In Praise of Natural Philosophy

A Revolution for Thought and Life

NICHOLAS MAXWELL

In Praise of Natural Philosophy

A Revolution for Thought and Life

NICHOLAS MAXWELL

McGill-Queen's University Press
Montreal & Kingston • London • Chicago

ISBN 978-0-7735-4902-9 (cloth)
ISBN 978-0-7735-4903-6 (paper)
ISBN 978-0-7735-4904-3 (ePDF)
ISBN 978-0-7735-4905-0 (ePUB)

Legal deposit first quarter 2017
Bibliothèque nationale du Québec

Printed in Canada on acid-free paper that is 100% ancient forest free (100% post-consumer recycled), processed chlorine free

McGill-Queen's University Press acknowledges the support of the Canada Council for the Arts for our publishing program. We also acknowledge the financial support of the Government of Canada through the Canada Book Fund for our publishing activities.

Library and Archives Canada Cataloguing in Publication

Maxwell, Nicholas, 1937–, author
In praise of natural philosophy: a revolution for thought and life / Nicholas Maxwell.

This book is an expansion of an article published in *Philosophia* 40 (4), 2012, 705–15.
Includes bibliographical references and index.
Issued in print and electronic formats.
ISBN 978-0-7735-4902-9 (cloth). – ISBN 978-0-7735-4903-6 (paper). – ISBN 978-0-7735-4904-3 (ePDF). – ISBN 978-0-7735-4905-0 (ePUB)

1. Physics – Philosophy. 2. Science. 3. Philosophy. I. Title.

QC6.M39 2017 530.01 C2016-906502-2
C2016-906503-0

This book was typeset by Marquis Interscript in 10.5 / 13 Sabon.

Contents

APPENDICES

Acknowledgments

This book grew out of an article with the same title I published in *Philosophia* 40 (4), 2012, 705–15. I am grateful to Asa Kasher and Springer, editor and publisher of *Philosophia*, for permission to reuse the title, and to republish in the present book a few paragraphs from the original article. Part of chapter 3 has been adapted from text published in Nicholas Maxwell, "What Philosophy Ought to Be," in *Death And Anti-Death, Volume 11: Ten Years After Donald Davidson (1917–2003)*, edited by Charles Tandy (Palo Alto, CA: Ria University Press, 2014). Charles Tandy is thanked for permission to republish this text.

Preface

The central thesis of this book is that we need to reform philosophy and join it to science to recreate a modern version of natural philosophy; we need to do this in the interests of rigour, intellectual honesty, and so that science may serve the best interests of humanity.

The book seeks to redraw our intellectual landscape. It leads to a transformation of science, and to a transformation of philosophy, so that these two distinct domains of thought become conjoined into one: natural philosophy. This in turn has far-reaching consequences for the whole academic enterprise. It transpires that we need an academic revolution. We urgently need to reorganize universities so that they become devoted to seeking and promoting wisdom by rational means – as opposed to just acquiring knowledge, as at present.

Modern science began as natural philosophy. In the time of Newton, what we call science and philosophy today – the disparate endeavours – formed one mutually interacting, integrated endeavour of natural philosophy: to improve our knowledge and understanding of the universe, and to improve our understanding of ourselves as a part of it. Profound discoveries were made, indeed one should say unprecedented discoveries. It was a time of quite astonishing intellectual excitement and achievement.

And then natural philosophy died. It split into science on the one hand, and philosophy on the other. This happened during the eighteenth and nineteenth centuries, and the split is now built into our intellectual landscape. But the two fragments, science and philosophy, are defective shadows of the glorious unified endeavour of natural philosophy. Rigour, sheer intellectual good sense, and decisive argument demand that we put the two together again, and rediscover the immense merits of the integrated enterprise of natural philosophy. This requires an intellectual revolution, with dramatic implications for how we understand our world, how we understand and do science, and how we understand and do philosophy. There are dramatic implications, too, for education.

And it does not stop there. For, as I will show in the final chapter, resurrected natural philosophy has dramatic, even revolutionary *methodological* implications for social science and the humanities, indeed for the whole academic enterprise. It means academic inquiry needs to be reorganized so that its basic task becomes to seek and promote wisdom by rational means, wisdom being the capacity to realize what is of value in life, for oneself and others, thus including knowledge, technological know-how, and understanding, but much else besides.

The outcome is institutions of learning rationally designed and devoted to helping us tackle our immense global problems in increasingly cooperatively rational ways, thus helping us make progress towards a good world – or at least as good a world as possible.

IN PRAISE OF NATURAL PHILOSOPHY

1

Triumphs of Natural Philosophy

In this book I set out to expose an intellectual disaster at the heart of our culture – at the heart of our world. It has a multitude of adverse repercussions for the way we think and the way we live. Science and scholarship are adversely affected. Our understanding of our place in the universe is obscured. Our ability to see what is of value in life, and our ability to achieve what is of value, are undermined. Peace, justice, liberty, democracy, sustainability are all compromised. The disaster obstructs attempts to develop institutions and social endeavours that work in our best interests. It sabotages our efforts to make progress towards a good world.

What is this malignant intellectual disaster that spreads its tentacles in such an abundant fashion throughout our world? It is, to begin with, a blunder about the nature of science. But it is also a long-standing blunder about how to understand our human world – the world as we experience it, imbued with consciousness, free will, meaning and value – given the new vision of the universe ushered in by modern science. It is a blunder about the nature of rational inquiry and, perhaps even more important, the nature and desirability of rational living, of rational institutions. Our very psyches are affected, the way we split off reason and intellect from feeling and desire, fact from value, science from art.

It is, at root, a philosophical blunder – or a series of philosophical blunders.[1] At once it will seem absurd to hold that philosophical blunders could have such dire, far-flung consequences. Everyone knows that philosophy is a dry, esoteric discipline, of absorbing interest no doubt to its academic practitioners, but otherwise devoid of relevance to anything else whatsoever.

Academic philosophy as it exists today is however one of the products of the disaster I seek to expose, and correct. The very act of correcting it reveals that philosophy as it should be pursued is far too important, for thought and for life, to be left to its current academic practitioners.

The intellectual disaster that we shall be concerned with in this book threads its way far back into our history. It has its roots in the seventeenth century, with the birth of modern science. That is where we will begin.

I must stress, however, that what follows in this chapter is only a sketch of those elements of the scientific revolution just sufficient to provide a historical background to the blunder about the nature of science (and inquiry more generally) that is the real theme of this book.[2] Towards the end of the chapter, I make a few remarks about what historians of science have said about the scientific revolution in recent decades.

SCIENCE BEGAN AS NATURAL PHILOSOPHY

Modern science began as natural philosophy, or "experimental philosophy," as it was sometimes called. In the time of Isaac Newton, in the seventeenth century, science was not only called natural philosophy. It was conceived of, and pursued, as a development of philosophy. It brought together physics, chemistry, and other branches of natural science as we know it today, with diverse branches of philosophy: metaphysics, epistemology, methodology, philosophy of science – even theology. Science and philosophy, which we see today as distinct, in those days interacted with one another and formed the integrated enterprise of natural philosophy.[3] Its basic aim was to improve our knowledge and understanding of the universe – and to improve our understanding of ourselves as a part of the universe. And around the time of Newton there was this great upsurge of excitement and confidence. For the first time ever, in the history of humanity, the secrets of the universe, hitherto wholly unknown, had been revealed and laid bare for all to understand – or at least, for all those who understood Latin and the intricate mathematics of Newton's *Principia*.[4]

Today we look back at the great intellectual figures associated with the birth of modern science and we unhesitatingly divide them up into scientists on the one hand, philosophers on the other. Galileo, Johannes Kepler, William Harvey, Robert Boyle, Christiaan Huygens, Robert Hooke, Edmond Halley, and of course Isaac Newton are all scientists; Francis Bacon, René Descartes, Thomas Hobbes, John Locke, Baruch Spinoza and Gottfried Leibniz are philosophers (see table 1 for dates). But this division is anachronistic. They did not see themselves in this fashion. Their work interacted in all sorts of ways, science with philosophy, philosophy with science. They all sought, in one way or another, to improve our knowledge and understanding of the universe, to improve our understanding of how we can acquire knowledge of the universe, and to work out the implications, for our understanding of ourselves, of the new view of the universe that the new natural philosophy had ushered in.

