwork, *Leviathan*, was an attempt to develop a political theory out of this mechanical world-view. He set himself a goal that today sounds absurdly ambitious, although at the dawn of the Enlightenment it must have seemed a natural marriage. Hobbes wanted to deduce, by logic and reason no less rigorous than that used by Galileo to understand the laws of motion, how humankind should govern itself. Starting with what he believed to be irreducible and self-evident axioms, he aimed to develop a science of human interactions, politics and society.

It is hard now to appreciate the magnitude not just of this challenge in itself, but of the shift in outlook that it embodied. There has never been any shortage of views on the best means of governance and social organization. Almost without exception, proposals before Hobbes – and many subsequently – were designed to give the proposers the greatest (perceived) advantage. Emperors, kings and queens sought to justify absolute monarchy by appeal to divine covenant. The Roman Catholic Church was hardly the first theocracy to set itself up as the sole conduit of God's authority. In Plato's Republic, one of the earliest of utopian models, cool and self-confident reasoning argued for a state in which philosophers were accorded the highest status. The rebellious English Parliament of the early 1640s demanded that the King transfer virtually all governing power to them. One could always find an argument to put oneself at the top of the pile.

Hobbes was different. What he aimed to do was to apply the method of the theoretical scientist: to stipulate fundamental first principles and see where they led him. In theory, any conclusion was possible. By analysing human nature and how people interact, he might conceivably have found that the most stable society was one based on what we would now call communism, or democracy, or fascism. In practice, Hobbes's reasoning led him towards the conclusion that he had probably preferred at the outset – from which we may be sure that his method was not as objective as he would have had the world believe. Nonetheless, its claim to have dispensed with bias and to rely only on indisputable logic is what makes *Leviathan* a landmark in the history of political theory.

But it is something more too. Hobbes's great work is seen today as historically and even philosophically important – but political science has become a very different beast, and no one seriously entertains the notion that Hobbes's arguments remain convincing. Nor should they, in one sense – for as we shall see, his basic postulates are very much a product of their times. Yet *Leviathan* is a direct and in many ways an astonishingly prescient antecedent to a revolutionary development now taking place at the forefront of modern physics. Scientists are beginning to realize that the theoretical framework that underpins contemporary physics can be adapted to describe social structures and behaviour, ranging from how traffic flows to how the economy fluctuates and how businesses are organized.

This framework is not as daunting as it might sound. Contrary to what one might imagine from the popular perception of modern physics, we do not have to delve into the imponderable paradoxes of quantum theory, or the mind-stretching revelations of relativity, or the origins of the universe in the Big Bang in order to understand the basic ideas behind these theories. No, this is an approach rooted in the behaviour of everyday substances and objects: of water, sand, magnets, crystals. But what can such things possibly have to say about the way societies organize themselves? A great deal, as it happens.

Hobbes had no inkling of any of this, but he shared the faith of today's physicists that human behaviour is not after all so complex that it cannot occasionally be understood on the basis of just a few simple postulates, or by the operation of what we might regard as *natural forces*. For Hobbes, contemplating the tumultuous political landscape of his country, the prime force could not be more plain: the lust for power.

THE LEVIATHAN WAKES

Thomas Hobbes (Figure 1.1) had never been able to take anything for granted. His father was a poorly educated and irascible vicar, a drunkard who left his family when Thomas was sixteen and died 'in obscurity'. This put his son to little inconvenience, since from a young age Thomas was supported and encouraged by his wealthy and

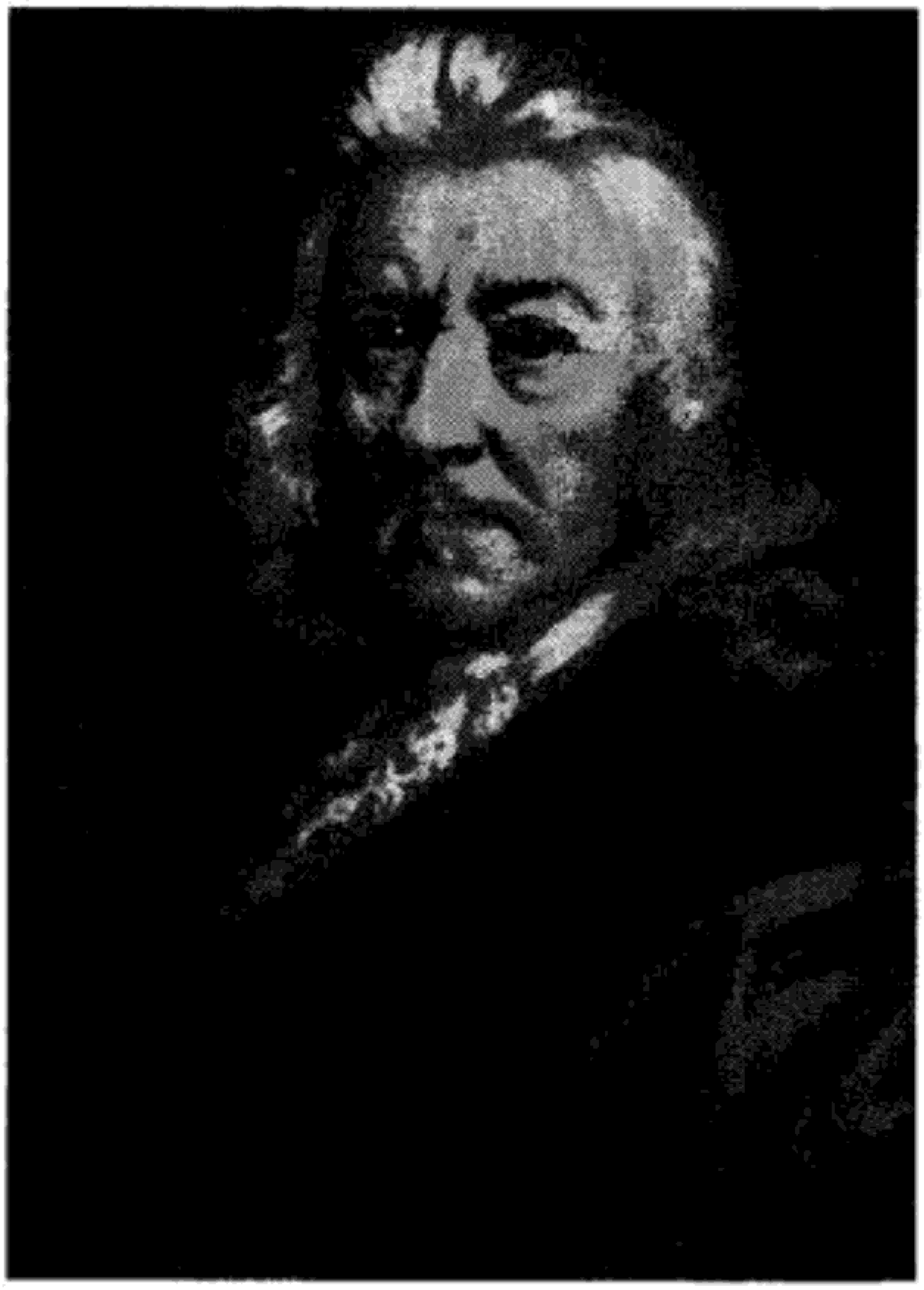

Figure 1.1 Thomas Hobbes was the first to seek a physics of society.

altogether more respectable uncle, Francis, a glover and alderman of Malmesbury. Francis watched over the boy's education, helping to nurture a clearly prodigious intellect: by the time the fourteen-year-old Thomas won admittance to Magdalen College at Oxford, he had already translated Euripides' *Medea* from Greek to Latin. He so excelled at the university that, when he graduated, he was recommended to the Earl of Devonshire as a tutor to the earl's son (himself only three years younger than Thomas). From such a position Hobbes was free to continue his studies of the classics. In his early twenties he acted as secretary to Francis Bacon (1561–1626), whose interests ranged from natural science and philosophy to politics and ethics. During this time, until Bacon's death, Hobbes showed no evident inclinations towards science; but Bacon's rational turn of thought left a clear imprint on his thinking.

It was not until 1629 that the forty-year-old Hobbes, a committed classicist, had his eyes opened to the power of scientific and mathematical reasoning. The story goes that Hobbes happened to glance at a book which lay open in a library, and was transfixed. The book was Euclid's *Elements of Geometry*, and Hobbes began to follow one of the Propositions. 'By God, this is impossible!', he exclaimed – but was soon persuaded otherwise. As Hobbes's contemporary, the gossipy biographer John Aubrey, tells it,

> So he reads the Demonstration of it, which referred him back to such a Proposition; which proposition he read: that referred him back to another, which he also read, and *sic deinceps* [so on], that at last he was demonstratively convinced of that trueth. This made him in love with Geometry.[2]

Hobbes was deeply impressed by how this kind of deductive reasoning, working forward from elementary propositions, allowed geometers to reach ineluctable conclusions with which all honest and percipient people would be compelled to agree. It was a prescription for certainty.

The axioms of geometry are, by and large, statements that few people would have trouble supposing. They assert such things as 'Two straight lines cannot enclose a space.' We can often convince ourselves of their validity with simple sketches. Other fields of enquiry struggle to muster analogous self-evident starting points. 'I think, therefore I am' may have convinced Descartes that, as an axiom, it is 'so solid and so certain that all the most extravagant suppositions of the sceptics were incapable of upsetting it'; but in fact every word of the sentence is open to debate, and it has none of the compelling visual power of geometry's first principles.

