Preface
Isaac Newton's Experimental Astronomy

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On A Mystery

I

Isaac Newton was once the scientist nearly every natural philosopher wanted to emulate. He had produced the great *Principia,* where he had deciphered how the solar system works. He had found a new universal force of nature - gravity. Before his book, there were many competing models of planetary arrangement, and experts were divided on which, if any, resembled reality. Physical astronomy was a subject fraught with multiple thorny difficulties. Using a new scientific method, he dissolved those difficulties and found the system of the world. For that reason, the scientific method he used in that book and his model of the planets were celebrated by admiring philosophers as a new beginning for human knowledge. In the 18th century, he was lionized by the European Enlightenment movement as much for his method of gaining knowledge as for the knowledge he gained. They thought we had turned a corner in human history. Knowledge would soon replace the superstitious opinions of the past, they thought. Admirers envisaged an era of sustained progress by applying the new method to everything useful for humans to thrive.

Astonishingly, this wonderful new method was lost at about the same time. No one could state the highly regarded method coherently. Though several brilliant philosophers could not state it, they could emulate Isaac Newton in their research, and some did so successfully. Scientists have done well since those days in several subjects by plying his craft. But a great mystery has remained. What was his new method when fully stated? No one can say. Another mystery: if scientists can use it successfully, why can they not describe it? There is a subject called "philosophy of science," my subject, in which brilliant colleagues – philosophers and scientists - have taken great pains dissecting modern science to discern its method. But it has disappeared. How did that happen? That is my detective story.

II

This book is a sequel to an earlier book on Francis Bacon's skeptical recipes for discovering new knowledge[i]. I outlined his method, called a "new organon," which he published in the first quarter of the 17th century. He proposed an early form of the new scientific method – i.e., Isaac Newton's method. Robert Boyle modified the Baconian formulation, and in this amended form, it was adopted by Fellows of the Royal Society of London in 1662. Isaac Newton made a contribution to the method and used it to great acclaim.

The new method was experimental - it recounted experimental histories on topics. Experimentalism was a skeptical method, but there is a reason why it was not recognized as such. The skepticism was tacit to keep theological worries at bay. Skepticism was easily confused with atheism, and few, if any, Fellows of the Royal Society were atheists. Robert Boyle alone announced that he was a skeptic (Boyle, 2020/1661), and he was certainly not an atheist, but his announcement did not reverberate. Though he acknowledges that Francis Bacon inspired his method, there is little commentary on skepticism at the time. The usual commentary declares or assumes that Francis Bacon subscribed to a method based on an empirical foundation, which he did not.

The Fellows of the Royal Society of London applied the experimental method assiduously. They recorded and published, or at least noticed, new experimental results on many different things in their famous *Transactions*. For every such experimental history, they hoped that someone would find new and previously hidden knowledge – i.e., a realistic model of the bit of reality investigated. Fellows wrote many histories, but the new abstract knowledge that should follow was not immediately or regularly forthcoming - not at first.

In an early success in 1672, Isaac Newton found a realistic model for some optical experiments. He showed how interpreting experiments could yield surprising new knowledge of sunlight. His announcement of an unfamiliar reality beneath its familiar observations was surprising. Using the new method, he discovered that pure white light – e.g., ordinary sunlight – is neither pure nor white if we dig deep down. There is no such thing as pure white light: what appears as a beam of white light is always a mixture of beams of colored light in some definite proportion to one another. Together, they appear white.

I expounded Francis Bacon's thought as the theme of my first book and showed how Isaac Newton used the method successfully in optics. I contrasted it with the application of older methods. I offer the chapters of the following book as a sequel to it.

III

In 1687, Isaac Newton used the experimental method to discover a new force of universal gravitation. How he found it is one prominent theme of this book. My claim is controversial. Many have challenged similar claims, so please beware. I will propose the following. He discovered (not guessed!) that each body tends to fall towards every other body in the universe. He calculated the tendency using a particular formula, measuring the "universal force of gravity" as it applies to each pair of things falling towards one another. This principle enabled him to make sense of all the phenomena of physical astronomy of his time, which were fraught with difficulty before his foray into the subject. He resolved all the extant difficulties (except one troublesome feature of the moon's orbit, reviewed in Chapter 8.) The *Principia* was immediately successful as a new physical astronomy and widely admired even by his critics.

