# 17
# Newton
## (Matthews 137-39, 146-158)

> As in Mathematicks, so in Natural Philosophy, the Investigation of difficult Things by the Method of Analysis, ought ever to precede the Method of Composition. This Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental Philosophy. And although the arguing from Experiments and Observations by Induction be no Demonstration of general Conclusions; yet it is the best way of arguing which the Nature of Things admits of, and may be looked upon as so much the stronger, by how much the Induction is more general. ... By this way of Analysis we may proceed from Compounds to Ingredients, and from Motions to the forces producing them; and in general, from Effects to their Causes, and from particular Causes to more general ones, till the Argument ends in the most general.
>
> – Newton
> *Optics*, Query 31 [as translated in Matthews, 157-58]

Descartes's philosophy was very attractive to all those sympathetic to the mechanistic project in natural philosophy. It neatly side-stepped the theological difficulties attendant on rival mechanistic systems, such as that of Hobbes, by demonstrating the existence of God and of immaterial souls and giving both a central role to play in an overall account of the world. But at the same time it presented a picture of all the non-thinking parts of nature as simply a vast machine. Descartes's appeals to God's activity in constantly preserving the same quantity of motion through collision and to the impossibility of void demonstrated the necessity of the formation of vortices of subtle matter. And Descartes's vortex mechanics held out the promise of being able to explain all the phenomena of nature. Not surprisingly, therefore, the Cartesian philosophy and Cartesian physics rapidly gained adherents and it quickly came to be recognized as the preeminent mechanistic theory of nature.

But within forty years of Descartes's death in 1650, his philosophy had died as well. If there is a single reason why almost no Cartesians were left after such a short time and such great initial success, it was the publication, in 1686, of a rival science in the *Principia mathematica* of Isaac Newton. Newton's *Principia* was phenomenally successful. It presented the most complete and powerful account of the workings of nature that had ever been offered, and few who read it and understood it could avoid being persuaded by what they found in it. Newton succeeded in accounting for physical phenomena as diverse as the motions of the planets and comets, the movement of the tides and the falling of apples, by appeal to a single law, describing them all as effects of gravitation. (Descartes, in contrast, needed to invoke a distinct vortex to account for each of these phenomena.) But in the process he also put forward a conception of what the world is like that shattered the mechanistic view. Newton's science abandoned Cartesian mechanistic explanations in favour of appeals to the agency of forces.

In the process, Newton's science also shattered Cartesian philosophy. Descartes's philosophy had been written as a prop for his mechanistic account of nature. Once that account was rejected, his philosophy was unmotivated. And it is a feature of the evolution of thought that a when a popular philosophical theory is abandoned it is seldom because there are problems with it (researchers merely treat the problems as puzzles that they hope to be able to resolve somewhere down the line) but because other, external circumstances have changed, rendering that system useless for achieving the purposes for which it had been constructed. This is the case with the demise of Cartesianism. Descartes's philosophy had been written to support his mechanistic physics. Newton's rival, force-based physics required its own support, but it was one that was quite different from any that could be supplied by Cartesian philosophy. Whereas Descartes had attempted to base his science on deduction from metaphysical first principles, Newton's forces could not be derived in any obvious way from metaphysical first principles. Newton instead turned to experience, and took the existence of the forces to be justified by observation of their effects. And he relegated the discovery of the causes of these forces to second (or even last) place, taking that something we would discover only after a long process of experiment and inference, if at all. But though Newton never explained what causes gravity, he succeeded at describing the laws in accord with which the force of gravity operates without having to commit himself to any particular position on what produces that forces. (In particular, Newton did not have to commit himself to the thesis that gravitation is produced by aether-pressure, or any other mechanical operation of particles on gravitating bodies, though he did confess to a liking for these hypotheses.) As a consequence, he inverted the Cartesian method, giving induction from experience pride of place over deduction from first principles, and a description of the laws of motion and change pride of place over an understanding of the true, inner nature of the bodies that are moving and changing. The success of Newtonian physics made it inevitable that the Cartesian deductive scientific methodology, and with it the Cartesian foundationalist epistemology, would be abandoned along with Cartesian science. It is for this reason that some study of Newton's work and how it conflicted with Cartesianism is important.

