CHAPTER 5

The Criteria of Theories, Simplicity for Instance

By what criteria should theories or explanations be judged to be good, over and above the requirement or at least the ambition for them to be true or correct? We may invoke appropriateness, relevance, economy, clarity, comprehensiveness, generality, parsimony, simplicity, elegance, even beauty, but what views did earlier investigators entertain on the subject? We have already seen that one group of ancient Greek theorists developed a model of axiomatic-deductive demonstration designed to bolster claims that a sequence of argument could yield results that are not only true but incontrovertible. That, we suggested, was in the context of competitive claims to authority, where, according to some at least, mere persuasiveness was not enough: certainty had to be attained. The main problem that was often underestimated was that of securing primary premisses that met the twin criteria of indemonstrability and self-evidence.

But elsewhere some ancient Greeks tussled with another criterion by which theories could be judged, namely simplicity, and it will be instructive to examine how this worked out in practice. It so happens that we have extended discussions of this criterion in Ptolemy, especially in the *Syntaxis* or *Almagest*,[1] where he explicitly recognises that the invocation of the principle may run into difficulties, but then endeavours to circumvent these. Here is a notable astronomer at work in the second century CE reconciling or trying to reconcile his sense of the complexities of the problems with some of the basic assumptions, even articles of faith, that in his view govern the scientific enterprise. We even have the further benefit of some explicit classical Chinese texts that similarly invoke notions of simplicity that allow us to offer some comparative judgements concerning their views on the subject.

[1] I shall cite this according to the standard two-volume edition of Heiberg 1898 and 1903, where I shall refer to the first as H 1 and to the second as H 2, citing the book number in Roman followed by the chapter in Arabic numerals.

First a little Greek lexicography is in order. The adjective we translate 'simple' is *haplous*, the cognate substantive being *haplotēs*, 'simplicity', but the range of meaning is considerable, not just 'simple' as opposed to complex, but elementary/elemental as opposed to composite/compound (*sunthetos*), and unqualified/absolute versus qualified/relativised (as in the contrast between Platonic Forms and particulars that share in them or imitate them). Used of human character and behaviour *haplous* may pick out what is frank, open and honest, as opposed to devious, but it may also have negative undertones of simple-mindedness, foolishness as opposed to what is sophisticated, urbane, *asteios*.

Where astronomy is concerned, however, the goal is often simplicity in the shape of what is considered the simplest hypothesis to account for the phenomena. The trouble is the phenomena are seldom simple themselves. The general principle is clear enough: it has affinities, of course, with what has become known as Ockham's razor (Sober 2015, cf. 1975 and 1988). This is often stated as the rule not to multiply entities without necessity, though that leaves the question of where that necessity kicks in. When two hypotheses yield the same results, the simpler one – the one that makes fewer physical or conceptual assumptions – is to be preferred. One of the main contexts in which we see this at work in Greek astronomy is in relation to the choice between an eccentric and an epicyclic model for the movements of the sun, moon and planets. As was apparently known to Ptolemy's predecessors already, Hipparchus in all probability, perhaps also Apollonius though the evidence for that is more disputed (Neugebauer 1975: I 263f., Toomer 1984: 555, Goldstein 2009), over a range of phenomena either an eccentric or an epicyclic hypothesis will serve equally well as the basis for an explanation of certain apparent irregularities.[2] When that is the case there is nothing to choose between them. Yet in practice Ptolemy favours an eccentric model for the sun, an epicyclic one for the moon and planets.