There was a query even then whether he was using the same method – the "experimental" method - as he had employed in his optics. Many careful scholars of his work remain doubtful. If you study my book's title, you will wonder, as many others have, how his astronomy could be called "experimental" when he cannot manipulate celestial bodies. Everyone agrees that his *Principia* was a great geometrical masterpiece. He developed Apollonius' conic sections, applying them to planetary orbits in ways that no one then had imagined, let alone proved. He gave brilliant proofs of new Euclidean geometrical theorems that astounded every mathematician of his time. Many have wondered, therefore, if his mathematical genius gained him that new knowledge in physical astronomy.

In 1713, however, Isaac Newton published a second edition of the *Principia* with some new text attached (called a "General Scholium") in which he explicitly claimed that he was plying the experimental philosophy. In my book, I will describe what he meant – and why he is right to claim that he was an experimental astronomer, peculiar though it sounds. Therefore, our knowledge (not hypothesis!) of gravity is experimental[ii]. We must first understand how he contrasted experiments with observations. A gist of my earlier book in the next section will introduce my sequel in this.

IV

My story is primarily about how we learn or acquire new wisdom – by which I mean new, abstract, general knowledge. Such knowledge has been sought and discussed in many different cultures and civilizations. My story the prequel to this book began with the life and death of Socrates and the dialogues on his philosophy written by his admiring student, Plato. In brief, I suggested that Plato tried valiantly but failed to show how we can gain new wisdom. He was a resourceful philosopher who tried valiantly all his life. His tragic personal failure had an excellent ending two millennia later – we now have modern science. We discovered how to acquire new abstract and general knowledge where Plato had failed. The new method was found by Francis Bacon, who called it, a bit misleadingly, a new "method of induction[iii]. It is useful to review that story.

Socrates spent his life questioning others considered their abstract knowledge, or wisdom - and showing that they were mistaken. He used a method of refutation, often called his "*elenchus.*" He restricted his *elenchus* to examining ethical and political questions. He would always ask people about their expert knowledge or wisdom in some field in which they were experts. He would ask them what it is, or, as we would say, to define it. But when anyone stated what it is, he would ask them if some other statements were also known. When the interlocutors allowed that additional knowledge, Socrates would show that the combined knowledge claims were logically self-contradictory. They could not all be true together. Often, his interlocutors would agree that he had disproved their "wisdom." They did so angrily in some of Plato's dialogues; in others, they did so respectfully. His use of the *elenchus* thus refuted experts about their expertise.

If you asked Socrates about his wisdom in such matters, however, he would say that he knew nothing – except for this, that he knew nothing. He did not know, and he admitted it – but, surprisingly, neither did their experts know their expertise. At least he knew his own ignorance. Perhaps that made him the wisest among them.

His self-critical attitude proclaiming ignorance was later identified as skepticism. As a skeptic, he preferred to inquire into wisdom. He preferred not to expound any wise principles that were known to him. But even if he did not expound wisdom, he may have had a wise item or two up his sleeve.

V

Socrates claimed to be seeking wisdom, not merely to find fault. He thought he could lead his interlocutors to knowledge – to knowledge he did not possess, like a midwife assisting another woman with her birth. But Socrates was a paradoxical person. He was also a moralist and a social reformer, describing himself as a "gadfly" to democratic Athens. He did not expound any doctrine, which is true, but in conversations, he brought forward his "wisdom," if we may call it that, without claiming to know it. For instance, he was well known for thinking that "getting even" with an adversary who wronged us is often incorrect. If getting even means wronging another, we should not try to get even. He seemed to believe, though he would not expound the doctrine as his knowledge, that it is better to be wronged than to wrong another. In his actions, he would show little hesitation in upholding the principle. Yet he proclaimed no wisdom.

Plato illustrated this paradox with his account of Socrates' last days. Socrates was tried in Athens by a duly constituted city jury and sentenced to death for crimes of which he was unjustly accused. Socrates denied the crimes. But when he was found guilty and sentenced to death by his jury, he accepted the verdict - even though the charges, he insisted, were false. While awaiting execution, there was an offer to let him escape - to live on, but in exile. He refused. He said that the right thing to do was to accept the sentence that was legally pronounced and to die, even though he was not guilty as charged. The jurors had erred, he said, but he would not dishonor the laws of Athens for that reason.

Socrates was a paradoxical character. When he was alive, he often said that to know what is virtuous is to do it (another moral principle he believed in but did not claim to know.) There is no gap between knowing what is right and doing it on this principle. If he knew that taking the prescribed poison after his trial was the right course of action, then he must do it – and he did.