That the distinction we make between science and philosophy is anachronistic when projected back into the sixteenth and seventeeth centuries becomes all the more apparent when one considers the *philosophy* that was done by those natural philosophers we now consider to have been scientists, and the *science* done by those natural philosophers we now regard as philosophers. Thus Galileo, for us a scientist, made a substantial contribution to what we would now regard as philosophy when he drew the distinction between what came to be called "primary" and "secondary" qualities. He writes:

> Whenever I conceive any material or corporal substance, I immediately feel the need to think of it as bounded, and as having this or that shape; as being large or small in relation to other things, and in some specific place at any given time; as being in motion or at rest; as touching or not touching some other body; and as being one in number, or few, or many. From these conditions I cannot separate such a substance by any stretch of my imagination. But that it must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odour, my mind does not feel compelled to bring in as necessary accompaniments … Hence I think that tastes, odours, colours, and so on are no more than mere names so far as the object in which we place them is concerned, and they reside only in the consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated.[5]

Galileo goes on, delightfully, to consider a hand tickling a person and a statue, and points out that we would consider it ridiculous to hold that the tickling is a property of the hand in addition to its motion and touch. The tickling sensation is in the person being tickled, not in the hand that does the tickling; and so it is, Galileo argues, for colour, sound, taste, and odour. He adds, very significantly, that "to excite in us tastes, odours, and sounds I believe nothing is required in external bodies except shapes, numbers, and slow or rapid movements."[6] Galileo is here, of course, elaborating on what Democritus had asserted 2,000 years earlier: "Colour exists by convention; sweet and sour exist by convention: atoms and the void alone exist in reality."[7] Galileo is in effect affirming the key metaphysical tenet of the new natural philosophy: the universe is made up of atoms in motion or, more generally, of physical entities in motion whose physical properties can be depicted in mathematical terms. Galileo is also, implicitly, invoking a key paradox inherent in the new natural philosophy: on the one hand there is the appeal to observation and experiment, while on the other hand, the new (or revitalized) metaphysical vision of the universe – atomism, or the corpuscular hypothesis – tells us that perception is profoundly delusive. This paradox, unresolved, played an important role in driving science and philosophy apart, as we shall see.

Newton, whom we undeniably deem to be a scientist, echoed Galileo's philosophical remarks concerning real physical properties and illusory perceptual qualities, in connection with light. He also put forward many metaphysical theses and speculations about such matters as space, time, the aether, and unknown forces governing physical and chemical phenomena. He engaged in philosophy of science in seeking to characterize scientific method by means of four "rules of reasoning in philosophy," as we shall see below. And he even engaged in theology in arguing that God played an important role in setting up the solar system, and in intervening from time to time to ensure its continuing existence.

Descartes, for us a philosopher, made a vital mathematical contribution to subsequent science by creating what we call "Cartesian coordinates." This made it possible to translate geometrical figures, curves and problems into algebraic equations and vice versa, thus facilitating the mathematical treatment of motion. Descartes was the first person to formulate the correct version of the law of inertia.[8] He put forward laws of reflection and refraction, and proposed what we would today call a physical "theory of everything" intended to account for all phenomena, including those associated with the solar system. According to this theory, what seems to be empty space is really filled with invisible particles that possess extension and motion but no other property. Swirling vortices of these particles sweep the planets around the sun. That this theory turned out to be unworkable,[9] or at least false on empirical grounds, does not negate its scientific character, or its important role in the history of science.

Leibniz, another philosopher, made a vital contribution to science by inventing the integral and differential calculus, independently of Newton, Leibniz's formulation being the one that was subsequently used.

Finally Locke, unquestionably for us a philosopher, declares at the beginning of his *Essay concerning Human Understanding* that he sees his task to be that of an under-labourer of the work of "such masters as the great Huygens and the incomparable Mr. Newton" in "clearing ground a little, and removing some of the rubbish that lies in the way of knowledge."[10]

There were good reasons why, in the seventeenth century, empirical science could not be split off from philosophy. Natural philosophers disagreed about crucial questions of method. Should evidence alone decide which theories are accepted and rejected, or does reason play a role as well? After the work of Galileo and Kepler, and with the work of Descartes and, above all, Newton, it became apparent that mathematics had an important role to play in science, along with observation and experiment. But mathematical truths can be established by reason alone. Reason must therefore have an important role in science. But how? In what way? Some held that all knowledge comes to us via the senses, via experience. Reason, according to this kind of empiricist view, could not establish any knowledge at all independent of experience. The nature of mathematical knowledge became problematic. Others – most notably Descartes and Leibniz – held that reason plays a vital role in natural philosophy, in the enterprise, that is, of acquiring knowledge of the universe. These different views about the roles of experience and reason in science led to different methods in science, and thus had practical consequences for science itself: they had to be discussed as a part of science.

Again, the new natural philosophy ushered in a new vision of the universe: it is made up of colourless, soundless, odourless corpuscles which interact only by contact. This metaphysical view[11] had an impact on what scientific theories are to be accepted and rejected; natural philosophers held different versions of the view, and different attitudes to the influence the view should have on science: all this had to be discussed as an integral part of science. Physics and chemistry could hardly be pursued without some thought being given to the manner in which corpuscles might produce phenomena associated with light, combustion, heat, chemical reactions, gravitation.

Table 1 Some natural philosophers of the scientific revolution

Leonardo da Vinci 1452–1519	Pierre Gassendi 1592–1655
Nicolaus Copernicus 1473–1543	René Descartes 1596–1650
William Gilbert 1544–1603	Robert Boyle 1627–1691
Tycho Brahe 1546–1601	Christiaan Huygens 1629–1695
Giordano Bruno 1548–1600	John Locke 1632–1704
Francis Bacon 1561–1626	Baruch Spinoza 1632–1677
Galileo Galilei 1564–1642	Robert Hooke 1635–1702
Johannes Kepler 1571–1630	Isaac Newton 1642–1727
William Harvey 1578–1657	Gottfried Wilhelm Leibniz 1646–1716
Thomas Hobbes 1588–1679	Edmond Halley 1656–1742

In addition, the corpuscular hypothesis provoked profound philosophical problems about how it is possible for human beings to acquire knowledge of the universe, and how it is possible for people to be conscious, free, and of value if immersed in the physical universe. If everything really is made up of colourless, soundless, odourless particles, how come roses are red, dogs bark, and lavender smells? If our bodies and brains are made up exclusively of these particles, what becomes of our inner sensations, our consciousness? If all our knowledge of the world around us is based on particles of light entering our eyes, other particles bouncing against our eardrums or nostrils, how is it that we know anything about what we think we see, hear, and smell? And if the corpuscles dart about and collide in accordance with precise, mathematical laws, how can we be responsible for our actions? What becomes of free will? Natural philosophers could hardly take the corpuscular theory seriously in what we might today regard as their "scientific" work, and then just ignore the radical and disturbing implications this theory seems to have for human knowledge, consciousness and free will. They did not, as we shall see.