Hobbes was sufficiently enthused to become a would-be geometer himself, but he was never a master of the subject. Through clumsy errors he persuaded himself that he had solved the old geometric conundrum of 'squaring the circle' (a task that is in fact impossible). But that was not his principal concern. In the 1630s the tensions between Crown and Commons led Charles I to dissolve Parliament and embark on an eleven-year period of 'Personal Rule'. In the midst of an unstable society, Hobbes wanted to find a theory of governance with credentials as unimpeachable as those of Euclid's geometry. First, he needed some fundamental hypothesis about human behaviour, which in turn had to be grounded in the deepest soil of science. And there was one man who had dug deeper than any other. In the spring of 1636, Hobbes travelled to Florence to meet Galileo.

The fundamental laws describing how objects move in space are called Newton's laws, since it was Sir Isaac who first formulated them clearly. But the tallest giant from whose shoulders Newton saw afar was Galileo Galilei (1564–1642), who laid the foundations of modern mechanics. Galileo taught the world about falling bodies, which, he said, accelerate at a constant rate as they descend (if one ignores the effects of air resistance). And with his law of inertia, Galileo went beyond the 'common-sense' view of Aristotle (384–322 BC) that objects must be continually pushed if they are not to slow down: on the contrary, said Galileo, in the absence of any force an object will continue to move indefinitely in a straight line at constant velocity.

Aristotle's view is the 'common-sense' one because it is what we experience in everyday life. If you stop pedalling your bicycle, you will eventually come to a standstill. But Galileo realized that this is because frictional forces act in nature to slow us down. If we can eliminate all the forces acting on a body, including gravity and friction, the natural state of the body is motion in an unchanging direction at unchanging speed. This was a truly profound theory, for it saw beyond the practical limitations of Galileo's age to a beautiful and simple truth. (An air pump that could create a good vacuum and thus eliminate air resistance was not invented until 1654.)

Galileo's law of inertia is without doubt one of the deepest laws of nature. On meeting the great man, Hobbes became convinced that this must be the axiom he was seeking. Constant motion was the natural state of all things – including people. All human sensations and emotions, he concluded, were the result of motion. From this basic principle Hobbes would work upwards to a theory of society.

What, precisely, does Hobbes mean by this assumption? It is, to modern eyes, a cold and soulless (not to mention an obscure) description of human nature. He pictured a person as a sophisticated mechanism acted upon by external forces. This machine consists of not only the body with its nerves, muscles and sense organs, but also the mind with its imagination, memory and reason. The mind is purely a kind of calculating machine – a computer, if you will. Such machines were popular in the seventeenth century: the Scottish mathematician John Napier (1550–1617) devised one, as did the French philosopher and mathematician Blaise Pascal (1623–62). They were mechanical devices for adding and subtracting numbers; and this, said Hobbes, is all the mind does *too*:

> When a man *Reasoneth*, hee does nothing else but conceive a summe totall, from *Addition* of parcels; or conceive a Remainder, from *Subtraction* of one summe from another . . . For REASON . . . is nothing but *Reckoning*.[3]

The body, meanwhile, is merely a system of jointed limbs moved by the strings and pulleys of muscles and nerves. Man is an automaton.

Indeed, Hobbes held that the ingenious mechanical automata created by some inventors of the era were truly possessed of a kind of primitive life. To him there was nothing mysterious or upsetting about such an idea. Others were less sanguine: the Spanish Inquisition imprisoned some makers of automata on the grounds that they were dabbling in witchcraft and black magic.

What impelled Hobbes's mechanical people into action was not just external stimuli relayed to the brain by the apparatus of the senses. They were imbued also with an inner compulsion to remain in motion. For what is death but immobility, and which person did not seek to avoid death? 'Every man . . .', said Hobbes, 'shuns . . . death, and this he doth, by a certain impulsion of nature, no less than that whereby a stone moves downward.'[4]

Mankind's volitions, therefore, are divided by Hobbes into 'appetites' and 'aversions': the desire to seek ways of continuing this motion and to avoid things that obstruct them. Some appetites are innate, such as hunger; others are learnt through experience. To decide on a course of action, we weigh up the relevant appetites and aversions and act accordingly.

What Hobbes means by 'motion' is a little vague, for he clearly does not intend to imply that we are forever seeking to run around at full pelt. Motion is rather a kind of liberty – a freedom to move at will. Those things that impede liberty impede motion. Even if a man sits still, the mechanism of his mind may be in furious motion: the freedom to think is an innate desire too.

What room is there in this mechanical description for free will? According to Hobbes, there is none – he was a strict determinist. Humans are puppets whose strings are pulled by the forces at play in the world. Yet Hobbes saw nothing intolerable in this bleak picture. After all, he believed that he had arrived at this basic, indisputable postulate about human nature by *introspection* – by considering his own nature. The first puppet he saw was himself:

whosoever looketh into himself, and considereth what he doth, when he does *think*, *opine*, *reason*, *hope*, *feare*, &c, and upon what grounds; he shall thereby read and know, what are the thoughts, and Passions of all other men, upon the like occasions.[5]

THE MECHANISTIC PHILOSOPHY

If we shudder at this concept of humanity today, it is partly because we regard mechanical, clockwork devices as crude and clumsy. There are now many materialist scientists and philosophers who believe that the brain is a kind of vast and squishy computer whose secrets reside in nothing more than the extreme interconnectedness of its billions of biological switches. As a superior version of our most advanced cultural artefact, this view of the brain is neither unusual nor eccentric.

To the intellectuals of the seventeenth century the same was true of the clock, which as a reliable timekeeper was still a recent innovation. In that age there was nothing inelegant about a mechanical picture of humanity; on the contrary, it showed just how wonderfully wrought people were. As Descartes said:

And as a clock, composed of wheels and counterweights, observes not the laws of nature when it is ill made, and points out the hours incorrectly, than when it satisfies the desire of the maker in every respect; so likewise if the body of man be considered as a kind of machine, so made up and composed of bones, nerves, muscles, veins, blood, and skin, that although there were in it no mind, it would still exhibit the same motions which it at present manifests voluntarily.[6]

As above, so below. If mankind was a clockwork mechanism, so too was the universe. The planets and stars revolved like the gears of a clock contrived by God, the cosmic clockmaker. This set in train the debate about whether or not God's skill had left him any cause to intervene in the world once it was 'wound', which culminated in an intemperate argument between Gottfried Leibniz and Isaac Newton (who seldom argued temperately).

And if the universe was a clockwork mechanism, the way to understand it was to take it apart, piece by piece: to apply the reductionist methodology of science. It was precisely this approach that Hobbes chose to use to analyse the workings of society: he would resolve it into its constituent parts and descry in their motions the simple causative forces. This was his intention in *Leviathan*'s precursor, *De cive* ('On the Citizen'), published in 1642, which contained many of the same ideas:

> For everything is best understood by its constitutive causes. For as in a watch, or some such small engine, the matter, figure, and motion of the wheels cannot well be known except it be taken asunder and viewed in parts.[7]

By this time Hobbes had joined other Royalist sympathizers in exile in Paris. He sensed what was in the air in England in 1640, when Charles I had been forced to reconvene Parliament in order to gather taxes to finance the suppression of rebellion in Scotland. So anti-Royalist was the new 'Short' Parliament, which had smouldered in banished discontent for eleven years, that the king rapidly dissolved it again, only to have to resurrect it once more when the Scottish army reached Durham on its march south. From there it was a downhill slide to the outbreak of civil war in 1642. Fearing that his political writings would draw censure (or worse) from the belligerent Short Parliament of 1640, Hobbes left for France.

So Hobbes had thus formulated most of his ideas on 'civil governments and the duties of subjects' before the war began; but its impending prospect lent his efforts some urgency. He had originally intended to write a three-part thesis that began with traditional physics, extended these ideas to the nature of humankind, and only subsequently developed a 'scientific' theory of government. But as he later explained, *De cive* was hastened by circumstances:

> my country some years before the civil war did rage, was so boiling hot with questions concerning the rights of dominion and the obedience due from subjects, the true forerunners of an approaching war; and this was the cause which ripened and plucked from me this third part.[8]

In France, Hobbes joined the circle of mechanistic French philosophers whose acquaintance he had made during his earlier European trip in 1634–7. Among them were Marin Mersenne (1588–1648) and Pierre Gassendi (1592–1655), colleagues of Descartes and two of the most enthusiastic supporters of the mechanical world-view. In this sympathetic environment Hobbes refined his theory of human nature and carried it through to deduce the consequences for civic structure. *Leviathan* was published in 1651, and Hobbes presented it to the fugitive Charles II in exile, to whom he had once taught mathematics. There was to be no one, Royalist or Roundhead, who was pleased by what it said.

THE UTOPIANS

Hobbes was not the first to imagine a utopia based on scientific reasoning. The governing philosophers of Plato's Republic live simply and own no private property, but they have absolute power over the lower classes of soldiers and common people, with whom Plato is little concerned. His is a utopia for aristocrats only; the mob might as well be living in a totalitarian, if benevolent, state. But the word 'utopia' comes from the imaginary land devised by the scholar and lawyer Thomas More (1478–1535). In his book *Utopia* (1518), a sailor named Raphael Hythloday describes the eponymous island where he dwelt for five years after sailing there by chance. The meaning of the name is debated; but the common interpretation renders it as either 'good place' or 'no place'.