But he was a skeptic, we say today. How could he know that taking the poison prescribed for his execution was the right thing to do? He should have escaped when given a chance if he were genuinely skeptical. If he did not know what was right, why not escape from death? It seems that he must have known more than he allowed. So which was he - a prophet or a skeptic? His paradox seems to mirror or foreshadow a problem all skeptics face when they need to act. Despite Socratic resolute actions, skepticism has been charged with being impractical ("*apraxia.*") He should have vacillated, we think.

VI

Perhaps the Socratic *elenchus* can be used to find new wisdom affirmatively. That would solve the Socratic puzzle. However, when Plato examined how the *elenchus* works, he discovered that it cannot yield knowledge of any general ethical principle. It could help us refute general principles, of course. We can find an opinion false because the combination logically contradicts what we know. But how can we find that a principle is true?

In Plato's dialogue called the *Gorgias*, he showed that a method of refutation does not seem to help us discover a true general principle. It is not enough to refute the contrary of a general principle to know its truth. Refuting an alternative or a contrary is insufficient because there may be many contraries, each internally logically coherent. We must show, therefore, that *every contrary principle to ours must fail*. Only then can we know the truth of our abstract principle. What is shown to be known must be uniquely coherent among its alternatives. But is this ever feasible for any wisdom? Can I show that my way of life, wisdom, or religion is the only logically consistent way of life? Can I show you that my narratives alone are logically self-consistent, while you must always be doomed to contradict yourself? It is a tall order. Perhaps Socratic knowledge of wisdom is unattainable.

Plato found that mathematicians also used a form of the elenchus. Like Socrates, they would refute the negation of a hypothesis they wished to prove. There are well-known proofs that there is no smallest rational number or largest prime. Of course, mathematical proofs make assumptions. Socrates' interlocutors also did when they were refuted by acquiescing to other knowledge claims. Mathematicians called such assumptions *lemmas*. Much later, this mathematical method of refuting a negation was called *reductio ad absurdum.* To prove some proposition, and assuming some lemmas, you show its negation to be self-contradictory. We could always devise another argument to demonstrate a lemma[iv]. Plato developed a lifelong interest in mathematics. Like Socrates, the Pythagorean mathematicians of Italy seemed to know how to generate knowledge by deploying their *elenchus.*

However, unlike Socrates, mathematicians did not insist that we investigate only our apparent knowledge or expertise, i.e., only whatever we think we know. They used a method that Socrates had not allowed. They would *assume* or *postulate* an abstract hypothesis. Assuming it to be clear and true, but without knowing it to be true, they would then use that postulate to shed light on all the particulars to which it applies. Plato introduced this method - the "method of hypothesis" - to philosophers in the *Meno.* Using this liberating method in this dialogue, he found a new answer to the Socratic paradox of finding new knowledge. The debacle for the *elenchus* illustrated in the *Gorgias* can be overcome*.* He explored how Socrates could have extracted new knowledge using the *elenchus.* Plato extended the method of hypothesis even more in the next few dialogues he wrote.

He was already using methods very unusually in the *Meno.* What he did was this. He used one method to shed light on the other – that is, using the mathematician's *method of hypothesis* to shed light on the Socratic *method of refutation*. That was ingenious. It allowed him to announce the famous results of what is often called Plato's dialogues of the "middle" period.

VII

Plato's leading thought about knowledge in the *Meno* was this: we must already have a clue what new knowledge looks like when we seek it. Undoubtedly, any knowledge we seek must be new, which is why we pursue it. But we must know something about it antecedently even to begin the search. If we have no inkling of what we seek, we will not recognize the truth even when we find it. To use a phrase that became popular much later - I suspect that he inspired it - we must have a prior *criterion* of truth. For instance, logical inconsistency in a conjunction is a good mark of the falsehood of the conjunct. But we need the mark of truth, which is harder to find. Negations of falsehoods are truths, of course, but usually too weak to interest us as new principles. What is the mark of a true new principle? Plato hypothesizes that we must know what we seek unconsciously (i.e., know it as the criterion) before we recognize it explicitly (as the true principle.)

Socrates was utterly mistaken! Plato respected his teacher too much to say so. Socrates said that he knew nothing while he sought new knowledge. But every seeker of knowledge (i.e., Socrates) already knows unconsciously everything that can be found, postulates Plato. Of course, *in a sense,* Socrates was right, for although he already knew what he was seeking, i.e., by *possessing* it at the back of his mind, it was without *awareness*. He did not know it explicitly. If he had, he would not be seeking it. To gain explicit access to knowledge, we must recollect the unconscious knowledge, and for this task, we still need Socrates. It would work like this: his *elenchus* will disabuse our mind of explicit errors. It will then jog our hidden memory of the known truth. Plato thus worked out how to reconcile the skeptical Socrates with the moral Socrates.

