Chapter 6

Newton; Rationalist or Empiricist?

6.1 Laws of nature

The title of Newton's great work, the *Principia Mathematica, The Mathematical Principles of Natural Philosophy*, is a deliberate allusion to Descartes' *Principia Philosophiae* (*Principles of Philosophy*). Newton's book was published in 1687, 43 years after Descartes', but Newton had studied both this work and Descartes' earlier *Geometry* carefully.

It was suggested in the Introduction that the central difficulty in theory of knowledge is that we seem to know more than we can account for on the basis of sensory evidence alone. One aspect of this is the regular, predictable behaviour of physical bodies; the sun will rise every morning, this chair will support my weight, the light will go on when I flick the switch, and so on. In such cases it certainly seems that physical laws are obeyed. Indeed it even seems odd to talk of laws being "obeyed" because there is no clear sense in which a chair or an electric circuit can disobey in the way that I can choose to disobey a direct order. We tend to take the regularities that physical bodies exhibit for granted and only notice when the unexpected happens—when something goes awry.

The title of Newton's book suggests that it is specifically *mathematical* principles he is interested in, and that his interest is limited to natural science, that is, physical science (as opposed to what used to be called "moral science", meaning the human and social sciences as well as philosophy as we now think of it). The regularities exhibited by physical bodies are usually theorised about mathematically; immensely complex mathematical models are used to design the shape of an aerofoil or the flow of the gases through the cylinder head of a car engine, for example. Newton concentrates mainly on the motions of bodies, particularly the heavenly bodies, and he begins his work with a series of eight definitions followed by three “Axioms, or the laws of motion”:

Law 1 Every body perseveres in its state of rest, or of uniform motion in a [straight] line, unless it is compelled to change that state by forces impressed thereon.

Law 2 The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the [straight] line in which that force is impressed.

Law 3 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. (*Principia Mathematica*, p.416–7/p.70–1)

These laws have an air of being self-evident; once they been stated, it is tempting to say that they are obvious. But now consider this—are they, in the sense set out at the end of the last chapter, *a priori* or *a posteriori*? If they are *a posteriori* then there must be some experience they can be derived from. Here is Newton’s own remark on his First Law:

> Projectiles persevere in their motions, so far as they are not retarded by the resistance of the air, or impelled downwards by the force of gravity. A [spinning] top . . . does not cease its rotation, otherwise than as it is retarded by the air. The greater bodies of the planets and comets, meeting with less resistance in more free spaces, preserve their motions both progressive and circular for a much longer time. (*Principia Mathematica*, p.416/p.71)

In short, the law is hedged around with qualifications because no-one has ever, or indeed will ever, see a body in a state of rest or uniform straight-line motion that is not acted on by some external force. A body at rest on or near the surface of the earth is acted on by whatever supports it (stops it from falling). Even in deep space a projectile is subject to gravitational fields from distant stars. Rather the law has the form, this is what would happen (or this is what we would experience) *if* this is the case, where of course this is not and never can be the case. (The qualifications to such laws are often called "ceteris paribus" clauses—"other things being equal, then ...") This suggests that Newton's laws of motion are not derived from experience, or at least not in any straightforward fashion.

This being so, are they *a priori*? Were they just thought up by a Cartesian mind, a thinking thing, with no reference at all to what we get out of experience? This seems even more implausible, if it is taken to mean that a human mind could have thoughts even if it had never experienced an outside world at all. If we take seriously the idea that scientific laws are *a priori* in this sense, the implication is that a mind with *no* perceptual contact with anything outside of itself, excepting only God as the original implanter of innate ideas, will nevertheless have thoughts whose content is **applicable** to what there is. In the case of physical bodies such thoughts are limited to the bare possibilities of such bodies. That is, if there are physical bodies then they must be extended in space, capable of motion, rest and impact, and it must be possible to model these basic properties mathematically (more specifically, geometrically). On this view mathematics, including geometry, is *a priori*, as the *Meno* demonstrates.

This is not as absurd as it may seem. Socrates' doctrine of recollection is intended to show that if mathematical/geometrical truths are **innate**, it does not follow that I am aware of them. They need to be stimulated for me to recollect them. This is why Socrates casts himself in the role of an "intellectual midwife", particularly in the *Theaetetus* (3.1). In Descartes' case he denies that the mind is "transparent to itself"—that innate ideas are immediately there and obvious—and claims that it takes intellectual effort to recover or recollect them (5.2). The *Meditations* is, of course, intended as a self-help guide that the reader can use in order to arrive at these ideas.