In More's Utopia, everything is ideal. There is no ownership: everyone lives in an identical house, but houses are exchanged every ten years to dispel any notion that individuals own their homes. All people of the same sex are dressed alike, and their clothing is simple and immune to fashion. Everyone works – enough but not too much – and they are offered non-compulsory educational lectures. All of the many religions are tolerated, and people live moderately and modestly. It is a vision on the one hand refreshingly liberal, equal and just, and on the other terrifyingly bland and spiritless.

When Francis Bacon drew up his own version of the perfect society, he made science its linchpin. *New Atlantis* was a book he never finished; it was published, incomplete, the year after his death. The title harks back to Plato, who mentions the fabled lost civilization several times in his dialogues. But Bacon employs the same conceit as More: European sailors are driven off course in the Pacific Ocean and find themselves at the previously unknown island of Bensalem (a Hebrew word meaning 'son of peace', although the implication is that this is the 'New Jerusalem'). It is a Christian society that dwells on Bensalem, welcoming, kind and compassionate but also fiercely patriarchal and hierarchical. Central to the culture of Bensalem is Salomon's House, an institution devoted to science and the acquisition of new knowledge. The scientists (Fathers) dress and act rather like priests, and have access to vast resources for research. There are laboratories where nature is not only examined but also imitated and manipulated. Artificial environments resembling mines reproduce the conditions in which metals and minerals are formed; new living species are devised and created. 'Neither do we this by chance,' a Father explains, 'but we know beforehand of what matter and commixture, what kind of those creatures will arise.'[9]

Salomon's House resembles in many ways a modern research institution, albeit one unfettered by any constraints on research ethics. Some might see in it the blueprint for biotechnological laboratories in which the stuff of life is cut up, spliced and reconstituted. The Fathers take an oath of secrecy and reveal their inventions only if it suits them. One cannot imagine Bacon having much difficulty with the modern concept of private companies patenting genes.

But Bacon's Bensalem is an essentially arbitrary society: a vision of what its author considered desirable, and one devoted to, rather than derived from, scientific principles. This is why Hobbes's *Leviathan* is original. He does not describe a society ready-made and shaped by his own preferences, but builds it up, with careful logic, from his mechanistic view of how humans behave.

We should take care with what we mean by that. Hobbes was not especially interested in psychology, or in deducing how people will respond to a particular set of circumstances. He was pursuing a moral philosophy – asking whether a course of behaviour is *right*. In this respect, the ground was prepared for him (and characteristically for the times, he does not acknowledge it) by the Dutch philosopher Hugo Grotius (1583–1645), whose *The Laws of War and Peace* (1625) attempted to find the irreducible characteristics of human social existence. Grotius was not looking for scientific or mathematical laws as we would now understand them, but for 'natural laws', which again might be better regarded as natural rights. With ruthless efficiency, Grotius stripped society of its more pleasant features – benevolence, he said, is all very well, but it is not fundamental. There are only two things that people have a natural right to exercise in the company of their fellows: an expectation that they will not be subjected to unwarranted attack, and the freedom to defend themselves if they are. So long as people confine themselves to self-preservation and refrain from injuring others without cause, society is possible. This, said Grotius, is the 'state of nature', the most basic state of social existence. Civilization generally does rather better than that, encouraging courtesies and friendships and learning and the arts and so forth – but these are all optional extras, and society as such can exist without them.

Thus Grotius's 'minimal society' was a grim affair, and his concept of natural rights was not, as we might suppose today, a precondition of liberalism. But it was not at all obvious how even such a brusque, unfriendly society might be maintained. For who was to say when aggression was warranted and when it was not? If food is short, are you justified in killing your neighbour to preserve yourself? Are you justified in doing that pre-emptively, as an insurance policy against possible famine next year? Even if everyone agrees to recognize their fellows' natural rights, social stability doesn't necessarily follow because there is no consensus about how to exercise them.

In the hierarchical societies of medieval Europe this seldom became a problem because people were accustomed to the idea that they should do as they were told by their superiors. They might resent this inequality, but it was rarely questioned. By the Renaissance those certainties had broken down – partly because of changes to the structure of society, partly because of religious unrest and the Reformation, partly because Humanism had exposed people to new ways of thinking and there was more awareness of the sheer diversity of societies past and present. Society suddenly seemed to lack foundational principles or agreed behavioural norms.

Hobbes realized that this relativism of opinions about how to exercise natural rights meant that in the end a 'state of nature' was all about one thing: power.

HOW TO BUILD A COMMONWEALTH

The person without liberty is without power. Even the most humble and self-effacing of us want a little power – to choose when we eat and sleep, where we live and with whom, what we may say or do. Many millions of people in the world lack some or all of these freedoms, but they are among those acknowledged internationally, in the Universal Declaration of Human Rights, as liberties that everyone deserves simply by virtue of being alive.

Hobbes defined power as the ability to secure well-being or personal advantage, 'to obtain some future apparent Good'. People, he said, have some 'Naturall Power' that enables them to do this, stemming from innate qualities such as strength, eloquence and prudence. And they may use these qualities to acquire 'Instrumentall Power', which is merely 'means and Instruments to acquire more': wealth, reputation, influential friends.

So Hobbes's model of society hinged on the assumption that people (if we say 'men' we are not, in this context, being inaccurate) seek to accumulate power, up to a personal level of satiety that varies between individuals. It is a cold-blooded prescription, for sure. The Scottish political scientist Robert MacIver has complained that it neglects all that is good and worthy in man:

> Hobbes ignored all the social bonds that spread out from the life of the family, all the traditions and indoctrinations that hold groups of men together, all the customs and innumerable adjustments that reveal the socializing tendencies of human nature.[10]

Doubtless that is so, and we may want to make the same complaint. The social historian Lewis Mumford condemns this kind of abstraction of society, saying that it reduces the individual to 'an atom of power, ruthlessly seeking whatever power can command'.[11] It has to be admitted that this is precisely what Hobbes intended.

Yet even the nineteenth-century Romantic Ralph Waldo Emerson seems to agree with the Hobbesian interpretation of human nature when he says, 'Life is a search after power.' And in any event, we can agree or disagree with Hobbes's wolfish view of humanity while nevertheless phrasing the valid question: given these postulates, what follows? *If* men behave in this way, what kind of society can arise and be maintained?

Power is relative: the true measure is the amount by which one man's power exceeds that of the others around him. It follows, Hobbes said, that the quest for power is in fact a quest for command over the powers of other men. But how does one command the power of another? In the bourgeois market society that had come to dominate the cultural landscape of the mid-seventeenth century, the answer was simple: he buys it. One man pays another to act on his behalf and to submit to his will.

This does not necessarily mean, as it might sound, simply that a powerful man may hire others to act as bullies, henchmen and mercenaries. Rather, Hobbes had in mind the way a rich merchant employs workers to make and distribute his goods, or a craftsman takes on assistants to execute a contract. Yet his formulation is as icy as his model of man as machine: 'The Value, or WORTH of a man, is as of all other things, his Price; that is to say, so much as would be given for the use of his Power.'[12] It is the ethic of the free market – buy out the competition.

It is not obvious that a society in which appetites for power vary need in itself be an unsettled one, for those with moderate ambitions might be happy enough to work for those with stronger desires. But Hobbes maintained that some men's appetites know no limits. Such power-hungry individuals destabilize a society in which less ambitious men might otherwise labour in harmony. 'I put for a generall inclination of all mankind', he said,

a perpetuall and restlesse desire of Power after power, that ceaseth only in Death. And the cause of this, is not alwayes that a man hopes for a more intensive delight, than he has already attained to; or that he cannot be content with a moderate power: but because he cannot assure the power and means to live well, which he hath present, without the acquisition of more.[13]

And so all are sucked into a perpetual power struggle. Unchecked, this leads to Hobbes's own vision of a State of Nature, in comparison to which Grotius's version – a crabbed, surly society – might sound positively idyllic. It is as bleak and frightening as you can get.

Without any law or law enforcers, every man is open to violent exploitation by others. When everyone seeks to dominate his neighbour without restraint, says Hobbes, there is

no place for Industry; . . . no Culture of the Earth . . . no Knowledge of the face of the Earth . . . no Arts; no Letters; no Society; and which is worst of all, continuall feare, and danger of violent death; And the life of man, solitary, poore, nasty, brutish, and short.[14]

Who would not do all they could to escape such a state? But to proceed logically to a better way, Hobbes found it necessary to introduce two more postulates, which he elevated to the status of Laws of Nature. The first says that a man will not seek actively to harm himself or endanger his life, or to overlook ways of making it safer. Reasonable enough at first glance, this in fact accords us extraordinary percipience in seeing the consequences of the actions we choose, so that we will always make the one most favourable to our self-preservation. But the second law is still more debatable:

> That a man be willing, when others are so too, as farre-forth, as for Peace, and defence of himselfe he shall think it necessary, to lay down this right to all things; and be contented with so much liberty against other men, as he would allow other men against himselfe.[15]

In other words, men will, as a corollary of their instinct for self-preservation, be prepared to suppress their exploitative impulses and cooperate with one another. Only thus can peace and stability be brought to the State of Nature.

But cooperation is not enough. For men's unceasing appetites for power will make them liable to defect from this contract the moment they see any advantage in doing so. We shall see later that Hobbes here essentially formulates, three hundred years ahead of time, one of the most influential behavioural dilemmas of the modern era. The solution, he reasons, is for men not simply to give up some of their natural rights to do as they please, but to *transfer* these rights to some authority which is then granted the mandate to impose the contract – by force if necessary.

