

4 What is science and how does it relate to *Denkstil*?

§1 What was seen to constitute knowledge and more narrowly certain ‘scientific’ knowledge has definitely changed over time. The panorama in part 2 of this book will present snapshots from the past 2,500 years. Especially when dealing with linguistic and semantic details, it is crucial to read the sources in order to avoid abstracted, general ‘facts’ that grow out of hypotheses being repeated in secondary and tertiary literature on the history of science. The myth, which arose from the Scientific Revolution, of a linear development of science more and more closely approximating ‘truth’ was only overturned for good in the twentieth century.¹ Fleck (2015 [1st ed., 1935]) pointed out how science depends on *Denkstile* (‘thought styles’) shared by a *Denkkollektiv* (‘thought collective’), and that truth or reality is not an immovable, fixed endpoint that can be steadily approached more and more closely, but rather that all understanding within language is like an ever-moving web depending strongly on such *Denkstile* (105). Fleck defines *Denkstil* thus (130; his emphasis):

Wir können also Denkstil *als gerichtetes Wahrnehmen, mit entsprechendem gedanklichen und sachlichen Verarbeiten des Wahrgenommenen, definieren.*²

1 Of course, some earlier scholars had similarly sceptical approaches to science before Fleck. For instance, Francisco Sanches wrote in *Quod nihil scitur* (1581: 92): *Quisque sibi scientiam construit ex imaginationibus tum alterius, tum propriis: ex his alias inferunt: et ex his iterum alias; nil in rebus perpendentes, quousque labyrinthum verborum absque aliquo fundamento veritatis produxere* (‘Everyone constructs his knowledge/science from ideas, be they someone else’s or his own, from these they infer others, from these again others; they examine none of them carefully in the things themselves, until they have produced a labyrinth of words without any foundation in truth’).

2 Fleck continues: ‘Auch ist Wahrheit nicht Konvention, sondern im historischen Längsschnitt: *denkgeschichtliches Ereignis, in momentanem Zusammenhange: stilgemäßer Denkwang*’ (‘Also, truth is not convention, but in a historical longitudinal section: an event in the history of thought, in a momentary context: a compulsion of thought following the *Denkstil*’; 2015: 131, his emphasis). Fleck was a medical researcher, and perusing his important book makes clear that it was written in haste, occasionally it contains gross errors; for instance, Fleck (41) believed the contemporaries of Columbus who would not finance his journey did so because they believed in a flat Earth. In reality, they knew that Columbus’ estimation of the Earth’s circumference was much too small. A more serious problem is that *Denkstile* quite obviously form a continuum and it is often hard to tell how much difference is required to speak of a different *Denkstil*. The *Denkstile* of Newton and Einstein may be much closer to one another than that of Aristotle, but are they to be addressed as the same one? This conceptual difficulty should be kept in mind when this concept is used in the present book.

'We can thus define thought style (*Denkstil*) as directed perception, with corresponding mental and factual processing of what is perceived.'

This important insight was developed further by Kuhn (1970 [1st ed., 1962]), who especially emphasised the revolutionary potential of *Denkstilumwandlungen*; *Denkstil* becomes 'paradigm' with him, *Denkstilumwandlungen* 'paradigm shift' and 'scientific revolution'.³ Some later authors, such as Feyerabend (1975), went even further, questioning science's validity in general and producing a 'relativist' current of thought among historians of science today that – in its extreme manifestation – believes there is no way to tell 'good' from 'bad' science (e.g. a flat Earth vs a round one).⁴ This was clearly not the intention of Fleck, who stands at the beginning of this development; he pointed out that such webs of scientific concepts may be more or less coherent and developed, that is, more or less adequate or 'true' in a certain sense; in the case of, say, magic they have many lacunas.⁵ He worked all his life as a research physician and was certainly convinced that he was doing something meaningful within the medical *Denkkollektiv* of his time.⁶ Fleck's and Kuhn's approach has been further developed by some into a

3 Fleck had rightly seen that revolutions were only one possible outcome of new discoveries: 'Jede empirische Entdeckung kann also als Denkstilergänzung, Denkstilentwicklung oder Denkstilumwandlung aufgefasst werden' ('Every empirical discovery can thus be understood as an addition, a development, or a transformation of the *Denkstil*'; 2015: 122). *Denkstilumwandlung* is what Kuhn means by 'revolution'.