[2] Those apparent irregularities included the inequality of the seasons, i.e. the movement of the sun, measured by the solstices and equinoxes, and the phenomena of the 'stations' and 'retrogradations' of the planets, which had earned them the label of the 'wanderers' (though Plato considered that a blasphemy, *Laws* 821cd). Their regular easterly motion (when judged against the background of the stars) is interrupted. Their position appears to remain unchanged over a number of days (their 'stations') and they then move in a westerly direction ('retrogradation') for a further period, eventually, after a second 'station', resuming their normal easterly movement. Figures 5.1 and 5.2 in the Supplementary Note illustrate the epicycle and the eccentric models in their simplest forms and Figure 5.3 shows how the two can give exactly the same results. Figures 5.4 and 5.5 show how these models can represent the inequality of the seasons and the retrogradations of the planets.

https://doi.org/10.1017/9781009029285.006 Published online by Cambridge University Press

Now this is in part because he believes that the eccentric model cannot account for one feature of planetary motion, namely that for each of the planets the time from greatest speed to mean is always greater than the time from mean speed to least (IX 5, H 2 250–1). On the other hand, the epicycle model can provide for this. So in this instance it is not that the eccentric and epicycle models are equivalent across the board – in his view at least – so the choice between them is not *just* a matter of simplicity, not at least where the planets are concerned. It is only in the case of the sun that his decision to favour eccentricity is motivated by that consideration. At III 4, H 1 232.10–17 he makes the point explicitly: the anomaly of the sun could be represented by either the eccentric or the epicyclic hypothesis. 'However, it would seem more reasonable to associate it with the eccentric hypothesis, since that is simpler and is performed by means of one motion instead of two.'

Actually, as the modern commentators note, it is strange that he does not see that the eccentric model can be fixed to yield precisely that feature of different times that bothered him, provided you allow the apsidal line to move – which Ptolemy himself later uses in XII 1 in relation to the outer planets. But that is a minor puzzle that need not concern us here.

So here is one context in which simplicity is invoked in the *Syntaxis* and at III 1, H 1 201.18–22 we have an explicit statement of the general principle, though one qualified by an important proviso. 'In general, we consider it a good principle to explain the phenomena by the simplest hypotheses possible, in so far as there is nothing in the observations to provide a significant objection to such a procedure.' We shall need to come back to that later.

But another context in which comparative simplicity is mentioned has been much more of a stumbling block, and this too will involve me in a bit of a digression. This is the chapter (I 7) in which he rules out any motion of the earth, where he mentions the alternative suggestion attributed to some unnamed ancient theorists that the phenomena could be accounted for not on the supposition that the heavens revolve around a stationary earth (the view he favours) but on the basis of the idea that it is the earth that revolves on its axis once in every twenty-four hours. In fact he mentions two versions of that suggestion, one that has the earth alone revolving and a second that assigns rotational movement in part to the earth *and* in part to the heavens.

He goes on to say that 'so far as the phenomena relating to the stars are concerned, perhaps nothing might prevent things from being in accordance with the simpler [form of this] theory' (I 7, H 1 24.14–18).[3] Yet in another translation (Taliaferro 1952) that was – disastrously – enormously influential, what Ptolemy is made to say is that the hypothesis that the earth rotates is simpler than the view that it is the heavens that do. He certainly goes on (all are agreed) to point out that on the grounds of physical considerations here on earth (movements of the clouds and of projectiles for instance) the earth's rotation has to be rejected. But where Taliaferro's and other renderings (cf. Pedersen 1974) go wrong is in attributing to Ptolemy a major concession that the earth's rotation is acceptable if treated as a purely instrumentalist hypothesis.[4] Rather, he is rejecting the more complex of the two rival views he has identified, for that makes the additional mistake of introducing an extra source of rotation. But that does not leave him *endorsing* the superior simplicity of the earth's rotation, for its greater or less simplicity compared to the theory of the heaven's rotation is not in view at all. True, he concedes that the earth's rotation is as it were a theoretical possibility, but it is one he immediately and emphatically denies on physical grounds – and it is clear that it is a physical, that is realist, account that he is after both here in the *Syntaxis* and in his *Planetary Hypotheses* (Lloyd 1991: ch. 11, 269, 271).

Several texts in the *Syntaxis* indicate that Ptolemy is keen on the principle of simplicity. But the problem he faces over and over again in the detailed investigation of celestial motions is that the data he has to deal with are in fact extremely complex, as indeed he repeatedly points out. None of the periodicities of the motions of the sun, moon and planets can be expressed in whole numbers. The tables he sets out give their values to six sexagesimal places and even then that is only an approximation. At III 1, H 1 209 he says that the sun's mean daily motion, expressed as a sexagesimal fraction, is 'approximately $0;59^{i}, 8^{ii}, 17^{iii}, 13^{iv}, 12^{v}, 31^{vi}$'. And that is one of the simplest periods. IX 3, H 2 214ff. sets out the mean motions in longitude and anomaly for each of the planets.