If there are *a priori* truths, then, it does not follow immediately that they are present and correct in the mind in the absence of any external stimulus. It means only that once they are there in the mind—once they have been suitably triggered—it can be seen that they are independent of experience. When, for example, you learn geometrical truths about right-angled triangles, how is it that what you learn applies to *all* right-angled triangles? What is it that we grasp when we see that mathematical/geometrical principles apply in all relevantly similar cases? Do we generalise from a particular experience or set of experiences, or do we come to grasp truths of a different order, perhaps of something akin to a "**form** of triangle" that we have in mind?

These are difficult questions that do not have clear answers, which is why philosophers spend so much time on them. If we did have the answers they would cease to be philosophical questions and become the subject-matter of other disciplines; for the moment they remain puzzling. But this difficulty of getting clear about the exact function of experience is key to understanding that the differences between rationalism and empiricism are not as clear-cut as they may at first appear. Given this, here is a suggestive rule-of-thumb for deciding whether a principle is *a priori* or *a posteriori*: if a counter-example to a rule is observed, would you be prepared to change the rule, rather than find some other way to explain it away? If the answer is no, it is likely the rule is based on an ***a priori*** principle. If yes, it is most likely based on an ***a posteriori*** principle.

We can see this in the case of Newton's laws. If we observe a body moving in a straight line, and then see it deviate from that line, even if we cannot see why it deviates from that line we would look for a cause. It is hard to envisage any circumstances in which we would be prepared to consider changing the law. Similarly when accident investigators look into an aircraft crash we expect them to come up with a cause that fits with our present science, and if they fail to do so we assume that they have not found the cause, not that there is something wrong with our science (or that some supernatural event has occurred, that the laws of nature were momentarily suspended).

6.2 "Hypotheses non fingo"

It is extraordinary that from laws that give every impression of being *a priori*, Newton creates by mathematical techniques a physics that is **applicable** to our world of physical bodies. Descartes failed to do this, and in an obvious dig at his work Roger Cotes, the Plumian Professor of Astronomy and Experimental

Philosophy at Cambridge, a close associate of Newton and editor of the second edition of the *Principia*, says in his editor's preface that:

> Those who take the foundation of their speculations from hypotheses, even if they then proceed most rigorously according to mechanical laws, are merely putting together a romance, elegant perhaps and charming, but nevertheless a romance. (*Principia Mathematica*, p.386/p.43, Cohen/Whitman translation)

Hall says of Descartes' *Principles* that it "was a triumph of fantastic imagination which happens, unfortunately, never once to have hit on a correct explanation" (*From Galileo to Newton*, p.120), which is all too true. Towards the end of his preface Cotes says this:

> These [laws of nature] therefore we must not seek from uncertain conjectures, but learn them from observations and experiments. He who thinks to find the true principles of physics and the laws of natural things by the force alone of his own mind, and the internal light of his reason; must either suppose that the world exists by necessity, and by the same necessity follows the laws proposed; or if the order of nature was established by the will of God, that himself, a miserable reptile, can tell what was fittest to be done. All sound and true philosophy is founded on the appearances of things ...Fair and equal judges will therefore give sentence in favour of this most excellent method of philosophy, which is founded on experiments and observations. (*Principia Mathematica*, p.397–8/p.56–7)

But what are these observations and experiments? In discussing Descartes, two ways of reading the *Meditations* were proposed; the "defence of Cartesian physics" and the "response to scepticism" approaches (5.4). The suggestion made is that our approaches to texts—the phenomena, so to speak, in a humanities discipline like philosophy—are inevitably coloured by our preconceptions. This extends, literally, to what we see. It might be thought, initially, that it is absurd to claim that the earth is spherical; how is it that people at the antipodes do not suffer a rush of blood to the head before falling off? But observation of ships sailing out to sea disproves the idea that the earth is flat, because if it is then as a ship sails out to sea it should appear to get smaller and smaller until it is no longer visible. But this is not what happens; the ship appears smaller and smaller, certainly, but what happens is that the hull of the ship falls out of view first, until only the tops of the masts can be seen, because, of course, the earth is a sphere. (It could be a cylinder, but correlating observations of ships sailing away in different directions shows it is a sphere.) It is a capacity to see things differently that has often been the key to scientific discovery.

Something similar can be said about Newton and gravity. To see gravity at work in the fall of an apple or the orbit of the moon is to see things differently from Aristotle, whose views we will look at briefly next.

Excursus—Aristotle's Physics

In some ways this constitutes a digression, albeit a brief one, to look at the world-view that Descartes and Newton rejected. In this context there are three significant aspects of Aristotle's physics:

(i) the conceptual nature of his approach,
(ii) that action can only occur through contact,
(iii) the difference between the earthly and the heavenly (the subjects of physics and of *first philosophy*, or metaphysics, respectively).