4 e.g. Wootton (2015: 510–555) argues convincingly against such an approach.

5 'So bildet sich ein allseitig zusammenhängendes Getriebe der Tatsachen, durch beständige Wechselwirkung sich im Gleichgewichte erhaltend. Dieses zusammenhängende Geflecht verleiht der "Tatsachenwelt" massive Beharrlichkeit und erweckt das Gefühl fixer Wirklichkeit, selbständiger Existenz einer Welt. Je weniger zusammenhängend das System des Wissens, desto magischer ist es, desto weniger stabil und wunderfähiger die Wirklichkeit: immer gemäß dem kollektiven *Denkstil*' ('Thus a web of facts interrelated on all sides is formed, maintaining its balance through constant feedback. This coherent network gives the "world of facts" solid persistence and produces the feeling of a fixed reality, of an independent existence of a world. The less coherent a system of knowledge, the more magical it is, the less stable and the more open for miracles reality is: always according to the collective *Denkstil*'; Fleck 2015: 135).

6 Indeed, Fleck writes: 'Dagegen bin ich überzeugt, daß das heutige Wissen unserer heutigen Welt näher ist, das Wissen vor hundert Jahren aber der damaligen Welt wissenschaftlicher Schöpfung näher war. [...] deshalb ist unsere Wissenschaft ausgedehnter, reicher an Einzelheiten, ist komplizierter und tiefer aufgrund der größeren Zahl innerwissenschaftlicher Zusammenhänge, aber das ist alles' ('On the other hand, I am convinced that today's knowledge is closer to our world today, but that knowledge a hundred years ago was closer to the world of scientific creation at that time. [...] this is why our science is more extended, richer in details, more complicated, and deeper because of its greater number of intra-scientific connections; but that is all'; 2011: 373). Fleck's point was to negate a final scientific truth that is being approached by science.

spiralling conception of scientific progress, one that although circular in some way due to the changing *Zeitgeist*, is also developing forward in a third dimension of *Sachkenntnis* ('factual knowledge').⁷ Kullmann develops this thought for embryology: since Antiquity there have been many paradigm shifts, but the amount of detail knowledge (*Detailwissen*) has steadily grown.⁸ There can be no doubt that epistemological systems (*Denkstile*) such as the one we now call 'science' change and grow over time. In Greek and Latin, this was seen above in the meanings of ἐπιστήμη and *scientia*: a distinct notion of *scientia* as 'science' (not just any 'knowledge') coalesced slowly over time. Already largely present in Aristotle, it was reanimated and introduced for good only in Latin scholasticism. But let us try to define 'science' more precisely.

It would seem that science is a hermeneutic system that needs to take into account and be consistent with (συμφωνεῖν) generally known basic facts.⁹ Only in early modern times does a feedback loop take shape, leading to a kind of science that produced new, previously unknown basic facts by its technological and experimental approaches, and that started to produce them on purpose and thus accelerated its pace greatly. Science may thus be likened to interpolating a mathematical function whose value is known for ever more points, although infinitely many are still not known. But then, this is too simple a conception: the fixed, known points themselves may be shifting, and science may be able to 'debunk' what is generally perceived as 'fact' in some cases and change the emphasis on which of these facts are especially important, how they relate to one another, and which ones should be cornerstones of a given science. In other words, the relationship between such 'basic facts' and scientific theories is more complex than it might seem at first sight. In part 2 of this book, examples of both such new and 'debunked' facts will be encountered. The wider question of science's relationship to 'reality' is today discussed by widely dissenting schools and cannot be pursued in detail here. In fact, this is not necessary in the present context; it suffices here

7 e.g. Graham (2013: 258), who professes a 'Kuhnian approach minus the anti-realism'.