So when he sets about constructing the epicycle models for each of the planets, the geometry is crystal clear (and I would say extraordinarily simple: the idea that epicycles are hard to deal with is often the reaction of those who have not undertaken to go through the relevant calculations). Yet the

3 My translation of this crucial text is based on that in Heath 1932.

4 That is, one that does not purport to describe physical realities, but only serves the purpose of yielding mathematical calculations that correspond to the observed data. Lloyd 1991: ch. 5 examines the relevance of the contrast between instrumentalist and realist interpretations to ancient Greek astronomy and engages in an extended critique of the then influential views of Duhem (1908) on that topic.

concrete parameters fed into the models are extraordinarily complex – as they need to be to give the best approximation possible.

Given the complexity of the phenomena to be explained, there is nothing particularly surprising in Ptolemy's invoking such complex parameters alongside his simple geometrical models. Indeed it is wholly admirable that in general he does not allow himself much grosser approximations and rounder numbers (his figure of 1° in 100 years which he settles on for the precession of the equinoxes is rather an exception).[5] Nevertheless this complexity may be thought to sit somewhat uncomfortably beside the ringing tones in which he describes the value of astronomy at the very outset of the *Syntaxis* I 1, H 1 7.17–24. Why is astronomy worth studying, he asks, and replies that it is not just to reveal and appreciate the beauty of the universe but also to improve human character:

> Of all studies this one especially would prepare humans to be perceptive of nobility both of action and of character. When the sameness, good order, proportion and freedom from arrogance of divine things are being contemplated, this study makes those who follow it lovers of this divine beauty and habituates them, and as it were disposes them naturally, to the same condition in their soul.

But that is not where the problems for Ptolemy's programme end. For most of the *Syntaxis* he is concerned with the movements of the sun, moon and planets in longitude, that is along the ecliptic, discounting for the time being the latitudinal movements of the planets, north and south of the ecliptic. But then in Book XIII he turns to the latter problem. After some preliminary remarks in XIII 1, the next chapter observes that in the case of the three outer planets the eccentre has a fixed inclination, so that diametrically opposite positions of the epicycle have opposite directions in latitude. But for Venus and Mercury the eccentre moves together with the epicycle in the same latitudinal direction, for Venus always to the north, for Mercury always to the south, and a further couple of pages describe how this works out to give an approximation for the latitudinal movements.

[5] The equinoctial points are where the ecliptic intersects the celestial equator. The term precession is used to describe their gradual displacement from east to west in relation to the fixed stars. The value of 1° in 100 years was the figure that Ptolemy obtained from Hipparchus, the discoverer of this phenomenon for the Greco-Roman world in the second century BCE. But it is clear from *Syntaxis* VII 2, which cites Hipparchus' work *On the Displacement of the Solstitial and Equinoctial Points*, that Hipparchus himself treated this as a lower limit for the rate of precession. Ptolemy's acceptance of this figure for the actual value, in part no doubt for reasons of convenience in calculation, was to have very negative consequences for subsequent Western astronomy, though to be sure he should not be blamed for the mistakes of later authors who used his work uncritically.

Then we come (finally) to the text XIII 2, H 2 532.12–534.6 that is my prime exhibit in this chapter (Toomer 1984: 600–1).