QUESTIONS ON THE READING

1. Why is mechanics a more fundamental science than geometry?
2. What is rational mechanics?
3. What are the chief things that a rational mechanics of natural powers is concerned with?
4. What is a natural philosopher supposed to uncover from an investigation of the phenomena of gravity, levity, elasticity, hydraulic pressure, and other such motions?
5. What does "reasoning from mechanical principles" consist in, according to Newton?
6. What did Newton speculate is the likely cause of all natural phenomena?
7. What determines whether a quality is to be considered "universal" or not?
8. What are the universal qualities of all bodies whatsoever?
9. How do we know that bodies are extended?
10. How do we know that even bodies so small we cannot see them are still extended and hard?
11. List some of Newton's chief objections to Cartesian vortex mechanics.
12. How did Newton reply when asked to explain what causes gravitational attraction, and makes it always proportional to mass and inversely proportional to distance?
13. How did Newton reply when asked to explain what causes cohesion, electric and magnetic attraction and repulsion, the emission of light, and sensation?
14. Did Newton think that motion is conserved?
15. What are the main active principles?
16. What properties did Newton speculate were originally put in particles by God?
17. Why did Newton think it is unlikely that matter is infinitely divisible?
18. How did Newton justify the practice of explaining natural phenomena by appeal to qualities like gravitation, even though the causes of those qualities are occult?

NOTES ON THE READING

The basic principles of Cartesian physics are few and simple. According to Cartesian physics, bodies are nothing more than cut up bits of space, and possess no other qualities than those they acquire through taking up a determinate amount of space. Moreover, space itself is no different from body, so that all space is necessarily full of bodies, since it just is body. All the phenomena of nature are supposed to be explained by the motion and shape of bodies, without recourse to forces like gravitation or electric charge, or to qualities like mass or hardness or solidity. (The mass of a body is just its volume, subtracting any pores or cavities, and hardness and impenetrability are just effects of its motion.) All motions must take the form of circulation in vortices, given that there is no vacuum, and the quantity of motion (considered as the product of the speed and the amount of body in motion, which just is the volume or bulk of the body) must be conserved throughout all changes in nature.

Accounting for all the phenomena of nature within the constraints imposed by this very lean view of what exists and how it behaves proved to be quite challenging for the Cartesians. Descartes himself had initially said enough to make the project look hopeful, but as time went on, success at applying his theory to explain and particularly to predict phenomena proved elusive. This was already the case in astronomy, a field of study where the motions of only a few, rather simple bodies (the planets and moons in the solar system, which are so many balls rotating around one another) are investigated. Since the motive behind the mechanical philosophy had been to try to get power over nature so as to improve the material conditions of life, the continued failure of Cartesian physics to work up an account able to reliably predict what will happen next (the first step to getting the sort of understanding that allows to control events), even with reference to the comparatively simple motions of the heavens, was a matter of some concern.

In the General Scholium prefaced to Book III of his *Principia*, Newton remarked on the lack of success the Cartesians had with astronomy, noting that "The hypothesis of vortices is pressed with many difficulties," (Matthews, 148). He went on to mention three in particular: The parts of the vortices carrying the heavenly bodies around the Sun would have to be simultaneously moved with different speeds in order to produce all of the observed phenomena; the observed motions of the comets are simply unaccountable if vortices carry the planets and comets around the sun, since the vortices for the comets would have to cut through those for the planets in order to bring them in close to the Sun in their highly elliptical orbits; and the uniformities in the orbits of the planets and moons (the facts that they all orbit in the same direction and in the same plane) are also unaccountable, if the vortices originate simply as a consequence of God's injecting motion into the universe, in the way Descartes had supposed.

In Query 31 of his *Opticks* Newton also attacked the other pillar of Cartesian physics, its claim that the quantity of motion is always preserved. He noted that in a simple system where two bodies of the same mass orbit at the same speed around a common center while that common center travels in a straight line (say, at the same velocity) in the plane of their orbit, the quantity of motion will be constantly increasing and decreasing. When the two bodies are at a point in their orbit perpendicular to the direction of motion of their center of mass, the one body will have 0 speed and hence 0 quantity of motion (where quantity of motion is the product of speed and bulk or volume), since its orbit carries it in the opposite direction and at the same speed relative to the direction the entire system of the two orbiting bodies is moving in. The other body will have a speed compounded from its own orbital motion and the motion of the entire system, and since those two motions are in the same direction its quantity of motion will be 2. But when the two bodies are at a point in their orbits that puts them in the same line in which the center of mass of the entire system is moving then each body will have a speed and hence a quantity of motion equal to the square root of 2, and thus in this position the overall quantity of motion will be two times the square root of two, which is greater than 2.