In whom should this authority reside? Hobbes felt that it did not greatly matter, so long as the authority was there. His fundamental postulates assume a degree of equality among men rarely voiced in seventeenth-century Europe: in the State of Nature, no man's status is greater than another's, although some have the advantage of greater 'Naturall Power'. But then the community *elects* some individual and confers on them absolute power. In effect, they choose a monarch and thenceforth defer to him or her without question.

This resolution is a peculiar mixture, for it amounts to the creation of a despotism by democratic means out of an anarchic state. Hobbes admits that the supreme authority could conceivably be an elected body, not an individual – a Parliament, in effect. But he suspects (and who can dispute it?) that with more than one head of state, internal power conflicts will arise sooner or later.

The powers of Hobbes's elected monarch are absolute, stopping only at the right of individuals always to preserve their own lives. It is up to the sovereign, once elected, to decide how much of each man's power he must enlist to maintain the social contract. Even to a tyranny, says Hobbes, citizens owe an obligation of duty and submission. At the same time this absolutism unites people into a cohesive unit, a Commonwealth: the Leviathan. It was a curious name to give to a supposedly desirable state of society – almost as though Hobbes positively wanted his readers to envisage a dreadful, oppressive regime. Leviathan is a fearsome sea-creature mentioned in the Book of Job:

> If you lay a hand on him,
> You will remember the struggle and never do it again!
> Any hope of subduing him is false;
> The mere sight of him is overpowering . . .
> When he rises up, the mighty are terrified;
> They retreat before his thrashing . . .
> Nothing on earth is his equal –
> A creature without fear.
> He looks down on all that are haughty;
> He is king over all that are proud.[16]

The message is plain – you disobey Leviathan's laws at your peril.

Yet because it has freely elected to be governed this way, the population in some sense shares in the political structure that results.

by election of the masses, like a common parliament! Whereas it was well known that kings ruled by divine decree, deriving their authority not from some social contract but from a heavenly one. To the Royalists, the book was pure treason.

There was no comfort here for supporters of the parliamentary system either. Hobbes's supreme authority, be it an individual or a collective body, subsequently had the right to decide who would succeed them – democracy is exercised once and then relinquished. And to make matters worse, *Leviathan* offended the devout by lambasting those nations who 'acquiesce in the great Mysteries of Christian Religion, which are above Reason'.[20] This was deemed by many to be a declaration of atheism. Hobbes endeared himself to no one.

So it was a dangerous game that Hobbes now played. In the winter of 1651/2, shortly after his book appeared, he retreated from the hostility of the exiled Royalists and returned to Cromwell's England, where the desire for peace and stability under the Protectorate had introduced a degree of tolerance. Hobbes made friends within the new regime, and he fitted in quietly enough until Charles II was restored to the throne in 1660. If there was one thing that the Royalists, new and old, disliked more than Hobbes's political philosophy, it was his views on religion. He had become widely regarded as an atheist, especially by the dominant Anglican Royalists, and he might well have faced imprisonment if the bill to make Christian heresy a criminal offence had been passed by Parliament in 1666. The threat was ever present for the remainder of Hobbes's lifetime; but in spite of this, and decades of ill health notwithstanding, he survived to the truly venerable age of ninety-one.

No nation chose to put the advice in *Leviathan* into practice. Indeed, according to historian Richard Olson, 'because they seemed to inspire both immorality and revolution, Hobbes's theories were generally feared and detested by all respectable persons.'[21] To Scottish philosopher David Hume, 'Hobbes's politics promoted tyranny and his ethics encouraged licentiousness.'[22] But because his ideas were argued with such compelling force and precision, they posed a challenge to all subsequent political philosophers. You could be appalled by Hobbes, but you could not ignore him.

Above all, *Leviathan* established the idea that there was room for reason in politics. Previous utopias were not deductive; their validity was simply asserted. In general they sought either to shore up the status quo or to portray a society conjured into existence from the author's imagination, with no explanation of how things got to be that way. The Leviathan, on the other hand, was at least ostensibly the product of mechanistic science. It was not even necessarily something to be celebrated, but was a necessary evil, the only alternative to grim anarchy.

The social contract proposed by Hobbes might sound like a forerunner of those advocated by John Locke (1623–1704) and Jean-Jacques Rousseau (1712–78), but it is instead the reverse. To Locke and Rousseau, the power conferred upon the head of state comes with an obligation to serve the interests of the populace; for Hobbes, the common people become contracted to serve their ruler. For Hobbes, the principal fear was of anarchy; for Locke it was the abuse of power, which is why he saw the need for safeguards to avoid absolutism.

But although apparently a proponent of autocracy, Hobbes also provides arguments which can be used to support both bourgeois capitalism and liberalism. He expressed an aversion to the way the mercantile society bred men whose 'only glory [is] to grow excessively rich by the wisdom of buying and selling', which they do 'by making poor people sell their labour to them at their own prices.'[23] Yet he saw bourgeois culture as largely inevitable, and sought a system which would accommodate its selfish tendencies without conflict. To this end he left it to the market to assign the value of everything, people included: 'the value of all things contracted for, is measured by the Appetite of the Contractors: and therefore the just value, is that which they be contracted to give.'[24] This free-market philosophy found voice in Adam Smith's *Wealth of Nations* in the following century. Those in Britain and the USA – and elsewhere – who lived through the 1980s will recognize it as an attitude that did not wane with the Age of Enlightenment.

MAN AND MECHANISM

A political scientist taking a chronological approach would track the trajectory of Hobbes's thought via Locke to later thinkers who believed there could be such a thing as a 'calculus of society'. Along this path we would uncover Jeremy Bentham's utilitarianism in the late eighteenth century, an attempt to harmonize the individual's pursuit of personal happiness with the interests of society. Bentham, like Locke, believed that reason alone could show how this might be achieved. His solution was the 'greatest happiness' principle, an optimal state in which the sum total of human happiness was as large as it could possibly be, allowing for the conflicts of interest that inevitably arise when each person seeks their own advantage. Bentham's utopia was quite different from Hobbes's: a democracy with equality for all, including votes for women. Bentham and the Philosophical Radicals, who included John Stuart Mill, paved the way for the socialism of Karl Marx. Marx, of course, was also determined to formulate a 'scientific' political theory – one which in his case was strongly (and misguidedly) influenced by Darwinism.

And so we might go on. But I shall not. These theories indeed seek a foundation in rationality, and we shall revisit them from time to time.

But they are not scientific in the way that the real topic of this book is scientific. There are few political thinkers who have defined a social model with the logical precision of Hobbes, and none who has carried those precepts through to their conclusions in a truly scientific, rather than a suppositional, way. This is not by any means to denigrate such models; rather, it is simply to say that their approach is different. Political theorists tend to concern themselves with what they think *ought* to be; scientists concentrate on the way things *are*. The same is true of the new physics of society: it seeks to find descriptions of observed social phenomena and to understand how they might arise from simple assumptions. Equipped with such models, one can then ask what we would need to do in order to obtain a different result. Such decisions about what is desirable should properly be in the realm of public debate: they are no longer scientific questions. In this sense, the science becomes – as it should be – a servant and guide and not a dictator.

How is it that physics has come to have the confidence, perhaps even the arrogance, to venture into social science? No one in recent decades has set out to construct a physics that would be capable of this. It just so happens that physicists have realized that they have at their disposal tools which can be applied to this new task. These tools were not developed for that purpose; they were first developed to understand atoms.

Carolyn Merchant, in her book *The Death of Nature* (1983), argues that the rise of mechanistic, atomistic philosophy in the seventeenth century sanctioned the manipulations and violations of nature that continue to blight the world today. The utopian society envisaged by Thomas Hobbes, in which people are little more than automata impelled this way and that by mechanical forces, and where scientific reasoning is the arbiter of social justice, sounds like a chilling place to live. It is hard to imagine how any model of society which regards the behaviour of individuals as governed by rigid mathematical rules can offer us a vision of a better way to live, rather than a nightmarish Brave New World.

That, I suspect, is the instinctive objection that many will have to the notion of a 'physics of society'. But I hope to show that the new incursion of physics into the social, political and economic sciences is not like this. It is not an attempt to prescribe systems of control and governance, still less to bolster with scientific reasoning prejudices about how society ought to be run. Neither does it really imagine that people are so many soulless, homogeneous effigies to be shuffled this way and that according to blind mathematics. Instead, what physicists are now trying to do is to gain some understanding of how patterns of behaviour emerge – and patterns undoubtedly do emerge – from the statistical mêlée of many individuals doing their own idiosyncratic thing: helping or swindling one another, cooperating or conflicting, following the crowd or blazing their own trail. By gaining such knowledge we might hope to adapt our social structures to the way things *are* rather than the way some architect or politician or town planner thinks they ought to be. We might identify modes of organization which fit with the way we actually and instinctively act.

These are potential practical benefits of a genuinely inquisitive physics of society; but there emerges from such efforts a broader message too. It is this: collective actions and effects are inevitable. No matter how individualistic we like to think we are, our deeds are often the invisible details of a larger picture. This is not necessarily a description of impotence. Environmentalists and other activists like to entreat us to 'think globally, act locally'. But the physics of society shows that the reverse can take effect too: by concerning ourselves with nothing more than how we interact with our immediate neighbours, by 'thinking locally', we can collectively acquire a coherent, global influence. The consequences of that – good or bad – are worth knowing.