> Now let no one, considering the complicated nature of our devices, judge such hypotheses to be over-elaborated. For it is not appropriate to compare human [constructions] with divine, nor to form one's beliefs about such great things on the basis of very dissimilar analogies. For what [could one compare] more dissimilar than the eternal and unchanging with the ever-changing, or that which can be hindered by anything with that which cannot be hindered even by itself? Rather, one should try, as far as possible, to fit the simpler hypotheses to the heavenly motions, but if this does not succeed, [one should apply hypotheses] which do fit. For provided that each of the phenomena is duly saved by the hypotheses, why should anyone think it strange that such complications can characterise the motions of the heavens when their nature is such as to afford no hindrance, but of a kind to yield and give way to the natural motions of each part, even if [the motions] are opposed to one another? Thus, quite simply, all the elements can easily pass through and be seen through all other elements, and this ease of transit applies not only to the individual circles, but to the spheres themselves and the axes of revolution. We see that in the models constructed on earth the fitting together of these [elements] to represent the different motions is laborious, and difficult to achieve in such a way that motions do not hinder each other, while in the heavens no obstruction whatsoever is caused by such combinations.
>
> Rather, we should not judge 'simplicity' in heavenly things from what appears to be simple on earth, especially when the same thing is not equally simple for all even here. For if we were to judge by those criteria, nothing that occurs in the heavens would appear simple, not even the unchanging nature of the first motion, since this very quality of eternal unchangingness is for us not [merely] difficult, but completely impossible. Instead [we should judge 'simplicity'] from the unchangingness of the nature of things in the heaven and their motions. In this way all [motions] will appear simple, and more so than what is thought 'simple' on earth, since one can conceive of no labour or difficulty attached to their revolutions.

Let me highlight just a few salient points in this amazing text.

(1) There is a clear recognition of the *lack* of simplicity, as *we* might judge that, in celestial motions.

(2) But that does not stop Ptolemy from claiming that they *are* simple, provided we adopt the right criteria for 'simplicity'.

(3) That in turn means that we have to accept that there are radically different criteria for judging 'simplicity', (a) in the heavens, and (b) on earth, a point he bolsters by observing (4) that even in the latter case (b) opinions differ.

(5) While that might come across – to his readers as well as to us – as quite arbitrary, he appeals to the difference in the natures of the heavenly regions and what we are used to. (5a) We might expect the movements of the epicycles and eccentrics would get in the way of one another, as they are liable to do with human mechanical models.[6] But that does not happen in the heavens. (5b) We might expect that lower circles and spheres would obscure and make invisible higher ones, as they would if they were made of ordinary opaque stuff. Again that does not occur.

(6) In effect what he has done in (5a) and (b) is to convert what might well be thought to be major objections to his models into part of his justification for driving a wedge between celestial and terrestrial spheres and so justifying his original claim (in (2)) that the heavenly motions *are* simple (despite the complexity of his devices).

From initial applications, where simplicity is invoked to prefer one motion (eccentricity) to two (in the epicycle hypothesis), the notion has undergone a major transmogrification. He had said (III 1) that we use simplicity if there is nothing in the phenomena to preclude it. But in practice, when he comes to the difficulties of latitudinal movement, 'simplicity' is transformed from an idea we can apply on the basis of our experience into a *postulate*. The heavenly bodies might look anything but simple: but that is because we are not using the right notion of simplicity. Adjust our perspective to what is appropriate to the heavens and those motions *must be* simple. We are just plain wrong to judge their simplicity by our standards. Think how wonderful they are in that all those celestial circles and spheres never get in the way of one another, never obscure one another.

Now in the *Syntaxis* Ptolemy has done a remarkable job of producing elegant models to account for a very wide range of astronomical phenomena (and as I said, they *are* elegant if one works through their construction and application). His not shying away from the difficulties, for example in relation to movements in latitude, is, I would say, wholly admirable (though for sure there are major difficulties such as the observed difference in the angular diameter of the moon at perigee and apogee where he does duck the problem).[7] But while he claims that when we contemplate

[6] That such physical models were made is clear not just from the written reports in Cicero, for instance (*On the Nature of the Gods* II 88, *Tusculan Disputations* I 63, *On the Republic* I 22) but from the sole extant example, the Antikythera mechanism described e.g. by Jones (2017). While aspects of its complex system of gear-wheels remain controversial, it was clearly designed to represent the movements of the sun and moon (including the cycles of both lunar and solar eclipses) if not also those of the five visible planets.