Plato postulated an immortal soul already possessing all the moral knowledge Socrates sought. The eternal soul, he postulated, perhaps forgot its store of knowledge during its birth pangs. But when Socrates got going on his interlocutors, they recollect explicitly what they always knew unconsciously.

VIII

The knowledge that Plato thought we have within us (we called it the criterion) would answer questions of the Socratic form: "What is it?" For instance: "What is courage?" or "What is temperance?" Socrates asked such questions. Plato called such knowledge our grasp of the Ideas or Forms of these virtues. He noticed that such Formal knowledge is not restricted to the moral realm. Answering those "what is it?" questions (for which Socrates was famous) could also resolve the paradoxical problems about motion that bedeviled Greek philosophy at the time. A Form or an Idea of a certain kind of thing is itself unchanging entity but it governs the laws of change of things of that kind. Forms govern all change. That was Plato's bold hypothesis.

Plato's hypotheses began with the doctrine of recollection, which he postulated. Ideas were provided to our souls by a divine being before our birth. We must assume that God is all-knowing. Later, he postulated hypotheses of not only an immortal soul and an all-knowing God but also a perfect (i.e., good) God who created the universe, i.e., who was all-powerful. He even postulated a day of judgment. All these hypotheses were products of his search for a Socratic theory of knowledge. We must note where it all began. If we postulate all that, Socrates could be a true moralist and a skeptic. Plato's grand Platonisms all started with the hypothetical presuppositions of the Socratic method of gaining new knowledge by refutations.

We will see that his theory of knowledge failed. But his grand hypotheses remained very influential. Later religions – such as Hellenistic forms of Judaism, Christianity, and Islam – rejected the

Socratic method, or skepticism, but embraced Plato's grand hypotheses as faith, or as fervent but assumed belief. In my story of modern science in the previous book, I described how the Socratic method was rescued by Francis Bacon from its fideist religious environment in which skepticism was suppressed as a danger to the faith. This sequel will begin with an chapter on how the political conditions in sixteenth-century England made Francis Bacon's feat possible in the next.

IX

Plato did not abandon the older skeptical method – i.e., the Socratic *elenchus*. He was undoubtedly trying to understand how the *elenchus* could give us knowledge affirmatively. But he did not abandon the use of the *elenchus* that he had rescued. His philosophy remained as self-critical as Socrates had demanded. He was, what I call in my earlier volume, an "active fallibilist" - not just admitting fallibility but ever trying hard to find out where he may have failed. This feature is also found in modern science when considered as a Baconian collective enterprise.

In later dialogues, such as the *Parmenides,* Plato raised difficulties in his theory of Forms and his explanation of change. As he peeled back his grand speculations, one after another, having found flaws, he was left with the first hypothesis he had introduced, in the *Meno.* That was where the method of hypothesis began. There, he showed how Socrates could successfully search for some knowledge by unconsciously possessing that knowledge. Was that beginning, at least, correct? In the *Theaetetus* - written when he was nearly sixty - he gave us excellent reasons to abandon that earliest of his Platonic hypotheses.

Plato's critique of knowledge by recollection – his critique of his earlier hypothesis - is devastating. Suppose that we already know (unconsciously) what we seek explicitly. In that case, how can we ever explicitly adhere to sincere and well-reasoned false judgments? How can a good mathematician ever make a sustained mistake, like 7+5=11? An error could be trivial, of course, like a temporary slip. But mathematical errors are not all trivial. Nor are they slips. Plato reminds us of Pythagorean false judgments by choosing Theaetetus as the interlocutor. How could Pythagoras assert that everything in the cosmos is a number, as in a ratio of whole numbers, when even the diagonal of a square is not a ratio of whole numbers of its sides? What do you mean, you may exclaim, could it be that the great mathematician Pythagoras was *mistaken*? How could he be mistaken? He must have known the truth all along (unconsciously) if Plato's doctrine of recollection were true. How is a false judgment possible? Plato raised this objection to Plato's hypothesis.