Aristotle has a profound and thoroughly worked-out world view, so this is an extremely partial choice of topics, intended to fit with themes developed in the present work.

To begin with (i), in Aristotle's day there was none of the penumbra of apparatus and experimental techniques that we take for granted. There are no equations or mathematical formulae in Aristotle's *Physics* or in his *Metaphysics*. Both works consist in the main of conceptual arguments conducted in abstract fashion, and are, to put it mildly, boldly speculative. Here, for example, is Aristotle's argument for the primary nature of circular motion:

> As for the fact that circular movement is the primary kind of movement, this is obvious . . . the higher degree of simplicity and completeness possessed by circular movement means

> that it has priority over [movement in a straight line]. In the first place, it is impossible to move over an infinite straight line, because there can be no such thing as a straight line which is infinite in this sense; also, even if there were such a thing, it would not be traversed by anything, because the impossible does not happen and it is impossible to traverse something which is infinite in extent. In the second place, movement on a finite straight line can either reverse direction or not; if it does, it is a composite of two movements, and if it does not, it is incomplete and must cease to exist. But where priority in nature, in definition, and in time are concerned, the complete is prior to the incomplete and that which does not cease to exist is prior to that which does. Besides, a movement that can be eternal is prior to one which cannot. Now, circular movement can be eternal, but no other kind of movement, and no other kind of change either, can be eternal, because they are bound to involve rest, and the presence of rest means that the movement or change ceased to exist. (*Physics*, p.265a13–26)

This displays a certain *a priori* philosophical style, as well as forming part of the distinction Aristotle draws between the earthly and the heavenly (iii, above). Movement on earth does not exhibit the eternal circular motion of the heavenly bodies, because the earth is the realm of the finite, of what comes to be and can be destroyed, whereas what is above the earth is eternal and neither comes to be nor ceases to be. First philosophy deals with these sorts of things, whereas physics or second philosophy deals with the perceptible things we interact with. (*Metaphysics*, p.1037a)

The claim that action can only occur through contact (ii) is a product of this conceptual approach. The idea of action at a distance seems fantastic; how can it be possible? Experience shows that things act on one another by impact, either directly in the case of hammers and axes and billiard balls and so on or indirectly, in the case of a varying series of pressure waves impinging on your eardrums leading you to act according to whatever warning or instruction you have heard.

Aristotle makes this point in *Physics*, Bk.VII, where he argues that:

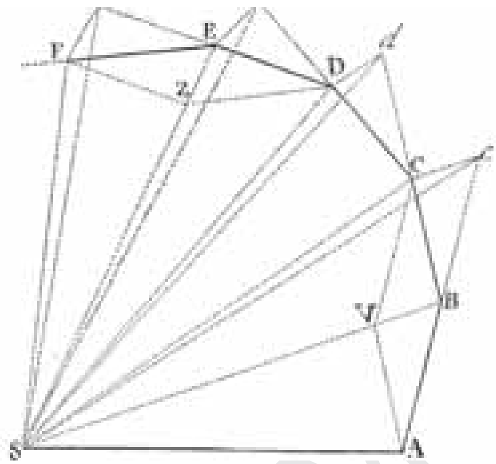
> [T]he immediate agent of bodily change of place must be either in contact with or continuous with the moved object, as we always observe to be the case. So it necessarily follows that the moved objects and the movers are either continuous or in contact with one another. (*Physics*, p.242b59–61)

This is not an isolated view. It occurs elsewhere in the *Physics* (at p.202a3, 266b25) and in *On Coming-to-be and Passing-away* (at p.322b–323a). It leaves Aristotle with a particularly vexing problem, of what it is that keeps a projectile in motion (*Physics*, p.266b), because on his account it should stop moving as soon as a contact force ceases; as soon as a spear leaves a soldier's hand, for example. The contact doctrine forces him into a deeply implausible claim that motion is somehow transferred to and from the air (or water) that a projectile moves through, in a sequence of impulses that gradually die out. However implausible we may find this, the conceptual nature of the argument is significant. Given the assumption, that change requires contact, any perceptible change requires something in contact to bring it about, so something must be found to do the job. And Aristotle's intellectual prestige lent his arguments enormous weight.