Laws make life simpler, and that can be liberating. Immanuel Kant realized this when he said, 'Man is free if he needs to obey no person but solely the laws.'[1]

It is not a trivial matter that science has come to use legal terminology to describe regularities in nature. 'I'm arresting you for breaking the laws of physics', says the policeman to the levitating man in a cartoon. Like many good jokes, this one reveals the snares that language sets. We can break society's laws if we dare, but the laws of physics do not need enforcing, for they are inviolable.

If the Enlightenment enthusiasm for a mechanistic philosophy looks naive to us now, let us not forget what it offered. Such 'natural laws' as Aristotle divined were hardly simplifications; often they were mere tautologies. Objects fell to Earth because they had a downward tendency. The Sun and Moon followed their arcs across the sky because heavenly bodies had a circulating tendency. In contrast, Newton's law of gravity rationalized why cannonballs fall and why the Moon does not. It condensed pages of astronomical data into a concise, simple formula. It helped to fit disparate observations into a single framework. And beyond all this, it suggested that humankind can understand, and not just experience, the hows and whys of existence.

The mechanical laws of Galileo and Newton hold true for planetary orbits and for motes of dust, for a falling apple and a falling star. They are deep and elegant truths, so far as truth can ever be discerned, about the way the universe works. Maybe we can therefore forgive Hobbes and his contemporaries their propensity to use mechanics to explain everything – even the mysteries of the human mind. But in the two centuries that followed the publication of *Leviathan*, delight in mechanics did not diminish. On the contrary, scientists saw ever more reason to believe that they had grasped the central governing principles of all matter, and that explanations for all phenomena simply required the right mechanical description.

It is this account of matter at the fundamental level, hatched in the nineteenth century, that underpins the physics of society. In this chapter we shall see where it came from and what it consists of. It is a theory which invokes many players, and each of them is too small to see. That the whole world can be constructed from a small variety of atoms is an astonishing thing. Understanding what they do when they get together is one of science's greatest triumphs. But no one could have expected this understanding to lead where it has.

PIECES OF EVERYTHING

As the fundamental, irreducible constituent particles of all things, atoms (meaning 'uncuttable') were postulated around 440 BC by the Greek philosopher Leucippus. His pupil Democritus worked out the implications of the hypothesis in great detail. The idea of atoms led to controversy about whether or not there was space (void) between the particles. Anaxagoras (*c.*500–428 BC) dismissed the notion of void, but the Athenian Epicurus (341–270 BC) questioned how anything could move if all space were packed full of atoms.

Democritus' atomism fell out of favour for two millennia, largely because Aristotle did not like it. Medieval theologians rejected the hypothesis because it could not be made to fit the Christian belief in transubstantiation. Interest was revived in the fifteenth century by the rediscovery of the poem *De rerum natura* ('On the Nature of Things') by the Roman philosopher Lucretius (99–55 BC), a follower of the atomistic doctrine of Epicurus.

Galileo, Francis Bacon, Pierre Gassendi and Isaac Newton believed in atoms, but many other great thinkers did not. While accepting that matter might be made up of small particles, René Descartes saw no reason to assume they could not be divided indefinitely. He asserted that they were borne along like grains and dust in swirling vortices of some all-pervading fluid.

It was generally agreed that the microscopic realm was a world in motion – which implied that mechanics could be used to understand the everyday properties of matter. The idea was first enunciated clearly by Daniel Bernoulli (1700–1782), a mathematician of Flemish descent born in Basle, Switzerland. In 1738 he proposed that gases are composed of tiny particles rushing around and colliding. The pressure exerted by a gas – on the side of an inflated balloon, say – was the result of all the little impacts of the particles hitting the surface.

In 1763 a Serbian Jesuit named Roger Joseph Boscovich (1711–87) identified the ultimate implication of this mechanical atomic theory. A crucial aspect of Isaac Newton's laws of motion is their predictive capability. If we know how an object is moving at any instant – how fast, and in which direction – and if we also know the forces acting on it, we can calculate its future trajectory exactly. This predictability made it possible for astronomers to use Newton's laws of motion and gravity to calculate when, for example, future lunar and solar eclipses would happen.

Boscovich realized that if all the world is just atoms in motion and collision, then an all-seeing mind

> could, from a continuous arc described in an interval of time, no matter how small, by all points of matter, derive the law [that is, a universal map] of forces itself . . . Now, if the law of forces were known, & the position, velocity & direction of all the points at any given instant, it would be possible for a mind of this type to foresee all the necessary subsequent motions & states, & to predict all the phenomena that necessarily followed from them.[2]

That is to say, a mathematician with god-like omniscience could deduce the rest of history, for ever and ever, from a mere moment in time. Compared with Hobbes's version of determinism, in which people are automata moving at the insistence of mechanical forces, this is an altogether more constraining straitjacket for the world. Nothing is unknown or uncertain, and there is no deviation from the inevitable play of forces. The fact that no human mind could possibly make such an astronomical calculation is irrelevant: in Boscovich's view, the future was already defined by the present. The eminent French mathematician Pierre-Simon Laplace (1749–1827) made a similar statement in 1814, which, like its author, is far better known. For such an awesome intelligence, said Laplace, 'the future, like the past, would be present before its eyes.'[13]

Mechanism, it seemed, had banished free will.

DISSIPATION AND DEATH

The implications of a mechanical universe were not just philosophical. With the Industrial Revolution in full swing at the dawn of the nineteenth century, there were pressing practical matters for scientists to address. In a short life terminated prematurely by cholera, the French scientist Nicholas Léonard Sadi Carnot (1796–1832) busied himself with one of the most important of these problems: how to optimize the fuel efficiency of a steam engine.

What was true of power generation in Carnot's time is largely true today: extracting work from an engine means generating heat and letting it flow. Think of a coal-fired gas turbine. Heat produced by burning fuel is transferred from the burner to the gas. The hot gas expands, the pressure rises, and a jet is released which drives the rotating blades of the turbine. The rotation turns an electromagnet, creating electricity in the coils. The steam engine, workhorse of the Industrial Revolution, likewise used the expansion of a hot gas: water vapour.

But what, exactly, is heat? In the late eighteenth century many eminent scientists agreed that it was a physical substance called 'caloric' which flows from hot to cold. The American scientist Benjamin Thompson (1753–1814) thought otherwise.* Heat, he suggested, is the random motion of atoms in collision. It is not the *product* of such motions – the frictional heating caused by the atoms' surfaces rubbing together. No, it must be identified with these motions themselves. A substance heats up when its atoms are made to jiggle more furiously, for example as a result of atomic collisions when the substance comes into physical contact with another material in which the motions are already very lively.† Carnot agreed with this proposal: 'Heat is then the result of a motion',[4] he wrote in 1824. The mechanical world of atoms had rationalized an old mystery.

Engineers needed to capture some of this microscopic motion and turn it into the motion of railway carriages, factory machinery and pumps. Carnot realized that this is contingent on getting heat to *flow* from a hot body to a cooler one. He deduced a general theory for calculating how much of this heat flow could be converted to useful work (the conversion is never perfect because some heat is inevitably squandered) and how this depends on the difference in temperature between the hot heat source and cold heat sink. To develop his argument, Carnot considered an engine in which heat flow allowed a gas to expand (when heated) and contract (when cooled), driving a piston in a cyclic process now known as the Carnot cycle. His analysis

* Thompson, who later became Count Rumford, founded London's Royal Institution in 1799.

† This was not an entirely unprecedented notion, for a mechanical theory of heat was first proposed by Robert Boyle in 1675.

In 1852 William Thomson (1824–1907), later Lord Kelvin, noticed something peculiar about the way energy gets transformed. There is, he said, 'a universal tendency in nature to the dissipation of mechanical energy'.[6] What he meant was that some energy is always 'wasted' as heat (that is, random atomic motion). Think of that rotating turbine, in which friction warms up the bearings. It is hard to win back any useful energy* from this heat, which leaks away into the surroundings. In 1854 the German physicist Hermann von Helmholtz (1821–94) perceived the consequences of this inevitable dissipation: the universe would end up as a uniform, tepid reservoir of heat. No further change would then be possible because there was nowhere colder for the heat to flow. Thus, he said, the universe would ultimately die a 'heat death'. In the behaviour of steam engines we can read the fate of all creation.

THE DANCE OF PROBABILITY

Right from the inception of thermodynamics, scientists wanted to know where its rules came from. If all the world is just atoms in motion, each of them obeying Newton's laws, should it not be possible to deduce the laws of thermodynamics just by considering all those invisible collisions?

Daniel Bernoulli began that quest with his explanation of gas pressure. An Englishman named John Herapath (1790–1869) wondered what manner of motions would be required to account for the pressure a gas exerted, and he calculated that the gas particles (atoms, or molecules – small clusters of atoms) would have to be travelling at speeds of something like two kilometres per second.

The pressure of a gas can be altered by changing its temperature.

* That is, energy that can be used to conduct some mechanical task, such as lifting a weight or moving a wheel. Scientists call useful energy 'work'.

If you heat up a gas in a sealed vessel – that is, in a fixed volume of space – its pressure increases. This is why aerosol cans explode if thrown into a fire. If, on the other hand, the volume isn't fixed – if the walls of the vessel are movable – then a hot gas expands. This is what drives the piston in Carnot's cycle. In other words, the three characteristics of a gas – its temperature, pressure and volume – are rather like the notorious trio one encounters in engineering or business: cost, speed and quality. That is to say, if you specify any two of them, you have no say over the third: it is decided for you. We can arrange for a gas to have a particular temperature and pressure, but then the volume (or equivalently the density – the number of molecules in a given volume of space) is preordained. Another way of putting this is that, if we keep one of the trio constant, there is a mathematical relationship between the other two. At fixed volume, for instance, the pressure of a gas is proportional to its temperature.