The new science did not just usher in a new vision of the universe. Its birth owed much to the advent of this new vision. One might have supposed, naively, that modern science began when people started to take evidence seriously. Is not modern science based on evidence? What more natural, then, than to suppose that science began when people based the pursuit of knowledge, not on mere tradition or authority, but on evidence?

To be fair, there is an element of truth in the idea – but only an element. Appealing to evidence did not begin with the birth of modern science. And factors other than appealing to evidence were of even greater significance. A key factor was a revolution in philosophy: the downfall of Aristotelianism, and the creation – or recreation – of the corpuscular hypothesis, or the more general view that the universe has some kind of mathematical structure, or that "the book of nature is written in the language of mathematics" as Galileo put it.[12] Kepler, Galileo, Descartes, Huygens, and Hooke all held versions of this view. And their adoption of the view played an essential role in their scientific work – as we should call it today.

Aristotelianism is the view that change comes about because objects strive to actualize their inherent potentialities, much as an acorn strives to actualize its potential to become an oak tree. Objects fall because they have an inherent potential to seek the centre of the earth. The natural world is, in a sense, alive. Purpose, goal-seeking is built into the constitution of things. According to Aristotelianism, a sharp distinction is to be made between terrestrial and heavenly phenomena. The earth is at the centre of the universe. On earth, there is imperfection, change, decay, and phenomena do not observe precise, mathematical laws. In the heavens, by contrast, there is perfection, no decay, and the motions of heavenly bodies do observe precise mathematical laws.

COPERNICUS AND THE DOWNFALL OF ARISTOTELIANISM

The first step towards the overthrow of Aristotelianism was the Copernican revolution.[13] The earlier theory of Ptolemy put the earth at the centre of the universe, the sun, planets, and stars rotating around the earth in uniform, circular motion. In order to account for deviations from uniform circular motion, Ptolemy was forced to postulate epicycles, and other devices. Thus planets move as if fixed to the rim of a uniformly rotating disk, the centre of which is fixed to the rim of a much bigger, uniformly rotating disk which has its centre at the centre of the earth. By means of a horrendously complex system of epicycles and other such devices, Ptolemy was able to account for the observed motions of the planets, the sun, and the stars.

Copernicus hesitated to publish his new theory of the cosmos (as the solar system was then thought to be) not, it seems, because he feared persecution from the Church, but rather because he feared ridicule from his fellow scholars. It was not until he lay on his deathbed in 1543 that his book *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Spheres), setting out his new theory, was published.

It was not evidence that prompted Copernicus to put the sun at the centre of the solar system. He may have been influenced somewhat by a tendency towards sun-worship. And he may also have been influenced by Aristarchus, a third-century BC Greek who put forward the heliocentric view. The decisive factor however was simplicity. A sun-centred solar system promised to be much simpler than Ptolemy's complicated system. Evidence, if anything, told against Copernicus's theory. Both theories accounted equally well for observed astronomical motions, but Copernicus's theory faced additional empirical problems. First, there was the problem that if the earth rotates on its axis every twenty-four hours[14] and sweeps at vast speed around the sun, why is this motion not felt? Why does a stone, thrown vertically into the air, not fall some distance away because of the earth's motion during the stone's flight? And if the earth goes round the sun, why do the stars have the same, fixed relative positions at six-month intervals? Stars would have to be absurdly far away for no parallax to be observed.[15]

If planets moved in circles round the sun, Copernicus's theory would indeed have been much simpler than Ptolemy's. But, as Kepler subsequently discovered, they move in ellipses. In order to reduce the motions of the planets to uniform circular motion, Copernicus was obliged to introduce complicated epicycles of just the kind that bedevilled Ptolemy's theory. And in the end, in order to do justice to observations, Copernicus had to stipulate that the planets went round, not the sun, but a point in space some distance from the sun. The beautifully simple idea of Copernicus, or of Aristarchus before him, became somewhat complicated and ugly when developed in detail so as to do justice to observation – although, even in its final, complicated form, Copernicus's theory is still simpler than Ptolemy's.[16]

There is, nevertheless, a beautifully simple idea, which does not quite work, buried in the complexities of Copernicus's actual theory, which does work. It was this beautifully simple idea that subsequently inspired Galileo, Kepler, and a few others.

The Copernican revolution has dramatic implications for Aristotelianism. No longer is the earth at the centre of the cosmos, utterly distinct from the heavens. The earth is thrown into the heavens, one planet among the others that encircle the sun. This may be taken to mean, on the one hand, that the earth, now itself a part of the heavens, partakes of the mathematical precision of the heavens. Apparently wayward, haphazard terrestrial phenomena such as weather, growth, and decay, all occur, perhaps, in accordance with unknown, mathematically precise law. On the other hand, the Copernican revolution may be taken to imply that since the earth is a part of the heavens, and imperfection, change, growth, and decay are everywhere apparent on earth, all this obtains on other heavenly bodies too – the moon, the planets, even the sun. Both these implications came to dominate the thinking and work of Galileo, Kepler, and those that came after them. The implications of the Copernican revolution only came to full fruition, however, with Newton. His laws of motion and law of gravitation apply with equal force to all phenomena, terrestrial and heavenly: to the motion of a stone thrown into the air on earth, and to the motion of the earth and other planets around the sun.

There is a diagram in Newton's *Principia* which vividly depicts the point. It shows the earth. Projectiles are hurled horizontally from a mountain peak with greater and greater force. The projectiles travel further and further around the earth before they crash into the ground. But eventually a projectile is hurled with such force that it goes all the way round the earth and returns to the mountain peak from which its flight began. It is in orbit – like the moon, or, more accurately, like today's satellites. Thus is continuity between the terrestrial and astronomical depicted in graphic terms. But we are getting ahead of ourselves!

The Copernican revolution was not the only reason for a reawakening of the ancient Greek idea that the ultimate nature of the cosmos might be mathematical in character – or such that it could only be depicted employing mathematical ideas. This reawakening came also from the Renaissance, and a renewed interest in the work of Plato, Pythagoras, Euclid, and Archimedes, all of whom can be regarded as holding that the physical universe is mathematical in character. Leonardo, who died before Copernicus's great work was published, nevertheless became convinced that mathematics held the key to understanding nature.[17] Others convinced of the importance of mathematics in this respect include Roger Bacon (1214–1294), Nicholas of Cusa (1401–1464), and Giordano Bruno.

Bruno was an early convert to Copernicus's heliocentric view. Influenced possibly by Nicholas of Cusa, who held somewhat similar views, Bruno argued that the universe is infinite in extent, in both space and time, and homogeneous in that the same four elements – (water, earth, fire, air) are present everywhere. He held that the stars are distant suns with their own planetary systems. Matter, Bruno held, is made up of atoms, but these are living, possessing a kind of intelligence (an idea which does not help much with the universe having a precise mathematical structure at a fundamental level).

In January 1600, after a protracted trial, Bruno was condemned as a heretic, partly for his religious views, partly for his cosmology, and on February 27 of that year he was burned at the stake.