Plato offers two ways of misjudging falsehoods as true – by subjective bias or objective error. First: when God reveals the Forms to us, according to his earlier grand hypothesis, our all too human mind may not be in a fit state to record a faithful impression of reality. He described how an impression of a shape on a wax block could be inaccurate in at least one of two ways. The wax may be too hard to record the impression or too molten to keep its shape. If our mind is like the wax block, then subjective errors or biases may undermine our capability. There is a second possibility. Two similar Ideas or Forms may also confuse us. We may apply the wrong Idea to an object, mistaking one kind of thing for another. A lookalike of the true Idea (an "Eidolon") may be taken as a criterion of the knowledge we seek. Eidola of both kinds (Francis Bacon's "Idols of the Mind") can explain how false judgment is possible.

We are now in real trouble! Plato's theory of knowledge in the *Meno* has been fatally wounded. No longer do we know how we know! The very sacred criterion of knowledge that we possess within us (as Plato had opined) can be misleading. How can we ever overcome its deficiencies? Where can we find a criterion to check up on a given criterion? Plato concludes the *Theaetetus* with the alarming thought that we do not even know what knowledge is[v]. More alarming is that his conclusion is the best description of the theory of knowledge even today.

Plato's tragedy as a philosopher was this. He could not defend a skeptic's search for knowledge. He had failed Socrates. Skeptical inquiry is self-defeating. It is also impractical. In his last unfinished dialogue, the *Laws*, Plato no longer has Socrates even participating in the dialogue.

We may conclude that we need only fervent belief, not knowledge. Fideism, or the doctrine that we abandon knowledge for belief, became the preferred philosophy after Plato. Fideism was taken up in many sects of Christianity and Islam as the only way to wisdom, though they disagreed and fought on what way.

X

Francis Bacon solved the almost insoluble problem of the affirmative *elenchus*. Out of old despair arose new hope. Being a faithful Christian, he rediscovered pagan knowledge two thousand years later as a part of his belief – i.e., pagan and secular within his Christian faith. As a good Christian, he allowed that ethics and all matters related to human salvation must be reserved for the Church. Ethical commandments come from God. Faith in God is the foundation of all our ethics, as revealed after the Fall. However, not everything springs from faith. Humans can still work out what is true of things that are not divine and unrelated to our salvation. We could still do natural philosophy.

Francis Bacon proposed that we should stop seeking knowledge at the most abstract level. Plato had made that mistake. We should begin by looking at minimal and concrete cases of natural reality. We choose a particular of a limited kind and ask: "What is its nature?" (like Socrates, in a way.) Then, we should follow Socrates in skeptically challenging what we think we know about it. Note how closely this mirrors Socrates running amok among the experts. Typically, the bits of apparent knowledge we upend in natural philosophy would be observations or our practically functional understandings of these things. The targets may also be mathematical truths about it or previously formed experimental conclusions. When we refute what we think we know of a thing's nature, we conduct a sustained skeptical inquiry, an ongoing *elenchus.* We put nature to a cross-examination. We seek a metaphysical understanding of some very local, concrete, particular. In simpler terms, in modern terms, he taught us to challenge common knowledge – even common sense knowledge - to see where it may be misleading.

We may find that a thing observed to have a given nature in one circumstance may lack that nature in a similar or proximate circumstance. That is how the Socratic *elenchus* worked. But we are looking at the natural world, not the supernatural, which was reserved for the Church of England. And we still need to go beyond Plato's Socrates.

Francis Bacon made two remarkable innovations to the *elenchus*. The first is to savor the paradox. Since a thing cannot both have a nature and not have it, we have created a paradox, a problem, a discrepancy when we find a nature missing in a thing after we have witnessed it in a very similar circumstance. Francis Bacon's new recommendation is to note the discrepancy without trying to resolve it. We must patiently write our discrepancies carefully in an account called an "experimental natural history." His second innovation was that in this fraught historical record, we must note the circumstances in which the original observation or experiment is made. The observation or experiment must be stated so transparently that it is replicable. Someone must also replicate it based on the instructions given. Then it is admissible into the experimental record. We seek more such discrepancies, piling them up in our experimental and natural history of a thing until we have become quite bewildered about it.

At some point we can treat the whole collection of discrepancies as a puzzle about the thing. We ask ourselves, why does it appear so paradoxically? Solving the puzzle is what Francis Bacon called "interpreting" nature. Imagine that the historical record is a cryptogram or a cryptic message. There is a cipher concealing the thing's true nature in its code – in its baffling appearances. We must decipher it. We must find out in each discrepancy why the thing appears thus in one circumstance but differently in another.