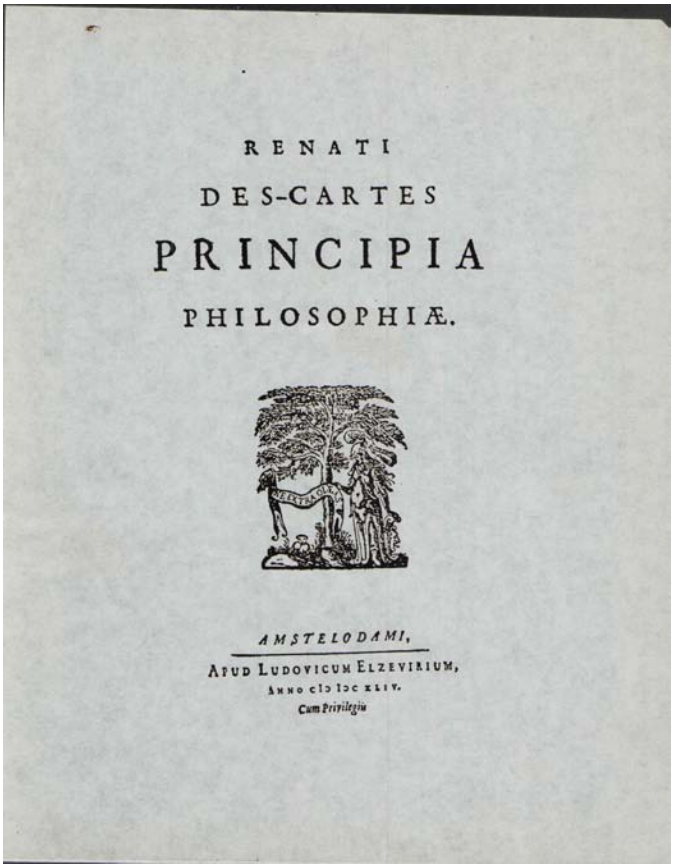
But this is not all. While in this simple system the quantity of motion is constantly fluctuating, Newton claimed that in nature more generally it is constantly decreasing. He based this claim on the assertion that in all but perfectly elastic collisions (that is, in collisions of bodies that deform upon impact, but then spring back to their original shapes so energetically that they rebound with all of their original motion) motion will be lost. He claimed that if soft bodies (ones that deform on impact and do not spring back, or spring back only slightly), or perfectly hard bodies (ones that do not deform on impact at all) collide, motion will lost. Indeed, in the case where two perfectly hard bodies of the same mass and equal but opposite velocities collide, motion should be entirely destroyed, and the two should come to rest.

In Newton's eyes, this illustrates a further problem with vortex mechanics. As long as the parts of a vortex collide with one another to some extent, and have some degree of softness, or hardness, or, for that matter stickiness or tenacity, the parts will lose their motion and the vortex will slow down. We see this happen with fluids like melted tar, oil, or water that have been stirred. All of these fluids eventually lose their motion and come to rest, some more quickly than others, because of the tenacity of their parts and the collisions between them. And while some of them, water for instance, might take a while longer to stop, Newton thought it is hardly to be supposed that there could be any rotating fluid with parts that have no tenacity and no relative motions and collisions. Thus, were the planets to be carried around the sun by vortices, they ought to slow down and stop, and sooner rather than later if we suppose that their vortices would have to be heavy enough to communicate their motion to the planets. Thus the fact that there been no apparent diminution in the speed of orbit of the planets over the centuries since recording of the heavens began poses a significant challenge to Cartesian astronomy.

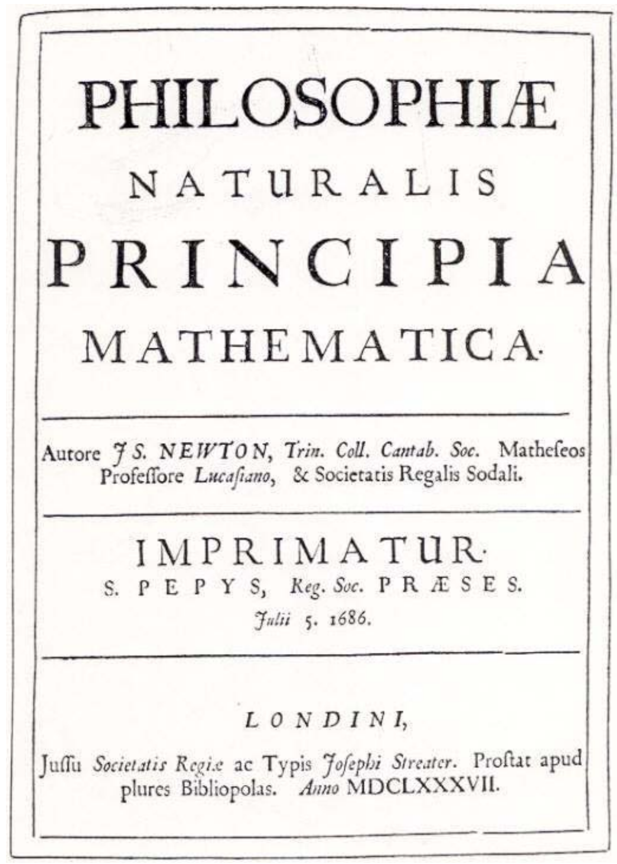
These reflections on the problems with Cartesian astronomy suggested two things to Newton: that the planets must be moving through a void or almost void space, and that even then new motion must be injected into the solar system by some sort of active principle or force. Indeed, Newton claimed that if motion is everywhere on the decay due to the inelasticity of bodies, then all the processes in nature more generally would eventually run down unless one or more active principles or forces are at work to generate new motion. One such principle would be elasticity, which is really a kind of force of cohesion in bodies by which they strive to preserve their shape or volume, and attempt to recover that shape or volume after it has been lost. But Newton mentioned others as well: gravitation, which is really a kind of force of attraction in bodies by which they strive to move towards one another, and by which they are accelerated towards one another, and what he calls "fermentation," which refers to a number of chemical reactions that today we think are governed by electromagnetic forces.