William Gilbert was another early convert to Copernicus's theory. His great contribution to natural philosophy, however, was to investigate magnetism experimentally. He discovered many properties of the lodestone, and discovered, too, that the earth is a gigantic magnet. In life, he fared rather better than Bruno. He was a successful physician, and ended up chief physician to Queen Elizabeth and, briefly, to King James.

The full rich implications of Copernicus's theory only began to emerge, however, with the work of Kepler and Galileo.

KEPLER

Kepler started out studying theology. It occurred to him that he could study God by studying His creation: the heavens. He decided to devote himself to astronomy. And in a flash of inspiration, he thought he might have discovered the secret of the cosmos. If one imagined the five Platonic solids – in a form both gigantic and invisible – being placed one inside the other, centred on the sun, then the planets could be understood as pursuing circular paths around the sun in the spaces within, between and around the five solids. Thus could one explain why there are only six planets (all that were known at the time), and why they are arranged as they are, with their various distances from the sun. (A great triumph of Euclidean geometry is the theorem that there are only five perfect solids, the so-called Platonic solids: the tetrahedron, the cube, the octahedron and so on.[18]) Even though Kepler discovered subsequently that the actual distances of the planets from the sun do not accord with those predicted by his great idea, he never altogether abandoned it.[19] What is really significant for the theme of this chapter is that Kepler's idea is a magnificent exemplification of the thesis that the universe has a mathematical structure. Kepler's first revelation into the structure of the universe amounts to a special (if false) case of the general, profound idea inherent in the birth of modern science, the scientific revolution, and the immense success of science ever since: *some* kind of beautiful mathematical structure is built into the universe, into the way all natural phenomena occur.

This general idea informed all of Kepler's subsequent great astronomical discoveries, his big contributions to science or, rather, to natural philosophy. In essence, these consist of the following three laws of planetary motion:

1. The planets orbit the sun in ellipses, with the sun at one of the two foci of each ellipse.
2. The planets move in such a way that a line joining any planet to the sun sweeps out equal areas in equal times.
3. The time taken for each planet to orbit the sun is such that the square of the time taken is proportional to the cube of the semi-major axis of the orbit.[20]

Kepler's works are packed with many additional numerical relationships concerning the solar system which he regarded as being of equal importance, but the above three laws embody Kepler's great contribution to science – to natural philosophy.

Accurate observation played a major role in Kepler's discovery of these three laws. Kepler was fortunate to meet and, for a time, work for Tycho Brahe, who had amassed a body of observations of the planets of great accuracy for the period.[21] When Tycho Brahe died, Kepler inherited his data, and was employed to work on them. It was Tycho Brahe's observational data that made it possible for Kepler to discover and confirm his three laws.

But if observational data were important, so too was Kepler's metaphysical view of the cosmos, his conviction that it had been created by God to exemplify a magnificent, harmonious mathematical structure. It was Kepler's conviction that the motions and distances of planets must exemplify simple and beautiful mathematical relationships that made it possible for him to discover his three laws, and accept them as representing genuine knowledge when they fitted the facts of observation.

Somewhat analogous considerations apply to Galileo, except that in Galileo's case what is most significant in his work depends even more on observations and experiments he carried out himself than is the case with Kepler.

GALILEO

Galileo, more than any other single individual, was responsible for the demise of Aristotelianism, the adoption in its stead of Copernicanism and what might be called the "mathematical" view of nature, and the creation of the new natural philosophy – or what we now call modern science. Galileo fruitfully developed both implications (mentioned above) of Copernicus's theory that result from the theory hurling the earth into the heavens: first, that heavenly phenomena exhibit change and imperfection just like phenomena on earth, and second, that apparently random, chaotic phenomena on earth actually occur in accordance with precise mathematical law – something hitherto associated with the heavens.[22]

The opportunity to develop the first implication arose when Galileo turned his newly invented telescope to view the skies.[23] He discovered that the moon has mountains and craters, and is far from the perfect sphere of Aristotelian orthodoxy. He discovered, most momentously perhaps, that Jupiter has four moons which rotate around it – an emblematic image of the Copernican vision of the solar system. He discovered that Saturn is not a perfect sphere – the first observational hint of Saturn's rings. He discovered that Venus has phases like the moon, an observation which can easily be explained given Copernicus's theory but which is almost impossible to explain given Ptolemy's. He discovered that the Milky Way is made up of a multitude of stars, an observation that supports the idea of Nicholas of Cusa, Bruno, Gilbert, and others that stars are spread out in an immense space – perhaps an infinite space. And he discovered that the sun has dark spots on its surface which rotate with the rotation of the sun and which come and go, a manifestation of imperfection and change.

Galileo reported these discoveries in *The Starry Messenger*, a book that made Galileo famous all over Europe – indeed, all over the educated world. A translation of the book appeared in China five years after its first publication in 1610.

Galileo worked on developing the second implication of Copernicus's theory, on and off, throughout much of his life. By far the most important of this work was his discovery of laws governing terrestrial motion.[24] His first discovery was made when he was sixteen years old, soon after first becoming interested in mathematics. During a sermon in the cathedral in Pisa, he noticed, using his pulse to measure time, that a swinging chandelier took the same time to complete a swing however wide or gentle its swings might be. Some years later, Galileo confirmed by experiments that the time a pendulum takes to execute one cycle of swings depends only on the length of the pendulum, and is independent of the amplitude of the swinging or the weight of the bob.

Galileo's most famous discovery concerning terrestrial motion is probably that all objects near the earth fall at the same rate whatever their weight may be, and fall with constant acceleration. Legend has it that Galileo dropped balls of different weight from the leaning tower of Pisa to refute Aristotle's claim that the rate of fall is proportional to the weight of the object. There is no evidence that Galileo did drop balls from the leaning tower of Pisa. The experiment was performed, rather, by an Aristotelian opponent to refute Galileo and confirm Aristotle. And that was the result claimed for the experiment: the heavy weight did hit the ground a bit before the light one! Galileo was scornful in his dismissal of this conclusion.[25] Historians of science used to believe that Galileo never did perform the experiment anywhere. But more recently, examination of Galileo's papers has revealed that he performed the experiment many times, noting the results with considerable accuracy. Galileo also sought to confirm his discovery that objects fall with constant acceleration by measuring the time balls take to roll down inclined planes – experiments which again, it seems, Galileo really did perform.[26]

Another achievement of Galileo is his discovery of the law of inertia: in the absence of friction or other forces, a body continues in its state of uniform motion in a straight line (and does not gradually come to rest as Aristotelianism holds). Closely associated with this is Galileo's enunciation of what, today, is called "Galilean invariance": laws governing motion – or, more generally, all laws – are the same with respect to all bodies as long as they are moving with uniform velocity in a straight line. In his *Dialogue concerning the Two Chief World Systems* published in 1632 (which in effect argued for Copernicus and against Ptolemy, and got Galileo into trouble with the Catholic Church), Galileo considers a ship travelling smoothly through a calm sea. He argues that no experiment performed in the cabin of the ship would be able to tell that the ship was in motion. Exactly the same results would be obtained as experiments performed at rest on land.

As I have indicated, these Galilean laws of terrestrial motion are of decisive importance when it comes to rebutting what were, at the time, standard objections to the Copernican theory. These laws explain why, for example, a stone thrown vertically into the air returns to the point from which it was thrown even though the earth is hurtling through space round the sun.