The solution would be found in a schematism or a model that rectifies all the apparent errors of the natural history of the thing. Our model is extraordinary – this is where Francis Bacon went beyond Plato. The fraught record makes every other model fail. They are all pre-refuted by the bewildering puzzle. Because of this, our model solution is uniquely consistent. Nothing else works! We conclude that uiniqeness gives us true knowledge of its underlying nature. We know the reality behind its fraught appearances because the discrepancies refute every other model of it.

When we have such a model of a thing, we also know how to manipulate the thing under study. To produce a new effect based on our experimental knowledge, which has been recorded as a discrepancy, we must reproduce the condition under which the discrepancy was recorded. In a Baconian natural history, the condition of its occurrence is always noted and checked by replication. All the effects covered in the model can be produced in this manner. We have found new powers over nature after our inquiry is completed as soon as we have a logically coherent model.

XI

The usefulness of science in practice was a necessity for Francis Bacon. He was writing about method as a devout Christian. If we seek knowledge for its own sake, we commit the sin of hubris like

Adam. He sought the fruit of the Tree of Knowledge in the Garden of Eden. He was cast out for his sin of hubris. No, no, no! We must not seek knowledge for itself!

But we may seek knowledge for charity. The Christian gospel asks humans to love others as they love themselves. There is no limit to how charitable we may be. If the knowledge we seek gives us power over nature, we may seek it. We can use that power charitably to alleviate human suffering. We are still seeking knowledge, just like Adam, it is true, but our aim is different – we do not search for truth for its own sake but to relieve human suffering. The power that true induction can give us over nature was central to Francis Bacon's aim of science.

A decade after Francis Bacon died, Robert Boyle was engaged as a young lay preacher. He came to appreciate the Anglican theology that he shared with Francis Bacon. The study of experiments in natural philosophy was a Christian duty – the duty of charity. Being a Baconian was being Christian. But the Baconian method had to be amended subtly to reflect a new star Robert Boyle had seen on the horizon.

Galileo Galilei transformed the study of nature by adding a new form of mechanical inquiry into it. The underlying reality of the Universe consisted not of Forms, Natures, Species, or Ideas but mathematically described motions. Nature is mathematical and mechanical through and through, according to Galileo Galilei. Soon after, René Descartes developed a fully formed modern philosophy for mechanists. The new metaphysical theory postulated reality at its basic level as matter in motion.

As a young man, Robert Boyle was deeply influenced by the new mechanistic thinking. It was becoming increasingly prominent in Europe, even if not everyone was convinced. The reliance on old Platonic Forms and Ideas and the search for natures, assumed gratuitously in Baconian texts, had come to seem otiose. As an admirer of the new science, Robert Boyle modified the Baconian search. The scientific search was not necessarily for true Natures, Forms, or Ideas that marked Baconian formulations. Baconian induction was loosened to include possible corpuscular and mechanical hypotheses that may help us find the true underlying reality. Fellows of the Royal Society of London in 1662 adopted Robert Boyle's relaxed form of the method of experimental philosophy. By adopting a mechanical hypothesis, as a "working hypothesis," the Baconian method was freed from its old Platonic assumptions. The new method flourished In this guise.

Isaac Newton was well-trained in mechanics and geometrical optics at Cambridge University. Soon after graduating, he studied a peculiar discrepancy in an image of a beam of light sent through a small circular pinhole into a darkened room. While the image on a screen should be circular when the apparatus is appropriately set up, the image appears oblong. The discrepancy defied geometrical calculations and René Descartes' sine law of refraction. Following up on the discrepancy, he recorded some more peculiarities as an experimental philosopher. Eventually, he came up with a new model of light that smoothed out the difficulties he had personally encountered. We may call this a "special induction" – a model-building exercise to solve some preliminary difficulties. Using the same model, he smoothed out many discrepancies in the experimental histories of color that Robert Hooke and Robert Boyle compiled earlier. He called this second step "general induction."[vi] The success in his general induction is what Francis Bacon had envisioned as an "Interpretation of Nature." He had solved the accumulated puzzle of refractions and colors.

His early triumph in optics showed Isaac Newton that experimental philosophy could produce new knowledge. His optical discovery was small compared to his later achievement in physical astronomy, which his my task to describe in this book, but his success is evident in both. Isaac Newton also made an important contribution to the scientific method. In the *Principia*, he carefully recorded how he built the "system of the world," and then applied it to solve the larger puzzle of discrepancies in physical astronomy. He was so impressive and explicit in his model-building that countless philosophers learnt from him, and emulated his model-building in different areas of study. Some such models even solved larger puzzles, as Isaac Newton had done. Building Newtonian models of problematic phenomena and watching them solve a bigger puzzle (if and when they did) became the stuff of modern science.