8 Kullmann (1998: 29–33). He continues: 'Dieser Einfluß von Tradition und Zeitgeist ist von dem linearen Fortschritt in der Sacherkenntnis, den es auch gibt, sorgfältig zu trennen' ('This influence of tradition and zeitgeist has to be carefully separated from the linear progress in factual knowledge that also exists'; 34).

9 Wootton (2015: 250–309) studies the term 'fact' and finds it to be typical for the Scientific Revolution. There is no doubt that English authors then had a special predilection for this term, but the same thing could easily be expressed before, for instance as *quae constant* or simply *res* in Latin. Besides, a society or a *Denkkollektiv* does not have to be conscious of and dispose of a name for generally accepted factual knowledge, but will (or: should in its own interest) still respect it. In Antiquity, at least in astronomy the related concept of σώζειν τὰ φαινόμενα ('saving the phenomena (in the sky)') already existed.

to identify some common ground over the past two and a half millennia regarding the criteria a human activity needs to fulfil in order to be called scientific. For this it will be best to avoid controversial philosophical concepts such as 'truth' or 'objectivity'.

Thus, we are, roughly, looking for activities that seek structures and patterns in a delimited field systematically; make use of theoretical explanations and methodology; are open to new insights; and produce a kind of feedback loop between basic known facts, observations,¹⁰ and theoretical frameworks. The interesting question of the extent to which the human mind creates or discovers such structures cannot be followed here. Of course, it may happen that such feedback loops go astray in a scientific approach and have to be completely abandoned at some point if they have become detached from the rest of science; examples include astrology, humoral medicine, or geocentrism. These are the scientific revolutions described by Kuhn (1970), or 'research programmes' (Lakatos) that ran aground.¹¹ This latter term is certainly fitting for contemporary science, but it sounds a bit grand for Antiquity, for 'much ancient speculation had always been and continued to be more individualistic and more opportunistic than the title research programmes would suggest or allow' (Lloyd 1987: 170).

§2 Today, the nature of concepts in general has become much discussed and unclear. What does seem clear is that concepts are usually not strictly delineated, mutually exclusive Platonic ideas. Indeed, it is often science (at least since Aristotle) that begins by fixing the exact meaning of terms by defining them more precisely or more fittingly for the science in question. For instance, a 'berry' in everyday language and in botany share some characteristics but not all; a cucumber would hardly pass as a berry in the former, but it does in the latter. Whereas botany has a strict definition,¹² common language works rather with something Wittgenstein (1953: 32) called 'family resemblance', in this case something like '[a]ny small globular, or ovate juicy fruit, not having a stone' (*OED*). The terms used are not very clearly defined (how large can it be and still qualify?); this is rather a set of characteristics that should mostly apply to something for it to be assigned to the

10 But Fleck rightly points out that observation always depends on *Denkstil*: 'Wir wollen also das voraussetzungslose Beobachten – psychologisch ein Umding, logisch ein Spielzeug – beiseite lassen' ('So let us leave aside observation devoid of any presupposition – psychologically an absurdity, logically a toy'; 2015: 121).

11 Lloyd (1987: 2) summarises the debate about the very criteria of science and lists the fundamental literature in it since Kuhn.