The law of inertia and Galilean invariance subsequently became key components of Newtonian physics and were not revised until the advent of Einstein's theory of special relativity in 1905.[27]

Galileo made clear that his laws of terrestrial motion ignored air resistance and friction. And indeed a feather falls as fast as lead shot in a vacuum.

Galileo did not succeed quite in enunciating the law of inertia in the form I have just stated it. He considered a ball rolling on a smooth plane and realized it would move in a giant circle as it travelled round the earth. For Galileo, inertial motion is circular motion, not motion in a straight line. It is possible that he hoped that his version of the law of inertia would somehow explain what he took to be the circular motion of the planets round the sun, the motion of the moon round the earth, and the motion of the moons of Jupiter. But any such idea neglects, of course, that these bodies are subject to the force of gravitation, and thus are not exhibiting inertial motion.

As I have already mentioned, it was Descartes who first articulated the law of inertia in its correct form: bodies continue in their state of rest or uniform motion in a straight line unless a force is impressed upon them.[28]

Galileo also discovered that projectiles trace out parabolas as they fly through the air – neglecting air resistance. (A parabola is an ellipse with one focus moved to infinity.) That projectiles do move along parabolas is a consequence, as Galileo demonstrated, of two of his other discoveries: the law of inertia, and the law of free fall with constant acceleration. It is because a thrown stone continues to have the motion it acquired when it left the hand, and at the same time falls towards the earth with constant acceleration, that it executes the path of a parabola as it flies through the air.

Galileo's achievements are remarkable, both for *what* he achieved, and for *how* he achieved it. More than any other of his contemporaries, Galileo strikes one as doing science in the way that scientists do it today. He is the first modern scientist – as well as a great natural philosopher! Not only does he exploit the telescope brilliantly to obtain observational results highly pertinent to the key cosmological problem of the time: Ptolemy or Copernicus? Even more strikingly, he performs experiments to test, to falsify or corroborate, theoretical conjectures. And he derives consequences from theories and tests them against the results of experiments.

Galileo was not, however, an out-and-out empiricist. He is quite clear that physical objects and natural phenomena exhibit mathematical structure. And not just any mathematics, but rather in essence *simple* mathematics. Thus it emerges that objects move in accordance with mathematically *simple* laws once one puts aside inessential complications due to friction and air resistance. The intrinsically simple mathematical structure of the universe makes it possible for us to discover what this structure is – as long as we acknowledge that it does have such a structure and develop, as a result, conjectures and theories that reflect this mathematical reality. There are, in short, two crucial components in Galileo's conception of scientific method. There is, first, the appeal to observation and experiment. But equally, there is the appeal to a quite definite metaphysical view of the universe: the book of nature is written in the language of mathematics – ultimately *simple* mathematics. Both play essential roles in Galileo's discoveries, not just psychologically, but methodologically.[29] As for Kepler, so for Galileo: *evidence* and *metaphysics* are both essential – the metaphysics being that the universe has some kind of underlying simple mathematical character.

One astonishing feature of Kepler's and Galileo's achievements is that the somewhat different astronomical and terrestrial motions that they discovered are both examples of conic sections. Conic sections are curves produced by the intersection of a plane with a circular cone. Imagine the cone stands upright on a table. If the intersecting plane is horizontal, the resulting curve of intersection is a circle. Tilt the plane, and the curve of intersection becomes an ellipse. Tilt the plane further so that its slope is as steep as the slope of the cone's side, and the curve of intersection becomes a parabola. Tilt the plane even further so that its slope is even steeper than the sides of the cone, and the curve of intersection becomes a hyperbola (or a pair of straight lines if the plane intersects the apex of the cone). The elliptical paths of planets, and the parabolic paths of stones thrown on earth, though different, nevertheless belong to a common class of curves. Even more astonishingly, conic sections were first identified and studied by ancient Greek mathematicians, Menaechmus, Apollonius, and others, almost 2,000 years before Kepler and Galileo discovered that planets in the heavens and stones hurled on earth travel along conic sections. We have here a dramatic example of something that has occurred on a number of occasions in the history of science: mathematicians exploring mathematical ideas with no thought whatsoever for applications to the physical universe nevertheless come up with discoveries which turn out to depict the way physical phenomena occur with incredible accuracy. It is as if mathematicians' minds are attuned, in some mysterious way, to the inner workings of nature. This capacity of pure mathematics to anticipate subsequent physics has baffled scientists and philosophers.[30] An explanation will be proposed in chapter 5 (note 17)!

NEWTON

The next great natural philosopher for us to consider is Isaac Newton. Building on the contributions of his great predecessors – Copernicus, Kepler, Galileo, and Descartes – Newton produced a kind of triumphant synthesis of their work. But it was much more than a synthesis of his predecessors. Newton laid the foundations for classical physics, which met with ever-expanding empirical success until the theories of relativity and quantum theory in the twentieth century. And even today, long after the advent of these twentieth-century theories, it is still Newtonian physics that is used to calculate the paths of spaceships and artificial satellites. Newton put forward the first fundamental dynamical theory of physics ever – his theory of gravitation.[31] There are only six successful fundamental dynamical theories in physics, and Newton's was the first.[32] To some of his contemporaries and immediate successors, it seemed that Newton had done something almost miraculous. He had discovered the secret of the universe. He had put his finger on what it is that causes the earth, the moon, the planets and the stars to move as they do throughout the universe, for all time. There is a sense in which, with Newton, modern science comes of age. But, as we shall see, though Newton was clearly a natural philosopher himself, his work nevertheless played a key role in the demise of natural philosophy – its disintegration into science and philosophy.[33]

What, in a bit more detail, did Newton achieve? First, he created the differential and integral calculus, mathematics required to describe motion and change more generally, and essential for the subsequent development of physics.[34] But it is in the three Books of his *Principia*,[35] published in 1687, that Newton laid the foundations of classical physics and demonstrated how his universal law of gravitation was able to predict and explain the motions of the planets, moons, and comets of the solar system, together with a wealth of other phenomena as well. In the preface to the first edition of the *Principia*, Newton makes clear what he sets out to do – and even specifies clearly the research programme for the future of physics.

> The whole burden of philosophy seems to consist in this – from the phenomena of motions to investigate the forces of nature, and then from these forces to demonstrate the other phenomena; and to this end the general propositions in the first and second Books are directed. In the third Book I give an example of this in the explication of the System of the World; for by the propositions mathematically demonstrated in the former Books, in the third I derive from the celestial phenomena the forces of gravity with which bodies tend to the sun and the several planets. Then from these forces, by other propositions which are also mathematical, I deduce the motions of the planets, the comets, the moon, and the sea. I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards one another, and cohere in regular figures, or are repelled and recede from one another. These forces being unknown, philosophers have hitherto attempted the search of Nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy.[36]

Newton's suspicion – the conjecture he expresses here about the nature of the physical universe and the path physics would take in the future – has turned out to be substantially correct, even if Newtonian principles have had to be revised along the way. Three forces in addition to gravitation suffice in principle to account for all the known phenomena of Nature – properties of matter, electromagnetic, chemical and nuclear phenomena.[37]

In Book 1 of the *Principia*, after defining crucial notions such as "quantity of motion" (mass times velocity, or momentum), Newton formulates the following three laws of motion, the basis for classical mechanics:

> I Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.
> II The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.
> III To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.[38]

The second of these laws in effect asserts that the force, F, on a body is equal to the mass, m, times the acceleration, a, of the body, that is: $F = ma$.