These relationships between the temperature, pressure and volume of a gas – the so-called gas laws – were studied in the seventeenth century by Robert Boyle. Nearly a century later, Boyle's investigations were refined by the Frenchmen Jacques Charles (who made the first hydrogen-balloon flight in 1783) and Joseph Louis Gay-Lussac.

The challenge was to see whether the gas laws could be derived from a mechanical model in which atoms are like billiard balls, moving in straight lines until they collide with one another. Rudolph Clausius laid much of the groundwork for this so-called kinetic theory of gases in the 1850s, but it was brought to fruition mostly by one man, the Scottish physicist James Clerk Maxwell (1831–79) (Figure 2.1).

When a snooker player strikes a ball, it is not difficult to calculate what its motion will do to the other balls on the table. But in a single thimbleful of air there are about ten billion billion atoms. We cannot possibly know how they are all moving at any instant; and even if we did, the task of calculating how the motion would be altered by

Figure 2.1 James Clerk Maxwell, whose introduction of statistical ideas into the atomic theory of gases was just one of his major contributions to science. He also clarified the nature of colour, pioneered colour photography, and unified all electromagnetic phenomena in a single theory.

collisions in the next instant, and the next, is imponderable. So how can we hope to account for everyday behaviour, as described by the gas laws, starting from 'first principles' – from atomic motions?

Maxwell's key insight was that we do not need to know all the details. What is important is not the precise trajectory of every gas particle but their *average* behaviour. He pictured a swarm of bees, all buzzing about furiously in the air while the swarm itself hovers as a stationary mass, because on average the bees are no more likely to be flying in one direction than in any other.

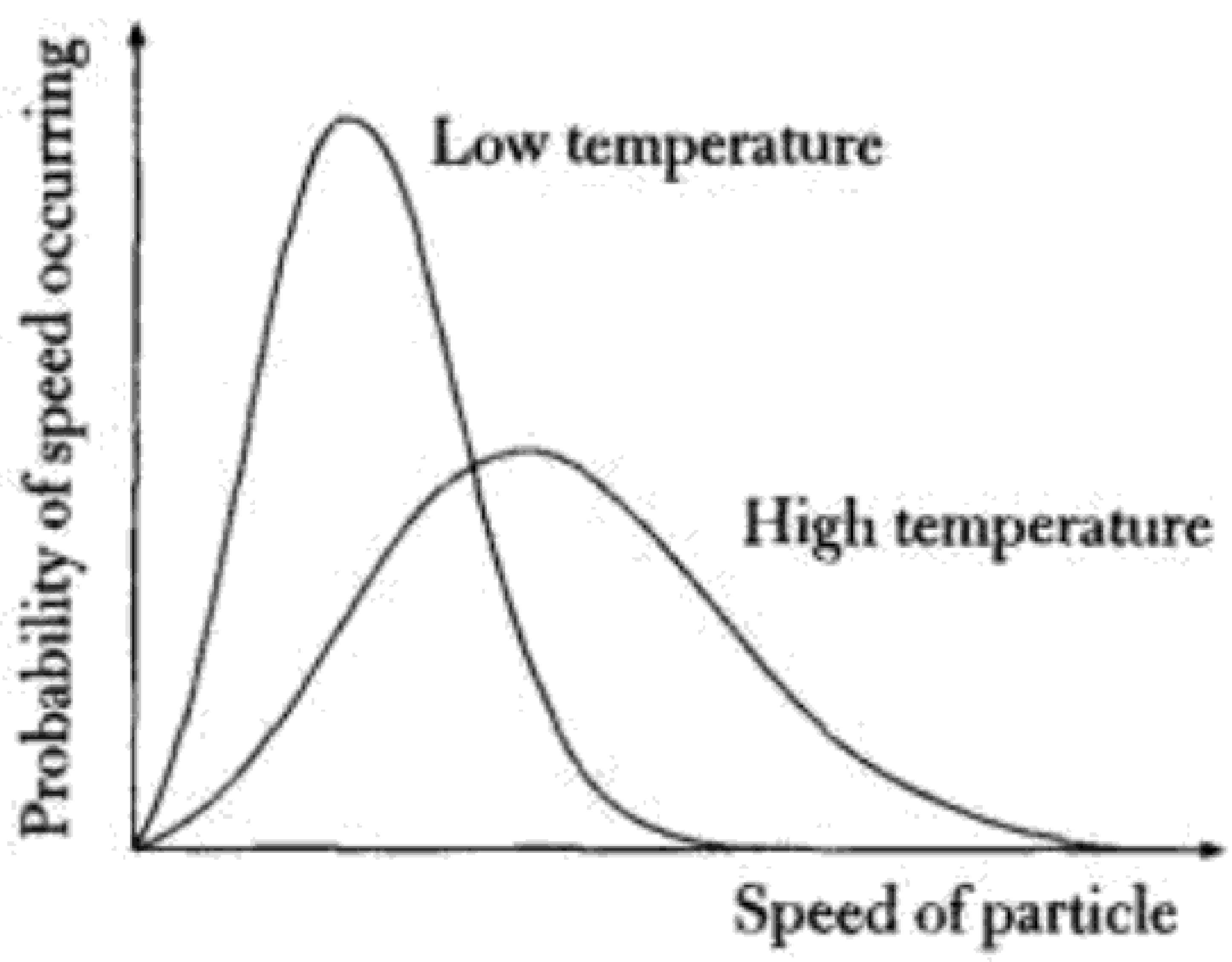

Figure 2.2 Maxwell's probability distribution for the speeds of particles in a gas. As the gas gets hotter, the peak shifts to higher velocities and gets broader and flatter.

All that matters about the motions of the gas particles, said Maxwell, are two things: how fast, on average, each particle is moving – which determines their average motional (kinetic) energy – and how broad is the spread in speeds either side of that average. Maxwell intuited that the distribution of speeds resembles the kind of bell-shaped curve you see in statistical surveys of, for example, the spread of wages. We shall see in the next chapter that this intuition owed a great deal to a nascent science of society.

Maxwell's curve, indicating how many gas particles are moving at each speed, rises smoothly from low speeds, hits a peak at the average, and then tails off smoothly towards high speeds (Figure 2.2). This distribution shows that rather few particles have speeds *much* higher than the average. As Welsh physical chemist Emyr Alun Moelwyn-Hughes once prophetically put it, 'Energy among molecules is like money among men. The rich are few, the poor numerous.'[7]

The average speed of the particles depends on how much kinetic energy the gas as a whole contains. Pump in more energy – heat the gas up – and the average rises: the peak of Maxwell's distribution shifts to higher speeds. But another thing happens too. The bell curve gets flatter and broader, transforming from a tall, steep-sided pinnacle to a lower, more gently sloping hillock (Figure 2.2). That is to say, the spread of speeds gets wider. (Whether pumping more 'energy' into an economy has the same effect on the distribution of wealth is another matter.)

Maxwell's gas does not in fact behave quite like a swarm of bees staying stationary in the air. The particles, unlike the bees, are constantly colliding. This means that their direction of motion is constantly changing, essentially at random. Yet even though each particle moves at random and there is no overall preference for movement in any direction, this does not mean that the particles stay clumped in a swarm. Particles moving at random do actually get somewhere, rather than forever meandering about a fixed position. Their erratic paths take them gradually farther from the starting point, but in a random direction. This is called a random walk, and physicists like to compare it to the path of a drunken man staggering uncontrollably towards no particular destination (Figure 2.3). A particle moving this way is said to be diffusing.