12 *OED* (s.v.) defines 'berry' as a 'many-seeded inferior pulpy fruit, the seeds of which are, when mature, scattered through the pulp; called also *bacca*'.

concept in question. So, within science one often sets out with a definition of the entity to be studied. Unfortunately, for a historical study of what science is, this approach is not feasible. Indeed, it seems that for very high-level, ‘abstract’ terms that emerged out of groups of coalescing lower-level concepts, it will be safer to work bottom-up from these ‘defining’ lower-level entities than to define the term in question right away. Similar examples might include ‘art’, ‘religion’, or ‘magic’. Our approach will be to find out what qualifies and qualified as science, whether together it forms an organic and meaningful whole, and then whether we can find ‘defining’ lower-level criteria that were shared and are still shared. Above (chap. 3 §1), it was pointed out that semantics must be structural in kind, that concepts form groups with other concepts, from overlapping to contrasting, and that they thus form *Bedeutungsfelder*. In Latin, a single central term ‘science’ engulfing its *Bedeutungsfeld* as a whole crystallised only in the twelfth century, as we have shown (chap. 2 §4), although sciences clearly existed before that time. Now, can descriptive criteria be found that are wide enough to describe scientific methodology and hold good not only today but also since at least the earliest clear examples of ‘science’ among the Greeks¹³ and then the Latins, and yet are narrow enough to remain distinctive? Through these two and a half millennia, science has to be delineated from similar activities such as mythology, philosophy, religion, magic, divination, technology, or pseudo-science. The goal will be to find a set of criteria wide enough to encompass the scientific activities of people such as, say, Aristotle, Archimedes, Galen, Albertus Magnus, Leibniz, Newton, Paul Maas, and Stephen Hawking, yet narrow enough to exclude the other activities just mentioned. It has become clear (chap. 1) that the English word ‘science’ – in contrast to its French, German, Russian, or Modern Greek counterparts – has strayed further from the Mediaeval Latin meaning of *scientia* and Greek *ἐπιστήμη* (chap. 2), and it will be better to stick to these latter senses in the present context. The list of criteria proposed below (§5) will be abstracted from historical cases and does not make a modern ahistoric, deductive, or ‘ontological’ claim. But first some past attempts to address this question should be reviewed.

§3 A glance at history and philosophy of science from the past few decades shows that many authors have in fact completely given up trying to define what science is; some even believe that seeking to do so is the wrong approach.¹⁴ For example, William H. Newton-Smith states (2000: 2):

¹³ Chap. 24 will return to the question of whether science should be seen as beginning in Classical Greece.

¹⁴ Thus Feyerabend (1975), who cites much further literature arguing against a common structure to all sciences. Of course, he does not mean to offer a solution to the practical problem of de-

And what is science? Once upon a time it was fashionable to attempt neat answers to this one. The logical positivists defined science in terms of what was cognitively meaningful. Sentences other than definitions were cognitively meaningful just in case they could be verified by experience. Science is then coextensive with cognitively meaningful discourse! The discourses of ethics and aesthetics were not scientific. They were not even meaningful. And Popper declined a theory as scientific if it could be falsified. But neither of these definitions even fitted all of physics, which they took to be the paradigm science. The dominant tendency at the moment is to reject the question. Science has no essence. We have constituted our idea of science around a list of paradigm exemplars (including biology, chemistry, geology, medicine, physics, zoology) of particular disciplines.

We have the impression that this could be partly due to the fact that the history of the meaning of the English word 'science' is not usually taken into account. Moreover, it may well be that science does not have an 'essence' – indeed, it may be that no human concept has one¹⁵ – but nonetheless, it must be possible to tell science apart from non-science by some criteria. To claim the contrary is tantamount to a complete relativism in which the Earth's flatness is just as good a theory as its roundness (which is, indeed, also only an approximation, but a much better one). Of course, there are also practical reasons that make it important to be able to tell science apart from, say, pseudo-science, such as state funding institutions, which must be able to decide whom to fund. Even in authors who do not define 'science', such as Wootton (2015: 1), it often still becomes clear what they intend; in the case of Wootton, science needed 'a substantial body of evidence and could make reliable predictions', and it also had to have 'a research programme, a community of experts' and to be 'prepared to question every long-established certainty'. Wootton sees this combination emerging for the first time between 1572 and 1704, in astronomy.¹⁶ Some of these points will be used below to delineate

termining whether an activity can be termed 'scientific' or not. The German translation of his book as *Gegen Methodenzwang* sounds much less extreme than the English *Against Method*. Feyera-bend was certainly right when he argued that it is often not at all clear at the outset what method works best for a given scientific question. In fact, much of scientific activity today consists in finding the appropriate methodology for a problem at hand.