Newton then goes on in Book 1 to prove a great number of propositions and theorems, many, but by no means all, related to the tasks of establishing his universal law of gravitation and using it to explain the System of the World – that is, the solar system – to be taken up in Book 3. Thus the first theorem proves that a body attracted by a force to a fixed point moves in such a way that the line joining the body to the fixed point sweeps out equal areas in equal times – echoes of Kepler's 2nd law! Theorem 2 establishes the converse: if a body moves so that a line joining it to a fixed point sweeps out equal areas in equal times then it is attracted to the fixed point by a force. Proposition 11 establishes that a body moving in an ellipse experiences a force directed at a focus of the ellipse, the strength of the force being inversely proportional to the square of the distance. Newton goes on to establish similar results for bodies moving in hyperbolas and parabolas. He then goes on, in Proposition 17, to prove the converse of these results, namely that if a body moves under the influence of a force directed towards a fixed point, the force varying inversely as the square of the distance, then the body will move in a conic section – an ellipse, parabola or hyperbola.

Book 2 is in the main concerned with the motion of bodies through fluids. It may have been written in part to refute Descartes' vortex theory of the solar system, according to which invisible swirling matter in space sweeps the planets round the sun (a modified version of which was also held by Huygens).

Book 3, exploiting the results of Book 1, sets out to establish Newton's universal law of gravitation and explain the System of the World. First, Newton makes explicit his conception of what we would today call "scientific method" in what he calls "Rules of Reasoning in Philosophy":

> Rule 1: We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.
>
> Rule 2: Therefore to the same natural effects we must, as far as possible, assign the same causes.
>
> Rule 3: The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.
>
> Rule 4: In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypothesis that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.[39]

Newton goes on to specify six "phenomena" – six regularities of the solar system – that form the empirical basis for arriving at the law of gravitation. These are that the moons of Jupiter and Saturn obey Kepler's 2nd and 3rd laws of planetary motion, and so too do the planets other than the earth in their motion round the sun; and our moon, in its motion round the earth, obeys Kepler's 2nd law.

We come now to the central claim of the *Principia* – a claim that was to have profound consequences for the subsequent development of science. Newton sets out to derive his law of gravitation from the phenomena by induction, appealing at various points to his laws of motion, theorems, and rules of reasoning.

Newton first proves, in Proposition 1, that the moons of Jupiter move subject to a force directed towards the centre of the planet that is inversely proportional to the square of the distance to the centre (i.e., $F \propto 1/D^2$, where D is the distance from the centre of the moon to the centre of Jupiter). He goes on to establish the same for the moons of Saturn and, in Proposition 2, the same for the planets (D in this case, of course, being the distance to the centre of the sun). The moon too is shown to obey the inverse square law (in Proposition 3). Then, invoking his first two rules of reasoning, Newton argues, in Proposition 4, that the force to which the moon is subject is the force of gravity – the very same force we feel on Earth and call gravity, responsible for bodies falling near the earth's surface. Likewise (Proposition 5), the moons of Jupiter are drawn towards Jupiter by the force of gravitation – as are the moons of Saturn towards Saturn. Indeed "there is a power of gravity tending towards all the planets." "And," Newton goes on, "since all attraction (by Law III) is mutual, Jupiter will therefore gravitate towards all his satellites, Saturn towards his, and the earth towards the moon, and the sun towards the planets." And "all the planets do gravitate towards one another" which means, Newton points out, that Jupiter and Saturn, when closest together, will sensibly disturb each other's motion, as the sun disturbs our moon's motion, and the sun and moon disturb our seas (causing the tides). Then (in Proposition 6), Newton sets out to establish that "all bodies gravitate towards every planet," weights of bodies, at any given distance from the centre of the planet, being proportional to the quantity matter (i.e., the mass). Newton then establishes in Proposition 7 that "there is a power of gravity pertaining to all bodies, that is proportional to several quantities of matter which they contain." Then, in Proposition 8, we have the theorem that, given two homogeneous spheres attracting each other by gravitation, the force on either towards the other "will be inversely as the square of the distance between their centres." Newton then establishes that the centre of the solar system is, not the centre of the sun, but rather the centre of gravity of the solar system, the sun being somewhat in motion with respect to this centre as it is tugged this way and that by the gravitational attraction of the planets. Newton then derives Kepler's laws for the planets *a priori*, as he puts it – the planets only moving precisely in ellipses, however, if gravitational forces between planets are neglected, and the sun is assumed not to move.[40]

Newton goes on to derive various consequences from his law of gravitation and what has been established so far. He discusses the flattening of the earth and other planets at the poles because of their rotation; variation in weight at different latitudes on the earth; gravitational attraction of the moon and sun producing the tides; the motion of the moon, affected by gravitational attraction of both the earth and sun (a difficult three-body problem which cannot be solved exactly); and the motion of comets, which are shown to be along conic sections (approximately parabolas close to the sun).

What Newton does in the *Principia* is extraordinarily impressive. It really does seem that Newton derives his universal law of gravitation from the phenomena, just as he claimed he had done. First, there are the purely mathematical theorems: bodies that move so as to obey Kepler's laws must be deflected from uniform motion in a straight line by a force that varies inversely as the square of the distance. Then, observation tells us that moons and planets do actually move so as to obey Kepler's laws. Therefore they must be subject to a force that varies inversely as the square of the distance. And since we can move, by degrees, from the motion of a stone thrown on earth to the motion of the moon round the earth, this force must be the force of gravitation, of which we are so familiar here on earth. Granted that every body in the universe gravitationally attracts every other body, it is clear that the motions of the moons and planets must deviate slightly from perfect Keplerian motion due to mutual gravitational attraction – the final, devastatingly convincing evidence in support of Newtonian theory.

The contrast with Kepler and Galileo is striking. Newton does not appeal to the metaphysical thesis that the universe has some kind of mathematical structure – or does not do so explicitly. He is quite clear. In a famous passage in the *Principia* he declares: "I have not been able to discover the cause of [the] properties of gravity from the phenomena, and I frame no hypotheses; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction."[41]

Newton, subsequently, was taken at his word. He became a hero of the Enlightenment. The *Principia* was seen as revealing what one has to do to secure knowledge. First, phenomena have to be reduced to precise regularities; then laws and theories can be inferred by induction, just as Newton had done, and had himself affirmed. No longer do natural philosophers need to engage in fruitless debate about metaphysics, philosophy, epistemology, and methodology. That could be left to the philosophers.

Newton's *Principia*, the moment of high triumph of the new natural philosophy also, paradoxically, spelled its downfall. It was Newton's *Principia* that led, eventually, to a decisive split between science and philosophy, and thus to the death of natural philosophy.

EPILOGUE: SCIENCE, PROGRESS, AND HISTORY

In this chapter I have argued that science began as natural philosophy, and this brings together two crucial elements: first, a new metaphysical vision of the universe (it is made up of atoms; it is governed by precise mathematical laws); and, second, associated with this, the empirical method of careful observation and experimentation. Both are essential. The second element stems, in part, from the first. New theories, in order to be acceptable, must meet two requirements: they must accord sufficiently well with the new metaphysical view of the universe, and they must meet with sufficient empirical success.

This picture of the origins of science and the scientific revolution has been expounded and defended by a number of notable historians of science: A.E. Burtt, Alexandre Koyré, Herbert Butterfield, Richard Westfall,[42] and others. But some historians of science have called aspects of this orthodox picture into question. Pierre Duhem[43] argued that there is far more continuity in the development of science than the orthodox picture allows; research conducted in medieval times anticipated aspects of the work of Galileo and his contemporaries. Other historians of science have pointed out that some of those who contributed to natural philosophy around the time of Galileo did not accept atomism or the mathematical view of nature, and may have seen the world in Aristotelian terms. This is true of both William Gilbert and William Harvey. Others have denied that there is anything unique or distinctive about the scientific revolution, or even that it existed at all.