The investigation of these "active principles," particularly astronomical gravitation, became the focus of Newtonian science.

Newton announced this radically non-mechanistic project in the Preface to the *Principia*. At the same time that he did so, he attempted not just to demolish the mechanistic position, but to seize its battle flag. The labels, "mechanical" and "mechanics" are ones he wanted to appropriate for himself. Thus, part of the job of the Preface is not just to announce the radically non-mechanistic project of supposing that there are forces actively producing motion in nature and to propose to investigate these forces, but to revise the very notion of mechanical natural philosophy so as to include this project under the title of "mechanics." (Perhaps Newton thought that the terminology of mechanism and mechanics had come to have too many positive associations, and the terminology of forces and potencies too many negative ones, for him to hope to be able to win an audience for his thought were he not to strive to make it at least appear in the guise of the popular program. He would certainly not have been wrong to think this.)


RENATI
DES-CARTES
PRINCIPIA
PHILOSOPHIÆ.

AMSTELODAMI,
Apud Ludovicum Elzevirium,
Anno cIↄ Iↄc xliv.
Cum Privilegio.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheſeos Profeſſore Lucaſiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Juſſu Societatis Regiæ ac Typis Joſephi Streater. Proſtat apud plures Bibliopolas. Anno MDCLXXXVII.

***Titles of Descartes's and Newton's principal natural philosophical works.*** *Newton seems to have intended his as both an echo of and a corrective to Descartes's.*

The Preface opens with a critique of Descartes's claim that nothing is necessary to do natural science other than an appeal to the principles of geometry. Mechanics, the science of motion, Newton claimed, is more fundamental than geometry, the science of the measurement of shapes. Before geometry can study shapes, those shapes must be produced somehow, and all shapes are produced by motion, be it the motion of a point (this is how shapes are classically described in textbooks of geometry) or God's supposed act of injecting motion into pure extension leading it to break up into chunks of a determinate shape.

But, for Newton, this more fundamental science, mechanics, is not just the study of motion. It is the study of the forces producing motion. We see various motions in the world around us, those associated with the phenomena of rising and falling (gravitation and levitation), springing back (elasticity), the viscosity and pressure of fluids, and so on, and understanding these motions means understanding the forces that produce them.

These forces, Newton speculated, are likely certain attractive and repulsive forces that operate between the parts of bodies to make them move towards or recede from one another. Just how this happens is not clear. Newton described the causes of attraction and repulsion as "unknown," indeed, as occult (a term that has the root meaning of "hidden"). But while the causes of the forces may be hidden, the effects of the forces are manifest. Bodies gravitate toward one another, spring back to their original shape or volume, radiate heat and light, resist compression, and so on. The forces must therefore exist, even if exactly what they are and how they operate is not clear. Indeed, for Newton, the existence of the forces is so manifest that he considered them to be among the qualities that are universally possessed by all bodies whatsoever.