A consequence of (iii) is that accounts of what happens on earth have no obvious relevance to what happens above the earth. The fall of an apple is no guide to the continual falling towards the earth exhibited by the Moon, a falling that keeps it in orbit (rather than flying off into space in a straight line). Aristotle's *Physics* operates with four elements—earth, air, fire, and water—each of which has a natural place that it tends towards. The fall of an apple is a natural motion whereby a heavy body tries to take up its proper place in the order of things, whereas the Moon as a heavenly body eternally sweeps out its circular motion. Newton's brilliance lay in seeing the same phenomena as everybody else—the motions of apples as well as those of the heavenly bodies—and realising that what makes the former fall, and keeps the latter in their orbits, might not be an intrinsic tendency on the part of heavy bodies to fall to earth or something in contact pressing them back from the outside but a force, albeit with no visible means of action, pulling them from the inside. Just as if you swing a weight round on a piece of rope you have to pull on the rope to stop it from flying off at a tangent.

Gravity

Newton's radical move was to propose a *centripetal* force that is equal and opposite to the *centrifugal* force that we're all familiar with. This centripetal force is, of course, the force of gravity. Newton realised that this can account for both sets of phenomena, the fall of apples and the orbits of the planets. Rather than attributing to apples a desire to rejoin bodies of their kind (i.e. bodies with mass), what makes them fall rather than float away is the attractive force of gravity. Similarly what prevents the Moon flying off into space is gravity as an attractive force between the earth and the Moon.



Centripetal forces

The diagram on the left is the first in Book 1 §2 of the *Principia*, entitled "To find centripetal forces". If S is the sun and A the earth, what stops the earth at B from flying off along the line Bc? Answer, a centripetal force, exerted along a celestial "piece of rope" with the sun at the other end. The "experiments and observations" that led to Newton proposing such a force took the form of astronomical data collected using telescopes. Some of this was available to Descartes, who saw what Newton saw, but was so taken by contact that he attributed free fall in the case of apples falling to earth or circular motion in the case of the planets to vortexes of "subtle matter" around the earth and the sun.

Descartes' approach relies on the **rationalist** way of accounting for our knowledge of what cannot be readily derived from experience. It is true that experience is required to bring out what is known innately, but the function of experience is only to prompt such bringing forth or recollecting. The problem for rationalism remains, though, of putting together our **innate** ideas (the ones we have in mind irrespective of anything external to us) and the world outside of us; why should it be the case that our innate ideas are appropriate for—are **applicable** to—this world? Why should not it be the case that our innate ideas are of chess but the world is a backgammon set? And if it is, would we ever realise? How could we ever come to modify and revise our theories, if we cannot step outside them to see that we are playing chess in a backgammon world?

To get over this, as we have seen (5.3), Descartes argues that a benevolent God has created us in such a way that our innate ideas are suitable for the world around us. This is less than convincing. To conclude this section, we will look at two passages from Newton's *Principia* that deal with observation and experiment and the nature of the rules and principles he puts forward. The first is from the "General Scholium", added to the second edition:

> Hitherto we have explained the phenomena of the heavens and of our sea, by the power of gravity, but we have not yet assigned the cause of this power. This is certain, that it must proceed from a cause that penetrates to the very centres of the sun and the planets, without suffering the least diminution of its force; that operates, not according to the quantity of the surfaces of the particles upon which it acts, (as mechanical causes [are wont] to do), but according to the quantity of the solid matter which they contain, and propagates its virtue on all sides, to immense distances, decreasing always in the duplicate proportion [square] of the distances, as far as the orb of Saturn ...
>
> But hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses [*hypotheses non fingo*]. 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**. Thus it was that the impenetrability, the mobility, and the impulsive force of bodies, and the laws of motion and of gravitation, were discovered. And to us it is enough, that gravity does really exist, and act according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies, and of our sea. (*Principia Mathematica*, p.943/p.92)

Newton's approach here exerted an enormous influence on **empiricist** philosophers and philosophers of science. The argument is that if the mathematics generates laws that serve as a predictive mechanism, that can be used to calculate the phenomena (for example the orbit of Saturn or the next return of Halley's Comet), then speculation about some deeper underlying causal mechanism can be discounted as metaphysical romancing. "Gravity" is a name for an observable, measurable phenomenon, whose effects can be calculated and predicted using mathematical models, and this is all that needs to be said about it. Science has no need for "feigned hypotheses" in such cases.

The second passage is from the "Rules for the Study of Natural Philosophy", as set out in the third edition of the *Principia*:

Rule 3 *The qualities of bodies, which admit neither intension nor remission [neither increase nor diminution] 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.*

For since the qualities of bodies are known to us by experiments, we are to hold for universal, all such as universally agree with experiments; and such as are not liable to diminution, can never be quite taken away. We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising: nor are we to recede from the analogy of nature, which uses to be simple, and always consonant to itself. We no otherwise know the extension of bodies, than by our senses, nor do these reach it in all bodies; but because we perceive extension in all that are sensible, therefore we ascribe it universally to all others also.