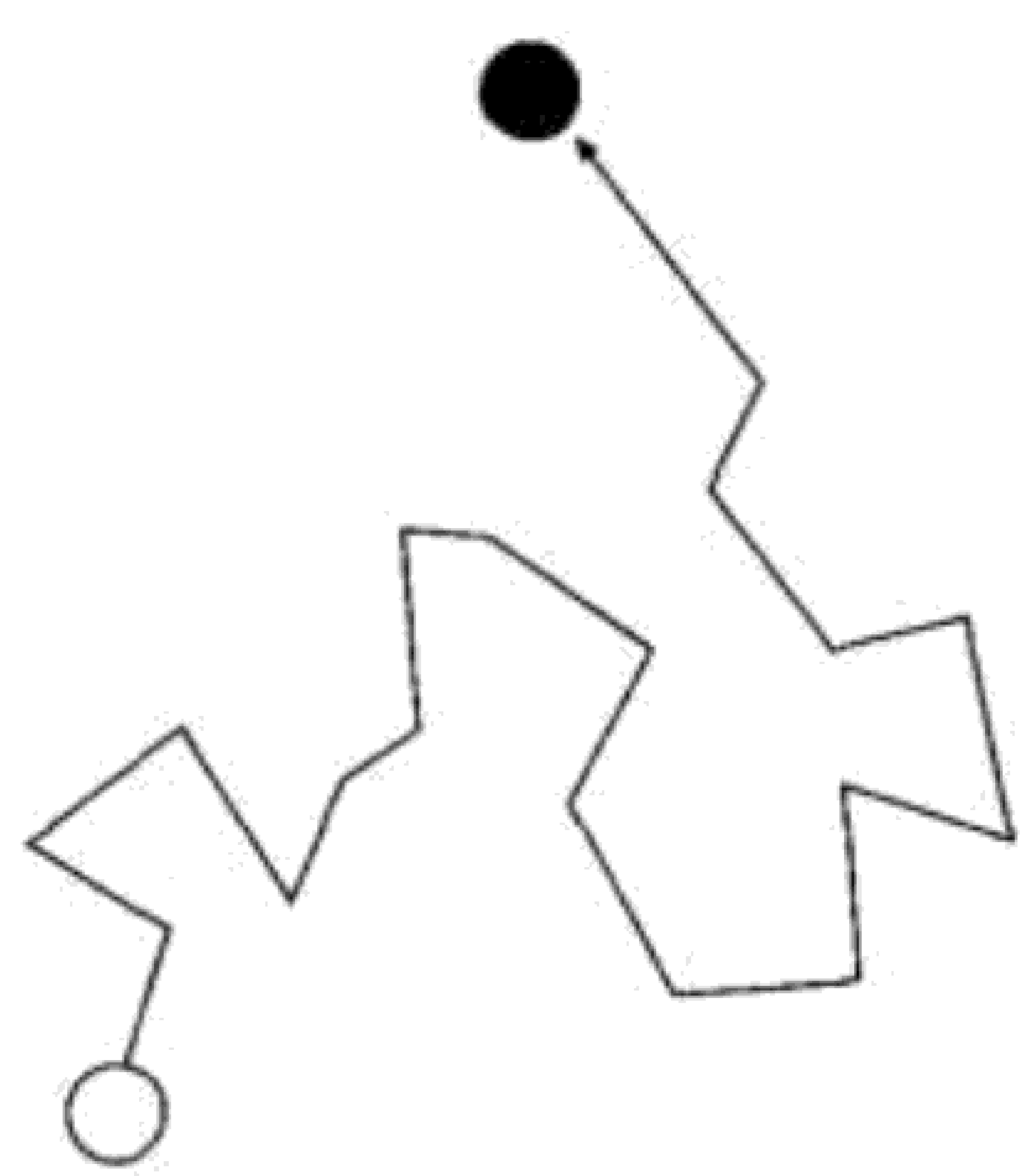

Figure 2.3 A particle bouncing between collisions in a gas executes what is called a random walk, drifting gradually farther from where it began.

typically dealing with billions of billions of molecules, and the statistical behaviour is utterly reproducible from one experiment to another. In other words, for example, for two jars of identical gas at the same temperature the Maxwellian distribution of velocities is absolutely identical.

Along with the introduction of statistics comes the notion of *probability*. Maxwell's distribution tells us nothing exact about the speed of any particular gas molecule. Instead, it tells us the probability that a particle selected at random will have a particular speed. The most probable speed is the average speed; there is a low probability that it will be much faster or much slower than this.* It is indeed extremely convenient that statistics are enough for us to account for the behaviour of gases, for even with modern instruments we could not gather detailed information on every gas particle.

Maxwell evinced a certain uneasiness about his kinetic theory, acknowledging that it broke with the mechanistic tradition of using Newton's laws of motion to deduce the exact trajectories of a system's components, as one does for example to explain planetary motions. This was, in other words, a new way of doing science. Maxwell realized that the theory had profound philosophical implications, and as we shall see later, he may not have risked publishing it had there not already been good precedent.

Maxwell's 'probability distribution' of the speeds of gas particles was a seminal contribution to the kinetic theory, but the truth was that he deduced it using a strong dose of informed guesswork rather than exact mathematics. The job was done more rigorously by a troubled Austrian physicist, Ludwig Boltzmann (1844–1906).

* In fact the *mean* and *most probable* speeds in the distribution are not identical – they differ by a small factor. The peak in the distribution is the most probable speed; the mean speed is slightly greater than this, because the curve tails off more slowly than it rises.

As someone employed regularly to scan the scientific literature for news stories, I have come to appreciate that any paper with a title that begins 'Further researches on . . .' should be passed over with alacrity. It tends to be science-speak for 'The odds and ends we did not think worth pursuing in our last paper'. So it is humbling to be reminded that had I taken this attitude in 1872, I would have missed one of the most explosive papers of the century. In 'Further researches on the thermal equilibrium of gas molecules', Boltzmann not only made Maxwell's case watertight but also proved that there truly exist irreversible processes, as the Second Law of Thermodynamics stipulates – and showed why.

Maxwell proved that gas particles, once they achieve a Maxwellian distribution of speeds, will stay that way. But he did not show how they get to that state in the first place. This is what Boltzmann did, by developing a way to calculate how probability distributions change over time. He demonstrated that, for particles moving at random, 'whatever the initial distribution of kinetic energy may have been, it must always necessarily approach the Maxwellian form after a very long time has elapsed.'[8]

Thus Boltzmann put *change* under the lens of the kinetic theory, which at once brought the Second Law into focus. Clausius had proposed that entropy always increases during an irreversible process; Boltzmann clarified what this meant for the probabilities of molecular motions. He showed that entropy can be equated with the number of different arrangements of molecules that, at the everyday scale, look identical.

Picture a child's balloon on the end of a string. It is full of gas molecules moving at random, and the collisions of these particles with the elastic wall create the pressure that keeps the balloon inflated. At any instant, each molecule is moving on a particular path with a particular speed. If we had a camera so sophisticated that it could take snapshots showing all the particles, then two snapshots taken an hour – or a minute, or a second – apart would show very different arrangements. Because of the huge number of particles, we could take a billion snapshots and never see the same picture twice. But on the scale at which we typically make laboratory measurements, the gas is just the same in every case: it still has the same temperature, pressure and volume.

The number of possible arrangements of the molecules here is truly astronomical. But nevertheless it is finite. We can imagine arrangements that would *not* be equivalent – for example, with all the particles in one half of the balloon. In that case, the empty half would deflate. Because the particles are moving at random, there is absolutely nothing in the laws of physics to prevent this arrangement arising by pure chance. But the likelihood that all the particles would suddenly happen to acquire velocities that took them into the same half of the balloon is so tiny that it is hard to distinguish it from zero. The same is true for just about any arrangement other than ones in which all the particles are distributed evenly throughout the balloon.

Thus the balloon stays fully inflated, not because Newton's laws of motion say it must but because the arrangements of particles that ensure this are *overwhelmingly* more probable than any others, simply because there are many, many more of them than there are of any other non-equivalent arrangement. By equating the entropy of a state with the number of equivalent molecular arrangements to which it corresponds, Boltzmann was thus saying that the fully inflated state of the balloon has the highest entropy. He deemed the mathematical equation relating entropy to the number of 'microstates' of a system to be the apogee of his life's work, and this recondite formula, $S = k \log W$, is engraved on Boltzmann's tombstone.

When change happens in any system, entropy increases because the new arrangement of the constituent particles is more probable than the old. To put it another way, the direction of change – the arrow of time – is determined by probabilities. An ink drop diffuses and disperses in water because it is vastly more probable that the random motions of the ink particles will carry them away from the original droplet in all directions than that they will all conspire to make the droplet move coherently sideways, say, or shrink.

The crucial point about this explanation of the Second Law is that it shows how the irreversibility of time can come about through the operation of mechanical laws which have no preferred direction in time. Picture a movie of two billiard balls coming together, colliding, and moving apart. Played in reverse, the movie would not look at all odd: the reverse collision also obeys Newton's laws.* But the coalescence of a droplet of ink within a glass of initially pale blue water would obviously be time-reversed footage, even though each of the individual collisions between particles that 'created' this arrangement would look like those balls hitting in reverse. This is simply due to the effect of very large numbers on the probability of certain processes happening. Entropy does not *have* to increase by cosmic decree – it simply does so because that is overwhelmingly probable.

The theory of Maxwell and Boltzmann was derived from nothing more than the application of Newton's laws of motion to vast numbers of moving molecules – from so-called classical mechanics. It marks the beginnings of the field of *statistical mechanics*. This is the field that provides modern physics with its central organizing framework. By connecting thermodynamics with the properties of atoms in motion, statistical mechanics describes the behaviour of matter from the bottom up.

* This assumes that no kinetic energy is dissipated in the collision as frictional heat or sound. In the real world these dissipative processes do occur, of course: even the striking of billiard balls is an irreversible process that results in an increase in entropy.

The shift from Newtonian determinism to statistical science is what makes a physics of society possible. It was not a smooth ride; but as we shall now see, it may have been bumpier still if scientists and philosophers had not already begun to appreciate that society itself is fundamentally a statistical phenomenon.

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thrall to convention. 'The notion', he says in *The Man Without Qualities*, 'that people who live like that could ever get together for the rationally planned navigation of their spiritual life and destiny was simply unrealistic; it was preposterous.'[3]

In this rigid and materialistic society, suicides were disturbingly widespread. They claimed the lives of three of Wittgenstein's brothers, Gustav Mahler's brother, and in 1889, the Crown Prince Rudolf of Austria (who killed his mistress first). Boltzmann's sad death does not speak to any broader context until it is seen in the light of the relevant demographic statistics.

To us this seems obvious, but before the nineteenth century hardly anyone would have thought so. Assessing individual events in the context of their average rate of occurrence is a relatively modern practice. Without it, the world is ripe for magic, superstition, miracles and conspiracy theories. A few chance events can become evidence for supernatural influence. Even now the relevance of statistics is routinely overlooked in subjective assessments of risk and coincidence. When the 'psychic' Uri Geller apparently stopped a few watches among his TV audience in the 1970s, no mention was made of the likelihood of such a thing happening by chance given the very large number of viewers.