We see this claim made in the third of the "Rules of Reasoning in Philosophy" at the outset of Book III of Newton's *Principia*. Rule III addresses the question of what the so-called "primary and real" qualities of bodies are, but it does so in a very different way from the way the question had been addressed by Galileo, Descartes, and Boyle. For one thing, Newton did not attempt to identify essential or necessary qualities that bodies must have if they are to exist at all. He instead spoke just of universal qualities that all bodies have up to now been observed to have. Included on his list of (brute factually) "universal" qualities of all bodies whatsoever are not just the standard, "primary" qualities that bodies acquire through being cut-up bits of space; namely, shape, size, position, order, and motion, but hardness, impenetrability, and inertial and gravitational mass. These latter "qualities" are really products of attractive and repulsive forces. Hardness is the product of a special, attractive force between the parts of bodies that makes them cohere so strongly that they cannot be moved relative to one another. Impenetrability or solidity is really a repulsive force, since bodies are only impenetrable if they resist being occupied by other bodies, either by pressing back or by pushing away from what approaches. Inertial mass is not really a quality (like weight) at all but rather a kind of repulsive force that bodies exert insofar as they press against and resist anything that tries to alter the speed or direction of their motion. And gravitational mass is likewise not the same thing as weight but is rather a kind of attractive force by which all bodies pull themselves towards all other bodies. These are the forces that provide the engine Newton was looking for: the means of generating new motion to replace the motion that is constantly being lost in collision, thereby keeping the machine of nature in operation.

The Cartesian and other mechanical philosophers of Newton's day were appalled by these innovations. Newton's claim that bodies ought to be considered to have hardness, impenetrability, and mass looked to them like a reintroduction of the old, exploded, Aristotelian notions of active and passive potencies, final causes, sensible forms, and real qualities, and it raised strong protests. The mechanists had braved civil and ecclesiastical persecution, and the bigoted prejudices of scholastic university education in order to rid natural philosophy of such magical and obscure notions, and they were not pleased to see Newton bringing what looked like these same occult qualities back into natural philosophy again. But what particularly irked them was that Newton seemed to be bringing these notions back in an especially disturbing and unacceptable way, one involving an idea that was so outrageous that even Aristotle would have nothing to do with it. This was the idea of action at a distance. Newton's account of gravitation appeared to involve this idea. After all, if the planets are not being carried around the Sun by vortices, but are moving through a completely or largely empty space, and are being preserved in their more or less circular orbits by a force of attraction towards the Sun, then it appears as if the Sun is somehow able to act in a place where it does not even exist. There are some 15 billion kilometers of apparently empty space between the Sun and the planet Saturn. If the Sun is nonetheless what keeps Saturn from flying off in a straight line, then the Sun must be acting in a place where it does not even exist, indeed, a place very far removed from the place where it exists. The notion of empty space was by itself hard enough for many people at the time to accept. When coupled with the idea that a cause need not be in contact with its effect, but can magically exert an influence on another body from which it is separated by billions of kilometers of empty space, Newton's natural philosophy seemed simply absurd. It not only reintroduced the old, exploded notions of force and endeavour, but it contradicted the most fundamental metaphysical principles: that what is not (and empty space is in effect a kind of nothing) cannot be, and that a body can only act in that place where it is and not in some place where it is not.

However, rail as they might against the absurdities inherent in Newton's account of gravitation, the fact was that Newton's account of the workings of the universe was, on the whole, more coherent and successful than anything the mechanists had managed to come up with. Newton's theory could predict how the heavenly bodies were going to move. But it did not just do that. As an added bonus, it also explained and predicted the motions of the tides, the motions of the moons around their planets, and the motions of bodies falling towards the Earth. Moreover, it did all of these things by appeal to a single, simple and universal law, the law that all bodies in the universe move towards all other bodies with a speed that is directly proportional to the product of their masses and inversely proportional to the square of the distances between them. With this one law people were suddenly placed in a position to not only predict a great deal concerning what would happen next, but determine what is necessary to prevent or induce the fall of bodies on earth. And they began to think that what Newton had achieved for the force of gravitation might also be achieved for the other forces: for cohesion, elasticity, repulsion, "fermentation" (i.e., chemical reactions of all sorts), and even the life forces responsible for human and animal growth, reproduction, and sensation. Despite his appeal to forces and purportedly "occult" qualities Newton had achieved what strictly mechanical natural philosophy had only ever promised to be able to do somewhere down the line. It was this fact, more than any of the problems mentioned earlier with Cartesian vortex mechanics or with the principle of the conservation of quantity of motion that ensured the triumph of Newton's philosophy of nature.

Of course, the metaphysical difficulties posed by Newton's positions on force, space, and action at a distance could not simply be ignored. People like to have a science that not only works to explain the phenomena but is able to answer the metaphysical objections that might arise. Newton himself worried about the nature of force, space, and gravitation, and attempted to answer the objections that his views naturally raised. It was in doing so that he undermined not just Cartesian physics, but Cartesian philosophy. To justify himself, Newton forged a new scientific methodology and pointed the way towards a new epistemology. This methodology and epistemology were radically at variance with Cartesian methodology and the Cartesian theory of knowledge. The new methodology and epistemology rehabilitated elements of an old one: the inductivist and empiricist methodology and epistemology of Bacon and Aristotle.