[7] In *Syntaxis* V 13 the values that Ptolemy assigns to the radii of the circles that govern the movement of the moon have the consequence that its distance from the earth should vary by as much as 34:65, or

https://doi.org/10.1017/9781009029285.006 Published online by Cambridge University Press

'sameness', 'good order' and 'freedom from arrogance in the heavens', astronomy inculcates virtue in the soul, many a soul must have been pretty confused first by the difficulties of the system – not the number of epicycles, but the adjustments that have constantly to be made to give a tolerable approximation to the data – and then by the arbitrariness of his turning simplicity into a postulate.

To get all this into historical perspective, however, it is worth comparing Ptolemy's performance with that of some of his successors. Ptolemy takes on board complexity (even though he turns it into a special brand of 'simplicity') and does his best with his models. But the difficulties of astronomy were often greeted with a very different reaction, namely a profound scepticism as to whether astronomy is possible in the first place. Proclus in the fifth century gives several accounts of current astronomy but flirts with Plato's idea that astronomy should 'transfer astronomy above the heavens' – turning it into a purely abstract subject, that is (*Outlines* 2.1–13, Lloyd 1991: 259–60) and he believes the refutation of the hypotheses that he nevertheless describes 'will be obvious to you from their very exposition' (*Outlines* 4.9–12, Lloyd 1991: 263). Then Philoponus too, in the following century, expresses profound doubts about whether astronomy was in any position to deliver causal explanations (*On the Construction of the World* III 3, Lloyd 1973: 163) and he was one of those in late Greco-Roman antiquity who flatly denied the precession of the equinoxes, even though the evidence to support it was growing all the time.

Materials from the later history of Western science can certainly be cited that serve to confirm the ongoing ambivalence of simplicity. While there are plenty of examples where it fruitfully guides observation and theory, there are others where it misleads. While there are instances where it enables regularities to be discovered, in others it turns into disastrous a priori dogma. Ptolemy's ambitions for astronomy certainly revolve around this concept (among others), but we see what a struggle he has to put it to work: indeed the price he has to pay (and pays not totally unwillingly) is to engage in what I called that transmogrification.

nearly 1:2. Since, for small angles, the tangents are nearly proportional to the angles, this in turn means that the apparent diameter of the moon at perigee should be almost twice its apparent diameter at apogee. Moreover Ptolemy was well aware that that is not the case as we can see from other evidence (in *Syntaxis* V 14 and 17) that yields reasonably accurate estimates of the moon's diameter at maximum and minimum distance. Yet in setting out his model for the moon's movements he ignores this problem (Neugebauer 1975: 1 101–3, Pedersen 1974: 198–9).

https://doi.org/10.1017/9781009029285.006 Published online by Cambridge University Press

Two final observations of Ptolemy's work in other areas of science need to be made. In harmonics the fact that the major concords of octave, fifth and fourth are expressible as ratios between small integers is a marvellous example where 'simplicity' seems thus far at least to be vindicated, though Ptolemy was one of those who flirted with the idea of the harmony of the spheres, where the complexity of the astronomical data rears its head once again.[8] In one area of optics his tactic seems to have been altogether more ruthless, though the problem we face here is that our sources are indirect (a twelfth-century Latin translation of an Arabic version of his text rather than the Greek original) and may well be corrupt. I am referring to his investigation of refraction, where the tables that we find in our source set out data that have clearly already been adjusted to fit what Ptolemy presupposes as the general law of the relation between the angles of incidence and of refraction for several pairs of media.[9] Simplicity in the equations that represent those laws, in that instance, was bought at the high price of 'simplifying' the 'data' themselves. But that was certainly not the last time that was to happen in the history of science.

Further aspects of the varying roles that some notion of 'simplicity' has played in different contexts in mathematics, science and cosmology come to light if we turn to some comparative evidence from other societies and periods. The Chinese term *yue* 約 picks out a procedure that is often explicitly invoked in mathematics, as we see both from the *Nine Chapters of Mathematical Procedures* and the commentary tradition on them, and from the first-century CE astronomical and cosmographical treatise, the *Zhoubi suanjing*. Thus in the former (I 5ff., Qian 1963: 94–5) when dealing with complex fractions our texts explain that the same quantity may be expressed in different ways. The ratio between 2 and 4 may be 'simplified' as 1:2, or complexified (the term is *fan* 繁) as 4:8. What is at stake here is the relative ease with which manipulations may be carried out.