15 Fleck already knew this: 'Worte besitzen an sich keine fixe Bedeutung, sie erhalten ihren eigenen Sinn erst in einem Zusammenhange, in einem Denkgebiete. Die Nuancierung der Wortbedeutung fühlt man nur nach einer "Einführung" heraus, möge sie nun eine historische oder didaktische sein' ('Words do not have a fixed meaning in themselves; they only acquire their very meaning in a context, in a field of thought [*Denkgebiet*]. The nuance of the meaning of a word can only be felt after an "introduction", whether historical or didactic'; 2015: 72).

16 It is clear that Wootton intends 'science' as experimental natural science (even excluding mathematics), an approach that seems too rigid. Among Anglo-Saxon writers, the rôle of the experiment is often exaggerated; classical physics is used too exclusively as *the* rôle-model science

ate what can be addressed as ‘science’ over time; others, especially the emphasis on prediction, were not central in many sciences and still are not in some, for instance in mathematics or linguistics.

Among those modern authors who do propose an explicit definition, many use concepts that cannot be used for premodern times at all. One such example is the definition by Roger French (1994: 101–102; he follows David Lindberg), who demands that science must be objective, non-religious, and experimental: ‘objective, non-religious, experimental, directed to the manipulation of nature, its manipulative nature linked to technology, universal law-like statements, often mathematical’. Although most of these defining terms ultimately go back to Latin or Greek words, their modern meaning is very far removed from ‘scientific’ endeavour in the times before the nineteenth century.¹⁷ The word ‘objective’ has a very different meaning in the modern languages than its ancestor *obiectum* – denoting a ‘topic’ or ‘subject-matter’ in Latin – the modern meaning presupposes the modern theory of the highly metaphysical dichotomy between ‘subject’ and ‘object’. The complete lack of the ‘religious’, especially of God as first principle, is likewise a very recent feature of scientific principles; in many of modern science’s founders, the situation was still very different. For example, Newton based his concept of absolute space on God’s omnipresence (see Burt 1954; chap. 13 §4 below). This point was pertinently criticised by Principe (2011: 36):

The notion that scientific study, modern or otherwise, requires an atheistic – euphemistically called ‘sceptical’ – viewpoint is a 20th century myth proposed by those who wish science itself to be a religion (usually with themselves as its priestly hierarchy).

Others also emphasised the technological aspect of science. Thus Crowther: ‘The system of behaviour by which man acquires mastery of the environment’ (1941: 1). This aspect was absent in the Middle Ages and of very limited importance in Antiquity. Indeed, it fits much better the concept ‘technology’, which must certainly be kept apart from ‘science’. Another anthropologist, Bronislaw Malinowski, follows the same thrust by claiming that the Trobriand Islanders he studied

(at a time when physics has overcome it to a great extent). Even among the paradigmatic sciences, some are not experimental (e.g. astronomy). Wootton also draws too strong an opposition between philosophy and science; he seems to overlook that science always has a theoretical and thus philosophical component. Despite these caveats, his book is good reading and the author admits (575): ‘It is no part of my argument to dispute the claim that we only have the sciences we have because Aristotle and the medieval philosophers opened up certain lines of enquiry; [...]’ On the Scientific Revolution, see further chap. 13 below.