Burtt and Koyré seem to be out of fashion. This may be, in part, because both stressed the importance of so-called "internal" factors – intellectual and methodological factors – in the emergence of modern science. These days, "external" factors – social, institutional, cultural, economic, political – are all the fashion among many historians of science, and internal factors are regarded as somewhat passé. In fact we need to attend to both.[44] Modern science has institutional, social, cultural, economic, and political aspects: in order to tell how it arose and evolved, all these features need to be appealed to. But science is also an intellectual endeavour; it seeks to improve our knowledge and understanding of the universe, and of ourselves and other living things as a part of the universe, and in that endeavour it has met with astonishing success. In order to understand how that intellectual success has come about, we need to attend to the intellectual and methodological aspects of science just as much as its social, political, and economic aspects. Indeed, there are grounds for holding that the intellectual leads the way. It was because natural philosophy began to be astonishingly successful *intellectually*, that it was able to attract support, social status, and funds.

Many contemporary historians of science seem incapable of doing intellectual history of science because such history would be of an enterprise that seeks, and achieves, intellectual progress, which in turn would mean – they believe – that it would inevitably be disreputable "Whiggish" history.[45] But that is nonsense. As Popper argued decisively long ago, all history is of something more or less specific: "the history of art; or of language; or of feeding habits; or of typhus fever."[46] There is no such thing as "total" history – history of everything that has happened. One entirely legitimate specific topic for history is any endeavour that seeks to make progress or, more specifically, *science construed as an endeavour that seeks to make progress in knowledge*. In writing history of science so construed, one should not, of course, just assume that progress is inevitable, or even that it has occurred; nor should one write propaganda on behalf of science and its claims to have made progress. It does mean, however, that one selects out for attention those past episodes, contributions, events, that in retrospect constitute steps in the progress of scientific knowledge and understanding. In order to tell the history of science properly, it is vital to consider blind alleys, failed efforts, theories, and research that may have seemed promising at the time but led nowhere.

and method, a specific view of the universe and a method of experiment and observation – experimentation linked to the new metaphysical view. (This has antecedents, of course, that go back to the ancient Greeks, to Democritus, Aristarchus, Eratosthenes, Archimedes, and Euclid.) This idea is all but encapsulated in the title of one of Koyré's books: *Metaphysics and Measurement*. There is a reason why *the* scientific revolution led to "uninterrupted and cumulative growth": a key discovery had been made about how to acquire knowledge progressively, not made by earlier "scientific revolutions."

In one respect I may differ from the views of Burtt and Koyré. I hold that the new methodological discovery, that led to modern science, never got properly articulated and understood. The natural philosophers who created modern science made a crucial discovery in scientific *practice*, but failed to make this discovery lucidly explicit. And this failure lingers on down to the present. Scientists today take for granted an untenable view of science that fails to do justice to what actually goes on in scientific practice – fails to do justice to what is responsible for the growth of scientific knowledge.[53]

It may be that it is this long-standing failure to get the progress-achieving methods of science properly into focus that is in part responsible for the failure of many historians of science to see that there is anything novel, methodologically, about the new natural philosophy. If *empiricism* is all that characterizes the methods of modern science then one may well hold that there is nothing especially distinctive *methodologically* about the scientific revolution, or the science that came from it.

A central concern of this book is to demonstrate that empiricism is not enough. Science needs evidence *and metaphysics*. Once this is appreciated, it becomes clear that we need a new conception of science which acknowledges explicitly metaphysical assumptions of science so that they can be critically assessed and, we may hope, improved. In chapters 3 and 5 I expound, argue for, and spell out implications of, this new conception of science, which I call *aim-oriented empiricism*. This view provides methods designed to facilitate the articulation, critical assessment, and improvement of metaphysical assumptions of science.[54] It is the methodological framework for synthesizing metaphysics and empiricism, science and philosophy, and thus recreating something close to seventeenth-century natural philosophy.

2

Emergence of Science

NEWTON AND METAPHYSICS

As I indicated towards the end of the last chapter, Newton in the *Principia* proceeds in a way that is dramatically different from his great predecessors. Kepler and Galileo appealed to both evidence and metaphysics. Observation and, in the case of Galileo especially, experiment, were of decisive importance. But so was the metaphysical thesis that the universe has some kind of harmonious mathematical structure, motion – whether terrestrial or astronomical – thus obeying simple mathematical laws. Neither claimed to have derived the laws they discovered solely from the phenomena by means of induction. Both assumed that the metaphysical thesis that the "book of nature is written in the language of mathematics" gives one an assurance that simple mathematical laws govern motion. The role of observation and experiment is then to select out those simple laws which nature has chosen to adopt.

But Newton, as we have seen, abjures any such metaphysical assumption. He makes the amazing claim to have derived his law of gravitation solely from the phenomena by induction. It was this, together with the immense success and prestige achieved by Newton's work, that led to the quiet death of natural philosophy and to the emergence of science. In this chapter I write the obituary of natural philosophy. I show how it died, and gave way to natural science.[1]

The first point to appreciate is that Newton did *not* do what he claimed he had done: derive his law of gravitation from the phenomena without recourse to metaphysical hypotheses. Indeed, Newton makes this clear himself in the *Principia*.

Newton's "derivation" of his law of gravitation appeals at various points to one or other of his four rules of reason,[2] and these rules all concern simplicity or unity and in effect make implicit metaphysical assumptions concerning the simplicity or unity of nature. As far as the first three rules are concerned, Newton makes this point quite clear himself in his comments. He makes it clear that adopting each rule amounts to making a big assumption – in effect a metaphysical assumption – about the nature of the universe.

Thus, in connection with rule 1 he declares that "Nature is pleased with simplicity, and affects not the pomp of superfluous causes."[3] Rule 1 is a good rule to adopt if Nature is indeed pleased with simplicity, but it would be a bad rule to adopt if Nature adored the pomp of superfluous causes. Adopting the rule as a rule of reasoning in natural philosophy thus amounts to accepting a big, highly problematic metaphysical conjecture about the nature of the universe.

Rule 2, it may be remembered, asserts that "to the same natural effects we must, as far as possible, assign the same causes," which Newton illustrates by remarking: "As to respiration in a man and in a beast; the descent of stones in Europe and in America; the light of our culinary fire and of the sun; the reflection of light in the earth, and in the planets."[4] Here again, this is a sensible rule to adopt if the universe is such that, on the whole, similar effects do have similar causes – that is, if the metaphysical doctrine asserting this is true. But in a perversely wilful universe which loves to assign quite different causes to similar effects, it would be a bad rule to adopt. And much the same holds as far as rule 3 is concerned.

For these rules to be good rules to follow in natural philosophy, ones which lead to authentic knowledge, the universe must be such that the same laws govern phenomena everywhere, so that, for example, it is reasonable to generalize from terrestrial phenomena to phenomena everywhere. If Aristotle had been right, and there is a fundamental distinction between terrestrial and heavenly phenomena, Newton's rules would have been exactly the *wrong* rules to adopt. Nothing could illustrate more clearly the point that Newton's four rules of reasoning make metaphysical presuppositions about the nature of the universe.[5]

That Newton's law of gravitation cannot be selected (let alone established) on the basis of evidence alone is decisively established by the fact that any number of theories different from Newton's can be formulated which predict, just as successfully as Newton's theory

mean that, in the end, everyone would be obliged to acknowledge that God must ultimately be in control.