Whenever one is trying to make sense of mass behaviour, whether it be of atoms or of people, statistics are indispensable. This now seems so beyond question that it is hard to comprehend the urgency of the philosophical arguments that surrounded the use of statistics in nineteenth-century science. At that time, it seemed that God and human free will were being held hostage to numbers. The roots of a physics of society are enmeshed in this debate, so that we shall find some of the moral issues raised by the new discoveries described in this book prefigured by soul-searching from over a hundred years ago.

The history of statistical mechanics outlined in the previous chapter is the orthodox one that physicists tell routinely. Very rarely is any hint given of the way it really began – not just among the insensate gases of the laboratory but in the behaviour of people in society. Speaking of a physics of society perhaps sounds a very postmodern thing to do, but truly there is nothing new under the sun.

MEASURING SOCIETY

In *Leviathan*, Thomas Hobbes was arguably taking to its logical conclusion the analogy drawn by his mentor Francis Bacon between the 'Body Naturall' and the 'Body Politick'. This notion implied that politics might be a kind of natural science, with an anatomy waiting to be dissected by the scalpel of systematic and rational enquiry. In attempting to create such a scientific political theory, Hobbes chose mechanical physics as his framework.

Today we think of physics as a supremely quantitative, not to say mathematical, science. Physicists measure the fundamental numbers of nature down to the tenth decimal place. Their formal literature is dense with symbols, equations and graphs. Things were not quite like this in Hobbes's day, yet still it is striking that *Leviathan* is wholly discursive – there is not a number or an equation in sight. Hobbes liked to make use of physical analogies but he had no intention of making political science mathematical.

That had inevitably to happen, however, if the endeavour was not just to borrow the ideas but to share the demonstrative force of natural science. William Petty, a disciple of Hobbes, seemed to recognize as much when he called for a 'political arithmetic'. 'To practice upon the Politick,' said Petty, 'without knowing the Symmetry, Fabrick, and Proportion of it, is as casual as the practice of Old-women and Empyricks.'[4]

What numbers was this arithmetic to manipulate? Why, naturally, those that measured society. In the 1660s John Graunt (1620–74), a London haberdasher and a friend of Petty, introduced the study of 'social numbers' as a means to guide political policy. Chief among the numbers with which he concerned himself were death rates. In *Observations upon the Bills of Mortality* (1662) he drew up tables of mortality figures 'whereby all men may both correct my Positions, and raise others of their own'.[5] How could one reasonably legislate and govern the population, he asked, without knowing the numbers in which they come and go?

Graunt's statistics were hardly a model of methodological finesse. As he freely admitted, those humble souls responsible for recording deaths were all too easily induced 'after the mist of a Cup of Ale, and the bribe of a two-groat fee, instead of one', to list the cause of death as something anodyne (consumption, say) when the truth was more scandalous (such as syphilis). Yet his tables of causes and ages of death were seen as a bountiful resource for those seeking to understand the flux of society. Graunt, although a mere businessman, was elected a Fellow of the Royal Society, and Charles II averred that 'if they found any more such Tradesmen, they should be sure to admit them without any more ado'.[6]

William Petty continued to revise the *Observations* after Graunt's death. He was the first to study political economy by means of such social statistics, which he argued could provide a rational basis for formulating policy. In this respect he was an empiricist, working with observations of social aggregates rather than trying to derive theories based on assumptions about the fundamental psychology of individuals in the manner of Hobbes. Petty enjoyed the favour of Charles I, Charles II and James II (and managed, pragmatically, to serve Cromwell too) and he was a founding member of the Royal Society. Yet his policy recommendations were largely ignored, and frankly this was often just as well. Petty often exemplifies the dangers of a hyper-rational, analytical approach to social policy that takes no account of its human costs.

Population measures – birth and death rates – were the major preoccupation of early quantifiers of society. It was thought to be of paramount importance for a nation to multiply its subjects – an injunction that was, after all, sanctified in the Bible. The power and glory of a country were believed to be reflected in the size of its population, so much so that some savants proposed that wars of conquest were driven largely by a desire to increase it. In the mid-eighteenth century, Johann Peter Süssmilch (1707–67), a German army chaplain, argued that war could be avoided by removing all checks to the growth of population, obviating the need for kings to gather new subjects from outside their realm.

A focus on mortality was understandable in an age that knew so much of it. Masses died in noisome cities, the 'Places of the Waste and Destruction of Mankind' according to Thomas Short in 1767.[7] Famine and starvation were endemic in the countryside. Few wars were quite as devastating as the Thirty Years' War, but war still seemed to be an ever-present part of human affairs and a steady source of attrition in the population. Procreation was the only remedy. Ironically from today's perspective, Protestants in England and Germany denounced Catholicism because its advocacy of celibacy compromised population growth.

By 1826, when the English economist Thomas Malthus (1766–1834) published his *Essay on the Principle of Population* – a compelling critique of unchecked population growth which had a profound influence on both Darwin and Marx – governments in Europe and the United States had begun to appreciate the wisdom of counting their citizens. Censuses in fact date back to the Norman efforts to record in the *Domesday Book* the population of England in the eleventh century, although this was not so much an exercise in quantification as the establishment of a bureaucratic basis for the exploitation of a conquered population. By the eighteenth century such social numbers were considered to encode insights into how society functioned. Süssmilch, for example, argued that the differences in birth and death rates of boys and girls balanced perfectly so as to provide marriage prospects for them all. In other words, from the chaos of human life arose a kind of law of the masses that stabilized society.

Süssmilch's observations helped to establish the idea that society observed rules that were ordained by no government yet could be revealed by counting. This led Immanuel Kant in 1784 to speak of 'universal laws' which,

> [h]owever obscure their causes, [permit] us to hope that if we attend to the play of freedom of human will in the large, we may be able to discern a regular movement in it, and that what seems complex and chaotic in the single individual may be seen from the standpoint of the human race as a whole to be a steady and progressive though slow evolution of its original endowment.[8]

On the one hand, this belief in 'laws' of society that lay beyond the reach of governments was a product of the Enlightenment faith in the orderliness of the universe. On the other, it is not hard to see within it the spectre of the Industrial Revolution with its faceless masses of toiling humanity like so many swarming insects. Before the nineteenth century, the laws that applied to Graunt's 'social numbers' were regarded as evidence of divine wisdom and planning. To later commentators they were the preconditions for catastrophe and revolution.

This study of social numbers needed a name. In 1749 the German scholar Gottfried Achenwall suggested that since this 'science' dealt threshold of a true utopia, as he indicated in his *Esquisse*:

How consoling for the philosopher who laments the errors, the crimes, the injustices which still pollute the earth and of which he is often the victim is this view of the human race, emancipated from its shackles, released from the empire of fate and from that of the enemies of its progress, advancing with a firm and sure step along the path of truth, virtue and happiness![10]

It is not hard to read in this passage an attempt by the author to console himself in the face of a bleak future. The *Esquisse* was written hurriedly in hiding while Robespierre's agents hunted for its author. His was a dramatic fall from favour, and tells us much about the nature of revolutions.

In 1792 Condorcet's intellectual reputation and his support for the Republican cause earned him a seat on the Committee of Nine that was charged to draft the new French Constitution. Among Condorcet's colleagues was Thomas Paine, a French citizen after his exile from Britain following the publication of his book *The Rights of Man*. The draft Constitution was blocked by Robespierre, who resented having been excluded from the Committee. When a new version, hastily redrafted by another makeshift committee and full of loopholes, was accepted, Condorcet published an anonymous letter urging the people to reject it. His authorship did not stay secret for long, and he was convicted of treason.

The *Esquise*, penned in a safe house in Paris run by one Madame Vernet, is, particularly under the circumstances, strikingly optimistic. Condorcet regards mankind as having 'evolved' from the level of beasts to a state of higher intelligence whereby people acquire an innate altruism. He sees no reason why this evolution (anticipating Darwin) cannot continue until people are 'perfected' – an idea in stark contrast to Jean-Jacques Rousseau's view that civilized man is corrupted. In the future utopia, says Condorcet, medical science will conquer all disease, and people will be too enlightened to go to war. Education will abolish social inequality, and all people will speak the same language. 'Are we not arrived at the point', he asked,

> where there is no longer any thing to fear, either from new errors, or the return of old ones? . . . Everything tells us that we are approaching the era of one of the grand revolutions of the human race . . . The present state of knowledge assures us that it will be happy.[11]

This soaring vision was not that of a worldly man. Although Condorcet eluded his captors as they came to arrest him, his refined manner aroused suspicion in the country inn to which he fled, and he was swiftly apprehended. He was taken to prison at Bourg-la-Reine, near Paris. With the guillotine his likely fate, he seems to have committed suicide by poisoning himself in his cell. Had he remained hidden for just several months more, he would have escaped his persecutor for ever: Robespierre himself went to his death in July 1794.

The *Esquisse* became posthumously celebrated. Malthus read it but did not share its rosy outlook. Condorcet was aware that population growth could eventually overwhelm available resources and threaten the stability of civilization, and he had a simple remedy – birth control. Malthus did not think it would be so easy. He reckoned that the 'passions of mankind' put population outside the control of governments, whether they sought either to encourage or to limit its rise. It was, he believed, a 'law of nature' that the populace would multiply exponentially, while society could not increase the means of feeding itself at the same rate. Thus nations must succumb sooner or later to overcrowding, misery, poor health and social unrest – which would bring with them the stark choice between repression and revolution. To escape this fate, people would do well to accept that government