XII

A model built for any investigated bit of reality is always approximate, even when it solves an experimental puzzle uniquely. Predicting planetary positions, for instance, is never exact. Measuring a model's constants and variations more carefully and using theory to correlate measurements is a normal part of modern science. The model is fleshed out better and better in time. For this reason, perhaps, Thomas Kuhn called this kind of measurement and recalibration "normal science," which is like the activity of a "mopping up" operation after a model is first proposed. However, another kind of recalibration of models also takes place. It has not received enough attention. It is at some odds with Thomas Kuhn's conceptualization of normal science. He imagined each train of normal science as driven by a single exemplar, paradigm, or disciplinary theory as its growth engine. But more happened in science since the early nineteenth century.

As Paul Feyerabend has noted, natural scientists are very often opportunistic. Philosophers interested primarily in one model will happily take advantage of a correlation of their theoretical entities in a different model if that helps them better recalibrate their model. I call this development of modern science its *growing density of knowledge*. When William Whewell invented the word "scientist" in the nineteenth century, models in science showed a certain growing interrelatedness, what we may call a consilience between them. Even though each subject pursued its own study in its own way, "results" from one subject were available for other subjects to make its model more accurate, secure, and realistic. Physical and chemical models were the first to see the growing density of interrelated scientific knowledge develop. Medical science and biology saw a similar development early in the twentieth century. In the second half of that century, all the sciences were seen to be able to assist each other in modeling the world a bit better.

Of course, though models work together to give us the growing density of knowledge that we have, they retain their propensity to conflict. Skeptical inquiry continues at one end of science – the experimental and theoretical end - while at the other – the practical and instrumental end - we can harvest its products. If we examine science since the early nineteenth century, both these processes are amply evident.

Natural science is a thing, all right. We can fully understand why Alan Chalmers asks, *What is This Thing Called Science*? (Chalmers, 1976). Science is sufficiently different from other intellectual crafts to set itself apart. Its burgeoning discoveries yield new powers over nature. With many of its models interpenetrating one another while being recalibrated better, natural science has become a secure bet for progress in human knowledge. It has won over the trust of almost the whole educated world. Its results seem secure, its path assured, its future assured.

You must be very learned and very selective with your facts to recog\nie science as a flimsy fabric of speculation. Of course, such learning exists, and such selectivity is not impossible. Its pessimism is based on a flawed methodology. First, we must assume that all models are speculative. Unless many models are known to be approximately true of reality, we could not work out how the density of scientific knowledge can grow. Second, we must assume that metaphysics must be grand. Science is very different from earlier metaphysical speculation, which was overly general in its starting point. Now, the scientific method restricts our metaphysical knowledge to local realities with new powers over nature.

Karl Popper thought that the demarcation of science from metaphysics is one of the two most fundamental problems of the theory of knowledge. If I have got it right – and by all means, please challenge me, I ask you as a skeptic – the demarcation of science from philosophy is to be found in its method. Karl Popper would have denied this. He would begin his lectures on method at the London School of Economics by challenging some astonished students – announcing that there is no scientific method. But there is one. It demarcates science from both speculative philosophy and faith-based religion.

For three hundred years, some of the greatest philosophers have said that there is no recipe for new knowledge. Why have they not seen it? I suggest an analogy. The method seems to me to have become invisible by being drowned out. Even the brightest of distant stars in the sky are invisible during the day. Brighter sunlight drowns it out. When Isaac Newton published his *Principia* in 1687, it was hailed as an outstanding achievement, and no one has seriously challenged that claim. His method was also proclaimed but lost in the firmament – because we cannot see it.

A year later, in 1688, the Glorious Revolution took place in England, with a promise of peace between warring Christian factions. Religious wars and intolerance had devastated Europe, and the promise of peace in a Liberal Democracy was a great bright sun in the sky. The Newtonian method was merely a distant star whose light was drowned out. Liberal Democracy proposed a new kind of peace between warring faiths, based on what I call the "*Pax Empirica.*" I hope my use of a Latin phrase sufficiently impresses upon you how important I think it was.