The choice was almost an inevitable one. The Cartesian method, with its emphasis on starting with absolutely certain first principles purportedly discovered through a clear and distinct, purely intellectual apprehension was not going to allow Newton to derive the existence of a force of universal gravitation. But an appeal to sense experience could. After all, there is nothing our sense experience teaches us more constantly than that all the bodies in our surroundings move towards the Earth, that the tides move towards the Moon, that the planets move in orbits because they are pulled towards the sun, and that all the parts of the universe as far out as telescopes can observe tend to move towards one another.

Newton appealed to this observation in Rule III, where he declared that it is sense experience and not a pure, intellectual apprehension that ought to serve as the ultimate judge of what qualities are the universal, and hence real, qualities of all bodies whatsoever. According to Rule III, if a quality has been universally observed to be present in all bodies that we have ever come across, and if that quality is not one that has ever been observed to come in degrees or to be present to a greater or lesser extent in a body, then it should be pronounced a universal quality of all bodies whatsoever. (Newton likely added the condition that the quality not come in degrees because, if there can be more or less of a quality in a body, then it is not impossible that it should vanish altogether from that body, and in that case the quality could not be considered a universal quality possessed by all bodies whatsoever.) It does not matter that sense experience might sometimes mislead us. We have to work with the tools we have available, and if sense experience informs us that bodies have a certain quality, then we should accept that information. Moreover, if all sensory experiences, in all times and places, inform us that all bodies whatsoever have certain qualities, then we ought to consider that information to be as good as certain. And even should some later experience reveal to us that we are mistaken, we should use that information to either construct a revised and corrected law that is able to account for the new totality of our experience (that is, for why the exceptions occur when they do as well as for why the usual case occurs) or at least take the old law to be probabilistic, and the exceptions to constitute initial data for a measurement of its degree of probability.

Appealing to this classic account of how knowledge can be obtained by induction from sense experience, Newton claimed in Rule III that extension, inertial and gravitational mass, impenetrability, and hardness all emerge as qualities that are universally present in bodies and subject neither to intensification nor remission in the degree to which they are present in bodies.

Newton's claims may seem less than obvious on both scores. After all, may not some bodies have more or less extension than others (that is, be bigger or smaller than them), and may not the same body shrink in size or grow fatter over time? Similarly may not two different bodies, even two bodies that have the same size, differ in mass? A cubic meter of gold will outweigh a cubic meter of water on a balance scale and be harder to accelerate in a centrifuge.

However, we need to consider that we think that if one body shrinks in size or grows fatter, it is only because some of its parts have been shaven off or some other body has been injected into it. This is something that all of our experience goes to confirm. It leads us to believe that bodies are never generated *ex nihilo* and never vanish into thin air, but only increase through an addition of material and decrease through its loss, so that exactly as much material as was present at the beginning is always present at the end, though it may have been cut up and scattered, or aggregated together. Even in fire, we think, matter is not destroyed, but merely rearranged, so that the ash and smoke left at the end actually consists of just as many parts as were present in the fuel to begin with. Thus, extension is not something that comes in degrees in bodies. Bodies can get more or less of it only by being divided or aggregated and in neither case do the parts that carry the extension change in size. They just change in position and arrangement.

The same observations hold for gravitational and inertial mass. Our experience leads us to think that the mass of a thing can only be increased or diminished through injecting and removing parts. And if identical volumes of two different materials, like water and gold, nonetheless have different masses, we think that this is because the less massive one must have its parts less tightly packed into it. Had our researches discovered some strange alchemical operation that might convert, say, a quantity of lead into an equal quantity of gold, we might think otherwise, and suppose that mass is a merely intensive quantity, that one and the same body can have to a greater or lesser extent, without being divided or having new material injected into it. But in the absence of such evidence, we consider gravitational and inertial mass to be qualities that are not subject to intensification or remission. (Of course, today we do think that it is possible to transmute materials in atomic reactors, but Newton had no evidence for that.) The same does not hold, of course, for qualities like colour or temperature. While we might speculate that a change in colour or temperature is the product of a loss of some very small chromatic or caloric particles, we have no evidence for that. We certainly do not see a stream of particles being removed from a cooling or fading object, the way we can see a stream of particles being removed from a shrinking one.