But in the *Zhoubi* (Qian 1963: 24, cf. Cullen 1996: 177) simplicity or conciseness (expressed by the same term *yue*) is a desirable quality in the

8 Lloyd 1996a: 174–80 sets out the convoluted theories stretching from the pre-Platonic Pythagoreans down to Kepler and beyond that aimed to reconcile what was known or assumed about the distances and speeds of the sun, moon and planets with the primary musical concords of octave, fifth and fourth. The idea that we cannot hear these harmonies because we have been habituated to them from birth is one that Aristotle dismisses with contempt (*On the Heavens* II 9: 290b12–31).

9 The data claimed to have been observed are all reported as approximations, introduced with the term *ad prope*, representing *eggista* in Greek, 'most nearly'. But they all tally perfectly with the law that Ptolemy assumes, but nowhere states, namely $r = ai - bi^2$, where r is the angle of refraction, i the angle of incidence and a and b constants that depend on the specific pairs of media in question, namely air to water, air to glass and water to glass.

search for the Way. It is methods that both have that characteristic and are of 'broad application' that are said to be 'the most illuminating of the categories of understanding'. Simplicity here is not just a matter of ease in manipulation. In the quest for understanding of the 'myriad things' what the investigator seeks is simplicity with no loss of generality, facilitating the ability to distinguish categories, as the text goes on to say, while at the same time uniting them, that is seeing the connections between them.

Yet in other contexts the very same term *yue* refers not so much to a simplification of a quantity as to an approximation to it (Chemla and Guo 2004: 1028–9 on *Nine Chapters* I 32 and I 36). In this kind of 'simplifying', ease of manipulation has been bought at the price of a certain loss in accuracy (just as we found it sometimes was in Ptolemy). Like the Greeks, the Chinese certainly recognised that some of the operations they had to use in mathematics, and some of the data they had to deal with in understanding the phenomena, are complex and difficult. But even if we can say that the Chinese assume that the phenomena *will* be simple, there is no classical Chinese parallel to Ptolemy's bald assertion that – despite those appearances – in fact the data *must* be simple. Nor do we find in China evidence of the further move that Ptolemy makes when he asserts that cosmic simplicity serves as a recommendation to us to behave in accordance with the principles of 'sameness, good order, proportion and freedom from arrogance', even though many Chinese held that studying the interactions of yin and yang in the cosmos can contribute towards attaining the Dao and the ultimate goal of sagehood.[10]

Insofar as many nowadays would say that natural science and cosmology have nothing to do with ethics and with values, they might express little sympathy for the moralising views to be found in Ptolemy but have little trouble accommodating the desire for simple procedures that we have also found in the Chinese authors we have cited. Yet that may itself be an oversimplification (if that expression may be excused in context). At least it is often the case that modern scientists finesse minor discrepancies in the raw data available to them as they work towards the discovery of underlying regularities. Results that deviate from the line that marks out the equation that is assumed to hold will be discounted, as Lakatos (1976, 1978: 31ff.) exemplified in his taxonomy of the devices used, and used, in his view, legitimately, to avoid having to abandon your initial hypothesis altogether in the face of discrepancies. Fluctuations around a dominant value will be

[10] This is the message that the master Chenzi conveys to his pupil Rong Fang at the start of the *Zhoubi suanjing*: see Cullen 1996: 176ff. on Qian 1963: 23–4.

https://doi.org/10.1017/9781009029285.006 Published online by Cambridge University Press

ignored. In the famous and well-documented case of Millikan's oil drop experiments (Holton 1978: 25ff.) data that gave complex 'messy' results were discarded and not even reported, even though his explicit methodological principle was to record every trial that was undertaken.[11]