That abundance of bodies are hard we learn by experience. And because the hardness of the whole arises from the hardness of the parts, we therefore justly infer the hardness of the undivided particles not only of the bodies we feel but of all others. That all bodies are impenetrable, we gather not from reason, but from sensation. The bodies which we handle we find impenetrable, and thence conclude impenetrability to be a universal property of all bodies whatsoever. That all bodies are moveable, and are endowed with certain powers (which we call the *vires inertiae* [forces of intertia]) of persevering in their motion or in their rest, we only infer from the like properties obeserved in the bodies which we have seen. The extension, hardness, impenetrability, mobility and *vis inertiae* of the whole, result from the extension, hardness, impenetrability, mobility, and *vires inertiae* of the parts: and thence we conclude the least particles of all bodies to be also all extended, and hard, and impenetrable, and moveable, and endowed with their proper *vires inertiae*. And this is the foundation of all [natural] philosophy ...

Lastly, if it universally appears, by experiments and astronomical observations, that all bodies about the earth, gravitate towards the earth; and that in proportion to the quantity of matter which they severally contain; that the moon likewise, according to the quantity of its matter gravitates towards the earth; that on the other hand our sea gravitates towards the moon; and all the planets mutually towards another; and the comets in like manner towards the sun; we must, in consequence of this rule, universally allow, that all bodies whatsoever are endowed with a principle of mutual gravitation. For the argument from the appearances concludes with more force for the universal gravitation of all bodies, than for their impenetrability; of which among those in the celestial regions, we have no experiments, nor any manner of observations. Not that I affirm gravity to be essential to bodies ...

Rule 4 *In experimental philosophy we are to look upon propositions collected by general* ***induction*** *from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

This rule we must follow that the argument of induction may not be evaded by hypotheses. (*Principia Mathematica*, p.795–6/p.87–9)

In Rule 3 Newton decisively rejects Aristotle's view of the heavens as divided into the sublunary sphere of change and decay, occupied by the earth and its inhabitants, and a celestial realm of unchanging eternal heavenly bodies in perpetual circular motion. As it is on earth, so to speak, so it is in the heavens. His emphasis on the role of experiment and observation is aimed squarely at the speculative philosophies of Aristotle and Descartes. He is careful to point out that he does not claim that "gravity is essential to bodies", which would amount to speculation about the **essence** of bodies; only that gravity is an observed, measurable phenomenon, because this is all he needs.

In Rule 4, he argues for the inductive method. The method of **induction** relies on accumulating observations, generalising the conclusions, and then arguing that it is probable that what has happened before will happen again. In the case of a counter-example, of course, the conclusions need to be modified unless some other way can be found of explaining the counter-example away. Until black swans were found in Australia it was thought (by induction) that the statement "all swans are white" is true. A sighting of a black swan falsified this statement. Closer examination might have shown that what appeared to be a black swan was a mutant duck, in which case the rule could be reinstated. Or it could have been argued that it was not really a swan at all, but such "ad hoc" strategies do not look to be good science.

6.3 Deduction and induction

The other technique for proof and argument is **deduction**. Deduction works by beginning with premises ($P_1, P_2, \ldots, P_n$) and then, by valid techniques, extracting conclusions (C). The underlying idea is that if the premises are true, whatever is validly derived from them must also be true; the rules of induction are *truth-preserving.* A deductive argument looks like this:

P_1 All swans are white.
P_2 Whatever is non-white is not a swan.
P_3 This swan is black.
C This "swan" is not a swan.

Deductive arguments protect their premises against putative counter-examples, as can be seen in this:

P_1	Every body perseveres in its state of being at rest or of moving uniformly straight forward, except in so far as it is compelled to change its state by forces impressed.
P_2	This body has deviated from its path.
P_3	No external force acting on the body has been detected.
C	There is an external force only we do not know what it is or how to detect it.

An inductive argument looks like this, with each premise (P_x) a record of an observation:

$P_1, P_2, \ldots, P_n$	This swan is white.
C_1	All swans are white.
P_{n+1}	This swan is black.
C_2	Swans are usually white but some are black.

The conclusion is modified in the light of the counter-example.

This is a contentious area in the philosophy of science generally, and what Newton meant by induction may not be exactly the same as our present notion. The interesting aspect here of Newton's work, which profoundly influenced later philosophers, is a deep tension between the *a priori* (what we know *a priori* and how we come to know it) and the *a posteriori* (what we know via the senses). In this sense Newton set the scene for the British empiricists (Locke, Berkeley and Hume), and for Kant.