Newton's claims about impenetrability and hardness are problematic for a different reason. We might think that they are not truly universal, because some bodies can be passed through or compressed, and others are soft. However, we do find that at least some bodies resist penetration, and we have no real evidence to prove that all do not. While we can pass through certain bodies, like air or water, this may be because they give way and flow around us rather than because they allow us to coexist in the very same space that they are simultaneously occupying (and that is what penetrability means, at least, it is what Newton meant by penetrability). Similarly, while we may be able to compress certain bodies, this does not mean that they are being penetrated. They could simply be getting the void squeezed out of them, and having their parts forced into closer proximity. That this is in fact the case is suggested by experience of the fact that as bodies are compressed, they exert increasingly greater repulsive force to resist further compression. Newton took this as an indication that there would be a point of maximal compression, where all the void has been squeezed out, the small parts are right up against another, and repulsive force, that is, resistance to further compression, is infinite.

A similar point can be made about hardness. While we discover by experience that some bodies are soft, we also know that others are hard. The hard ones must have hard parts (there is no way a hard body could be composed of soft parts). The soft ones, however, could also have hard parts, since softness may merely be the result of the fact that the hard parts do not stick to one another. Thus, we only really have evidence for the hardness of the ultimate parts of which bodies are made, not for their softness.

In Rule III Newton mentioned a final possible universal quality of body: its indivisibility. He expressed some reluctance to declare positively that bodies are ultimately indivisible, that is, composed of fundamental parts that cannot be further divided even though the composite things they build may be divided. However, in Query 31 of his *Opticks* he declared that the fundamental parts of bodies are most likely not only absolutely hard, absolutely impenetrable, extended, and massive, but also indivisible. His reason is that were the fundamental parts of which macroscopic materials like gold and water are composed themselves divisible, we would expect that over time gold and water should no longer be created, since fundamental particles of the particular sizes and shapes requisite to build these materials would no longer be available, those particles having in the meantime gotten ground down into some finer stuff that could no longer make gold or water of quite the same nature.

In this case, as in all of the others, Newton's ultimate justification for his position is an appeal to sensory experience. It is because we do not see the extension or mass of bodies being changed except through a removal or injection of parts, because we do not see that bodies are ever actually penetrated or composed of fundamental parts that are themselves soft, and because we do not see that the nature of materials is changing over time that we conclude that what was created in the beginning by God was hard, solid, massive, extended, movable, indivisible particles, which have remained in existence ever since.

However, for Newton these parts have not just remained in existence and moved around as hit, but gravitated towards one another, resisted changes in the direction or speed of their motion, and endeavoured to spring back to positions they previously occupied relative to one another. These are more-than-mechanical particles that are moved by forces.

This further feature of Newton's philosophy of nature is again one that he justified by appeal to sensory experience. We see the motions produced by these various attractive and repulsive forces. We do not see what causes these motions. The causes are therefore "occult" or hidden. But the motions are manifest or evident. It is evident, therefore, that there is something producing these motions. In the *Opticks* Newton speculated that those forces that operate on contact, like repulsion, elasticity, cohesion, and fermentation may perhaps ultimately be produced by the pressure of some sort of surrounding aether, but he declared himself reluctant to simply formulate some arbitrary hypothesis, after the manner so much favoured by Descartes. Instead of formulating speculative mechanical hypotheses to explain what makes the forces of nature behave as we do, he insisted that the business of natural philosophy ought to be just to study the motions that the forces produce, and to strive, insofar as possible, to account for as many of those motions as possible by appeal to the same force, operating in the same basic way. "To tell us that every Species of Things is endow'd with an occult specifick Quality by which it acts and produces manifest Effects, is to tell us nothing: But to derive two or three generall Principles of Motion from Phaenomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd." (*Opticks*, Query 31, Matthews, 156). What makes all the difference, for Newton, is whether the "occult quality" is specific and is merely named (so that there is a different quality named for every different phenomenon) or whether a variety of different phenomena are seen as instances of some "occult quality" that, whatever it may be, behaves in a characteristic fashion that we have succeeded in bringing under the scope of principles. This is what Newton had managed to do for universal gravitation. He may not have managed to determine what caused it. But he at least managed to determine how it works. And the latter is really all that needs to be done.

Newton codified this restrained, empirical, inductive scientific methodology in the passage cited at the outset of this Chapter. The proper way to do natural philosophy, he said there, is to begin with sensory experience and proceed inductively, trying to infer the forces and the laws of the operations of the forces from the observed phenomena of motion. Having arrived at specific laws, we may try to arrive at more general laws, of which the specific ones are merely special instances, and from there we should try to work up to most universal laws of nature. At that point the induction is complete, and we should then proceed synthetically, attempting to predict what will happen next by deriving it from the general and specific laws we originally established by induction. If the events corroborate our predictions, then we can place greater trust in our laws. If the events do not corroborate our predictions, then we must make revisions or allow exceptions to the laws to account for them.