While some aberrations may indeed be put down to human error, in observation or recording what is observed, it is still often enough the case that results are driven by an assumption that simple relations are there to be found. After all whenever a mathematical equation is set out with the equals sign it is imagined that the two quantities in question are indeed equal, not merely approximately so, for which we have of course a different symbol (≈). None of this leads modern investigators to draw conclusions about how we humans should behave or the values we should adopt. But simplicity often tends nevertheless to be not a result, but a presupposition with greater or less justification in different contexts. We evidently cannot know, in advance, when the simplicity of such ratios as those of the principal concords will apply, or when on the contrary we are dealing with something like the complexities of the relationships between the periods of revolution of the sun, moon and planets as observed from earth. But nevertheless the search for simplicity, at least the greatest simplicity possible, has been a recurrent driving force throughout Western science, receiving a ringing endorsement in a famous dictum of Albert Einstein (1934: 165): 'It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.' The problem always was, of course, how to meet that final proviso. Ptolemy, as we have seen, certainly sometimes seemed to be prepared to sacrifice some of the 'data' at the altar of what was assumed to be needed for the representation to be 'adequate'.

This study of ours differs from some of our other investigations in one respect. This is not a case where there are substantial problems of translation between one natural language, one system of beliefs, and another. The concept of simplification is recognisably similar (though similarly multivalent as we have seen) across the vocabularies we have cited. Rather what varies, what gives us food for thought, is the different roles that concept has been made to play in the work of different investigators and that may give us pause if we were so naive as to imagine that there is nothing problematic in its use. To be sure, no one can object to a simplification effected to make a calculation more manageable if the quantities in question are not altered.

[11] Cf. Hacking 1983: 235–40.

But where a simplification does indeed discount certain data as due to experimental or other observational error, that rests on a presupposition as to how things are in reality (however they may appear to some observer) and that certainly raises a metaphysical issue. On what basis and with what justification can we assume that the realities we are dealing with obey or exemplify simple laws or relationships? That is a question that can hardly be answered unqualifiedly irrespective of the issues being investigated. The problem has been that commentators have too often been tempted to advocate either a general approval of such a principle of simplicity or an equally general mistrust of it.[12]

As we have found so often in these studies, entirely general solutions to the issues elude us, just as they elude those whom we are studying, and when they are attempted they may mislead. Where the invocation of simplicity is concerned, the investigator inevitably has to exercise judgement in arriving, in any particular case, at a reasonable trade-off or reconciliation between the assumption that the laws of nature are simple and the complexity of the actual observational data. The assumption is, of course, an idealisation, often bought at the cost of discarding some of the data. The recurrent problem to which no general solution is to be found is to determine how high a price can or should be paid in a bid to sustain the idealisation.

As a coda to our discussion we may note yet another historiographical issue that underlies the philosophical one. For some commentators the appeal to the idea that there are such laws in nature is a hallmark of modern science. Yet that has sometimes been without due regard to the ambiguities of the trope, for some such expression may be used with or without any clear implication that such laws are the work of some divine transcendental lawgiver, and with or without an understanding that they are a matter of statistical probabilities rather than of exceptionless rules. Thus already in Mesopotamian celestial predictions there is a clear understanding that the phenomena are regular, though also expressions of a belief that the gods can do anything. Order is the work of the gods, Marduk especially, but he could by his command destroy, not create (Rochberg 2004: 250ff., 2016: 172, 196).[13] In China by contrast the essential characteristics of objects or processes may

[12] Among those who have been thought to favour some version of Ockham's razor is Newton (1687: Part 3 Rule 1) who proposed as a Rule (called a 'Hypothesis' in the first edition) that we ought not to admit more causes of natural things than such as are both true and sufficient to explain their appearances. Those who have warned against reliance on it include Crick 1988: 146. Cf. Ball 2016 on 'the tyranny of simple explanations'.