John Locke's Idea was that some matters of faith could not be known to anyone – and over which matters of faith warring claims were being made. An influential group or person must not impose such claims upon anyone else. We can impose on others only what is known or understood by universal reason. To distinguish what is knowable and what may never be known is the task of finding the scope of human understanding[vii]. John Locke suggested that what is knowable and understood is strictly empirical - all our knowledge is extracted eventually from simple ideas of sensation. Such things as the nature of the soul, the true nature of God, and the details of salvation in our life after death are unknowable and beyond rational understanding. They cannot be empirically determined. If I do not know something, I cannot impose on you what I think I know since it is only a personal belief of mine, a faith. We may enjoy our respective faiths so long as we respect rational knowledge and understanding in a polity. We can then live amicably by whatever else we have agreed upon mutually and voluntarily.

While this is a salutary argument for a liberal democracy, it fails to allow for the scientific method[viii].

Unfortunately, the world appears to each of us in wonderfully different ways. There are two ways of marshaling and rescording what we experience for science. We have an experimental history if we seek discrepancies in the appearances and highlight them. Such a skeptical critique of common knowledge can yield knowledge and science.

But empiricists insist all our knowledge comes from sensations, which are always logically compatible with other sensations. They are compatible because they have no logical form, being things, not propositions. When they are so construed, there are no discrepancies in such *data* (i.e., in what is presumed as the "given.") Experimental natural histories then become invisible within empiricist limits. No problems surface out of data, and no complex puzzle can exist in them to challenge us. Experimental natural histories have disappeared. We are left basking in the bright sunlight of John Locke's *Pax Empirica.*

An empiricist's method for science is a particular case of the method of hypothesis: we can always invent hypotheses to be evaluated by sanitized empirical data. We use a hypothesis to shed light on or explain whatever it can, assuming it is true. As we will see in the last chapter of this book, the empiricist method of assessing knowledge is also helpful in some limited circumstances. But all method is not empiricist. Among methodologists, we have assumed it for too long.

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[i] *Francis Bacon's Skeptical Recipes for New Knowledge,* Palgrave MacMillan, an imprint of Springer Nature, March 30, 2024.

[ii] In the General Scholium, Isaac Newton refused to speculate about the cause of the force of gravity, by using his famous announcement that in experimental philosophy, "hypotheses non fingo" i.e., I do not imagine hypotheses. This implies succinctly that he thought his method of the *Principia* was overall experimental, and that the result he announced (gravity) is not a hypothesis. We will see in what way he was right.

[iii] The word "induction" is a rendering of Aristotle's *epagoge*, which is a process of abstraction of the Form or Essence of a thing by looking at its observed instances. In the late seventeenth century, when the reliance on Forms and Essences declined, induction also came to be associated with calculating the probability of a general statement given its positive instances. Baconian induction is unlike either of these techniques, and much more like a Socratic method of refutation. However, because the word "induction" is used, Francis Bacon's method is often disregarded by those who think it must be one of the two other techniques.

[iv] If more and more lemmas are made into theorems, we may find that there are some residual lemmas that remain unproved. These may be called "postulates" or "axioms" from which all other theorems are derivable. Finding the fewest number of axioms for a science becomes a new task for mathematicians. In ancient Greece a simple axiom system was found for Geometry, attributed to Euclid, but not for Arithmetic, for which we had to wait until Giuseppe Peano was able to propose one late in the nineteenth century CE.

[v] Plato considers a solution to the problem of the criterion in the *Sophist.* If we add a second criterion, being a chain of being wherein all the forms are linked, it may be used to check veracity of individual Forms. If, however, the source of the interrelation of Forms is not different from each individual Form, then the new method only pushes the skeptical problem one step back, without solving it.

[vi] Isaac Newton refers to this two-step method in many different ways In the Preface to the first edition of the *Principia,* for instance, he describes it as follows: "… the whole burden of philosophy seems to consist in this – from the phenomena of motions to investigate the forces of nature, and then these forces to demonstrate the other phenomena". Philosophers may wonder whether what he describes is circular reasoning, which would be fallacious. It is not because the first part is an investigation (an abbreviated experimental history) leading to a model, and only the second part is a demonstration, when the model is applied to the puzzle in the entire experimental history to solve it.

[vii] John Locke's *Essay* (1689) is the first theory of knowledge to investigate what cannot be known, an agnotology but within epistemology, and he uses empiricism to limit the scope of human knowledge.

[viii] This thought calls for an investigation into the foundations of liberal democracy, which, however, is not attempted in either book. It requires a larger investigation.