Descartes's Scientific Method

Metaphysical First Principles

↓

Laws of Nature

|
/ ← Gap
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Specific Laws ← Hypotheses

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Sensory Experience

Newton's Scientific Method

Universal Laws

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Specific Laws

↑

Experience

→
Universal Laws

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Specific Laws

↓

Predictions

***"hypotheses non fingo"*** *Newton's famous claim that "I feign no hypotheses" marks only one respect in which his method differs from Descartes's. Newton also chopped the metaphysical head off of the Cartesian picture of the world. And he required that the "method of analysis" (induction from sensory experience) always precede the method of synthesis (deduction from general rules).*

This picture of scientific method is not only empiricist in its foundations, but positivist in its results. That is to say, Newton's method does not even set out to discover what makes the forces of nature behave as they do. It confines itself to uncovering the laws in accord with which those forces work, and considers the goal of natural science to have been achieved as long as this has been done. The thing that was so important to Descartes, the metaphysical foundation, is irrelevant to Newton. The entire system rests on experience alone and is so far from involving a base in metaphysical first principles that it does not even propose to deal with the metaphysical foundations of natural science. And, as things turn out, it gets along quite well on its own and establishes results that stand independently of what metaphysics may say about the ultimate causes of the forces it studies. With this approach, Newton natural "philosophy" divorced itself from "philosophy" more generally (that is, from metaphysics). This is a divorce that has since become permanent. Before Newton, there was no natural science. There was only natural philosophy, which was a branch of metaphysics and which was built upon metaphysics. After Newton, natural science proceeded with only occasional references to philosophy.

The fact that Newton, the author of the dominant view of nature of the later seventeenth and eighteenth centuries had identified this empiricist, inductivist, and positivist approach as the method he had employed in order to achieve his results was devastating for the future prospects of Cartesianism and cleared the way for the success of such radically anti-Cartesian views of epistemology and the workings of the mind as those of John Locke.

ESSAY QUESTIONS AND RESEARCH PROJECTS

1. Do a study of recent commentaries and papers on Newton's *Principia* in order to come up with an full account of Newton's objection that, were vortices responsible for moving the planets, their parts would have to move with two different speeds at once. That is, explain why the parts would have to simultaneously move at a speed that is proportional to the square of their distance from the sun and the 3/2 of their distance from the sun, and explain what it is about Newton's own account that resolves the puzzle.
2. Newton found a way of doing physics without talking about real causes (that is, about what it is that makes events in nature occur as and when they do) or about the nature of bodies (that is, about whether bodies are just solid, extended particles, or something less or something more, such as centers of repulsive or attractive force). Instead of talking about these things he simply talked about nomological causes (that is, about the laws in accord with one thing regularly happens after something else), and about generally observed behaviours of bodies (for example, about the fact that they all gravitate towards one another, or all push back against bodies that push on them). But he did commit himself to at least one metaphysical thesis: the existence of absolute space. An earlier question, in the Cartesian Science section, asked you to recount Newton's argument for the existence of absolute space. A further argument was later offered by the great German mathematician, Leonhard Euler, in his "Reflexions sur l'espace et le temps," originally published in *Memoires de l'academie des sciences de Berlin* 4 (1748): 324-333, reprinted in the second volume of the third series of Euler's *Opera omnia*, Andreas Speiser et. al. eds., (Geneva: Societatis Scientiarum

Naturalium Helveticae, 1942), 376-383, and unfortunately, so far as I know, not available in translation. Consult a copy of Euler's paper and recount his argument.

3. Newton's supposition of the existence of absolute space brought its own metaphysical difficulties with it. One of the most brilliant statements of some of these difficulties is to be found in Notes F and G of the article on Zeno of Elea in Pierre Bayle's *Dictionnaire historique et critique* (available in translation in Richard Popkin, ed., *Historical and critical dictionary: selections* [Indianapolis: Hackett, 1991]), 353-372. Recount and assess Bayle's case against the possibility of the existence of a real space.
4. Another critic of Newton's account of absolute space and of his philosophy in general was Leibniz, who engaged in a critical correspondence with Samuel Clarke that is widely available in various independent editions and collections of Leibniz's works (usually under the title of "the Leibniz-Clarke Correspondence"). Study the correspondence and identify Leibniz's main objections to Newton. Describe Leibniz's alternative account of the nature of space and assess whether it is more plausible than Newton's.