Newton is, in many ways, a complicated and paradoxical figure. His weirdly medieval outlook meant that he did not share the metaphysical views of the cosmos of many of his contemporaries and great predecessors. He both exploits and rejects the views of his predecessors. His work implicitly presupposed and required a metaphysical outlook similar to that of Kepler and Galileo, and his work is inconceivable without the example of their great prior work. At the same time, Newton's rejection of the metaphysics associated with the new natural philosophy freed him to entertain possibilities which even his great contemporaries, Huygens and Leibniz, could not take seriously.

Could Newton really have consciously set out to deceive his readers into thinking no metaphysical hypotheses were involved in his derivation of his law of gravitation from the phenomena? Who knows? What is beyond doubt, as we have seen, is that even though Newton acknowledged openly and fully the vital role of *metaphysical hypotheses* in the first edition of the *Principia*, he removed all trace of "hypotheses," and especially *metaphysical* hypotheses, from basic assumptions required to derive the law of gravitation in the later editions. Furthermore, in the second and third editions, Newton states strongly that he derives his law of gravitation from the phenomena by induction without recourse to hypotheses, whether metaphysical or physical; and in the third edition he adds his fourth rule of reasoning, to be employed "so that the argument may not be evaded by hypotheses."

All this looks to me like a conscious cover-up. Even though the *Principia* began as a great work of natural philosophy in the manner of Kepler and Galileo, Newton deliberately set out to obscure the hypothetical and metaphysical dimensions of his work in later editions, so as to mislead his audience into thinking his law was derived by induction solely from the *phenomena*, solely from *evidence*.

Certainly there were strong motives to do it, as I have indicated. And certainly Newton could be mean enough to do such a thing. He was not exactly the noble figure the Enlightenment liked to think of him as being.[23] To give just one example, Robert Hooke seems to have been the first person to have the key idea as to how the solar system works: bodies free of forces move in straight lines and therefore the planets must be attracted towards the sun by a force to cause

3

Failures of Philosophy, Part I

WHAT PHILOSOPHY OUGHT TO BE

Over the centuries, from Newton's time to our own, a gulf has opened up between science and *philosophy*. Science has made extraordinary progress, the outcome, it would seem, of attending to *evidence*, and repudiating all that which cannot be assessed by means of evidence – philosophy, metaphysics, epistemology, theology. Philosophy, in glaring contrast, seems to have failed to make progress at all. Classics in the field of philosophy have been published as the centuries have rolled by, but these disagree with one another, and hardly add up to overall intellectual progress, in the manner of science. Furthermore, whereas in the seventeeth century, science and philosophy intermingled in the unified enterprise of natural philosophy, as time passed some philosophical traditions became indifferent to science or even hostile to it. The great success of science, and the failure of philosophy, is something philosophers have themselves noted and lamented. The contrast between the two has even led to anguished questions about what on earth philosophy could legitimately be. Indeed, far from advancing and growing over the centuries, philosophy seems to have dwindled and become increasingly insignificant. Instead of advancing, philosophy has gone into reverse. Philosophers sometimes account for the present impoverished state of their discipline in the following terms.

Once upon a time, philosophy reigned supreme, just below theology. Then, as some part of philosophy began to achieve intellectual success, it broke away and established itself as a separate discipline, distinct from philosophy. This happened again and again, each time encourage others to do just that, or depict what needs to be done to solve our problems of living. The proper task of philosophy, in short, is to create and keep alive a socially influential tradition of tackling our fundamental problems *rationally* – that is, imaginatively and critically.

Furthermore, philosophy has the task of keeping alive awareness of the important role that fundamental problems, and our attempts at solving them, have in all aspects of life and thought. Implicit in the way we think and act there are invariably more or less inadequate assumptions about how fundamental problems are to be solved. Such assumptions are implicit in science,[2] politics, economic activity, art, education, law, and so on, whether we recognize them or not. The more or less defective character of these assumptions has more or less adverse consequences for life and thought as a result. It is worthwhile trying to improve assumptions we make about how fundamental problems are to be solved because, apart from anything else, this may enable us to improve our lives as well. It is worth doing for its own sake, and for the sake of everything else. Philosophy as intelligent thinking about how to solve our fundamental problems matters in its own right and because of the impact it can have on the rest of life.

It is crucial to this conception of philosophy that it does not have its own particular intellectual territory, its unique *field* of expertise. The whole idea of this kind of philosophy is to encourage everyone to become philosophers, in this sense. The very young do not need encouragement: they are instinctively philosophers. Three-year-olds have had to ponder ultimate questions, in one way or another, in order to have concocted for themselves, without formal instruction, a view of the world, and a view of human life.[3] Their elders may, however, have forgotten, and may need to be reminded of, their infant passionate, profound philosophical selves, their endless asking of: Why? Why? Why? Adult life, and all adult activities, however formal or institutional, however individual, haphazard or idiosyncratic, need to have at least a scrap of philosophy, an openness to, and readiness to engage with, some pondering of fundamental problems. Nothing in human life should be wholly immune to philosophy. Love, war, dying, work, politics, religion, parenting, play, art, science: all need some philosophy sometimes.

Professional philosophers, in encouraging everyone else to engage in a bit of philosophy now and again too, need to speak and write in a way that is engaging, lively, witty, and lucid, but also in a way that retains full intellectual responsibility. Philosophy is for everyone, and the task of the professionals is to help make it so, without deviating one iota from intellectual integrity – from the basic task of enhancing our general awareness of what our fundamental problems are, what we need to think and do to solve them. Both kinds of problems are the concern of philosophy – fundamental problems of knowledge and understanding, and fundamental problems of life, of action. Both kinds of question, "What are we to *think*?" and "What are we to *do*?," are equally important. And a basic task of global philosophy is to get into social life the habit of tackling problems of *thought* and *life* in cooperatively rational ways, in so far as circumstances permit.

I should perhaps make clear that this proposal to reform philosophy – so that its basic task is to keep alive awareness of our fundamental problems of thought and life – is put forward as a preliminary step towards the basic proposal of this book: we need to reform both philosophy *and* science, and put them together to recreate a modern version of natural philosophy. Of the two, it is *philosophy* that needs the most radical reform. My argument for bringing together science and philosophy to recreate natural philosophy does not begin to make sense without the prior reform of philosophy along the lines indicated in this chapter and the next. In chapter 5 I develop the argument for the reform of science.

I also need to make clear that the above is intended to indicate the proper *basic* task of philosophy. In pursuing the above task, philosophers will also need to tackle rather more specialized problems. An important task, indeed, is to explore the multitude of ways in which our fundamental problems, and our attempted solutions, interact with research pursued in other disciplines – physics, biology, cosmology, mathematics, neuroscience, engineering, social inquiry – and interact with personal and social life – politics, economics, global problems, education, the law, well-being. Interactions in both directions need attention: the way more specialized problem-solving in other fields of thought and life has implications for the way we understand and seek to solve our fundamental problems, and vice versa, the way thinking about our fundamental problems and how to solve them has implications for research in other fields, and for our personal and social lives.

It may be asked: when I declare that the basic task of philosophy is to keep alive awareness of fundamental problems, what do I mean

Index