[13] Rochberg 2016: 172, citing *Enūma Eliš* IV 23–4 ('At your [Marduk's] word the constellation shall be destroyed, "Command again, the constellation shall be intact"'). The question of the relevance of this belief to our understanding of those conditional clauses in Mesopotamian astronomical texts

be ascribed to 'heaven' (*tian* 天) without any idea that some divine will is involved.[14]

But the importance of recognising an underlying possible ambiguity here becomes clear from the Greek sources (cf. Lehoux 2006). In several authors we find a collocation equivalent to 'law' or 'laws' of 'nature' (*nomos* or *nomoi tēs phuseōs*), most notably in Plato (*Gorgias* 483e) in connection with the views there ascribed to Callicles concerning the principle that 'might' is 'right'. Yet in that context this must rate as something of an oxymoron, given first that *nomos* is a term that covers convention and custom as well as law, and secondly that it is generally concerned with the social domain where it was recognised to be culturally relative. But if we are not dealing with anything like our 'laws of nature' in that text, elsewhere Greek investigators do assume and claim they have identified not just the regularities in natural phenomena but the equations in which they can be expressed. This is certainly the case in Archimedes' statement of what we can call (though he does not) the law of the lever as also in the equations we have discerned (in note 9) in Ptolemy's *Optics*.

Moreover the idea that some such laws are not just true 'for the most part', but are immutable and could not be broken by the divine Lawgiver himself is stated explicitly by Galen (*On the Use of Parts* XI 14) when he contrasts his own view with that of 'Moses' whom he describes as holding that God could, if he wished, go against his own providential arrangements. Thus according to Galen, God would never have attempted to fix eyelashes in a soft and fleshy substance as opposed to a cartilaginous body. For if he had done so 'he would have performed more disastrously not just than Moses but any bad general who plants a wall or a camp on marshy ground'. Galen acknowledges that the Judeo-Christian tradition sides with him in adopting a teleological position against the anti-teleological Epicureans, but he clearly marks his distance from that tradition in insisting that his divine Demiurge would never attempt

that describe what we would consider impossible phenomena, such as the sun coming out at night, is controversial (Rochberg 2004: 250).

14 The issue of whether one can attribute some idea of 'laws of nature' to ancient Chinese thinkers was the subject of a notable controversy between Needham (1956: 518–83) and Bodde (1957, 1979), the former resisting any such attribution, the latter assembling the admittedly limited evidence for it, notably from the second century BCE compendium, *Huainanzi* ch. 5 (Major 1993: 264–8). There the emphasis is on the standards that apply to regulate the cosmos as well as human behaviour, where the human ruler should follow the patterns that a celestial one, the Lord on High, is said to use. However, these standards make use of technological images (levels, marking-cords, balance beams) more than they do ones drawn from the sphere of law.

things that are impossible in nature.[15] But while Galen's own brand of teleology is evidently open to criticism, his inquiries are clearly driven by a conviction that there are constant principles at work in nature which it is the goal of those inquiries to uncover.

We are alerted to the fact that *some* idea of the regularities in physical phenomena drives many different modes of investigation in different societies at different times, but what types of regularities in what domains remain open questions in ways that demand further inquiry from us. Once again the thesis of a radical break between 'ancients' and 'moderns' runs into difficulties over and above those that are implicated in attempts to generalise about those different ancients and moderns themselves.

[15] The issue of whether there are any constraints on the omnipotence of God continued to be hotly debated in later pagan, Arabic, Hebrew and Christian commentators. In the twelfth century, Maimonides, for example, defends Moses against what he sees as the misunderstandings of Galen under the influence of a mistaken belief in the eternity of the natural order (Maimonides, *Medical Aphorisms, Treatise* 25.61–7, Bos 2017: 171–91, cf. Walzer 1949: 35). Evidently those who (like Maimonides) believed in miracles as described in sacred texts such as the Old or New Testament were committed to a stronger concept of the supernatural than is normally implied when, as in Aristotle, what happens 'contrary to nature', *para phusin*, is a matter rather of what is unusual or irregular (cf. Plato *Timaeus* 83e where the processes that are contrary to the 'norms', *nomoi*, of nature are pathogens). The official position of the Roman Catholic Church when considering candidates for sainthood remains that to qualify they must have performed acts that cannot be explained in terms of natural causes.

https://doi.org/10.1017/9781009029285.006 Published online by Cambridge University Press