¹⁷ Some authors do really draw such extreme conclusions, e.g. Cunningham & Williams (1993: 410). For them, there is no science before the ‘revolutionary period’ (i.e. 1760–1848).

had science because they knew how to build ocean-going canoes. Now, in Latin terminology this would be an *ars* not a *scientia*; again, in English 'technology' would seem to be the more fitting term.¹⁸ Finally, experimentation becomes important only during the Scientific Revolution, equally so science's 'manipulative' character. The importance of mathematics is one of the main legacies of Galileo. The necessary conclusion from French's definition would be that before the eighteenth century, there was no science at all.¹⁹ Such definitions – of which many more could be quoted from older literature from the nineteenth and early twentieth century – arise from another modern myth, viz. that critical thinking without dogmatic presupposition was the invention of the age of 'enlightenment'. Rather it would seem that any kind of thinking is always dependent on its cultural background (or *Denkstil*) and makes use of it more or less unconsciously. Later epochs will discard or replace parts of this background with something else and then wonder how their predecessors could have been blind to its 'obvious' misguidedness.²⁰ The same will happen to our own present-day prejudices and misconceptions to which we are more or less blind. For historical or comparative research, such a modern definition is therefore clearly of no use and we must try to find one that is both broader and in its defining characteristics less dependent on unconscious contemporary philosophical concepts. Altmann (1993: 3, following Mario Bunge) uses a very mathematical approach when he defines:

Science = <Object, Approach, Theory>²¹

However, this does not seem to suffice either: although it may be that all science can be described in such a way, other things can be as well. For instance, the invocation of demons may be: <demons, magic spells authorised by tradition, classical demonology>. Besides, such a mathematical definition does not do justice to the way science actually works, develops, and is taught.

18 Compare Malinowski (1925: 35), discussed by Tambiah (1990: 67–68).

19 This conclusion is actually drawn by some authors, such as Wootton (see n16 above).

20 'Die Prinzipien eines fremden Kollektivs empfindet man – wenn man sie überhaupt bemerkt – als willkürlich, ihre eventuelle Legitimierung als *petitio principii*. Der fremde Gedankenstil mutet als Mystik an, die von ihm verworfenen Fragen werden oft als eben die wichtigsten betrachtet' ('The principles of an alien collective – if one notices them at all – are perceived as arbitrary, their possible legitimization as a *petitio principii*. The foreign style of thought [*Gedankenstil*] appears to be mysticism, the questions it rejects are often considered the most important ones'; Fleck 2015: 143).

21 Mathematically, this means that the 'science' is a function of the three concepts in the angled brackets.

One example of a definition that owes less to fashionable philosophical terms but is still meant to describe twentieth-century science (especially physics) is that proposed by an actual natural scientist, Richard Feynman (in Leighton 1964: 1). He presents it as the search for patterns (a word that comes close to one of the meanings of Greek λόγος), in which the goal of science is reached through experimentation:

The principle of science, the definition, almost, is the following: The test of all knowledge is experiment. Experiment is the sole judge of scientific ‘truth’. But what is the source of knowledge? Where do the laws that are to be tested come from? Experiment, itself, helps to produce these laws, in the sense that it gives us hints. But also needed is imagination to create from these hints the great generalizations – to guess at the wonderful, simple, but very strange patterns beneath them all, and then to experiment to check again whether we have made the right guess.

The emphasis on experimentation is still very modern, but the quest for underlying patterns seems promising. Others, especially authors concerned with the history of science beyond the past few hundred years, inevitably propose wider definitions. George Sarton defined his object of study in a very wide manner as ‘systematized positive knowledge’.²² This definition, again, may be too wide, as it will, for instance, include rules for magic practices (which Sarton, of course, does not treat in his monumental work). In the following pages, Sarton makes clearer what he means by this succinct definition: he rightly does indeed include fields such as philology and historiography in his work – quite against English usage even then, but agreeing with the ‘international’ one.²³ Van der Waerden uses a similar approach when he sees *Wissenschaft* as ‘systematisch geordnetes Wissen’ (‘systematically ordered knowledge’) in general.²⁴ These authors might argue that the magician has no real knowledge and therefore does not practise science. But how do they tell real knowledge apart from imagined knowledge (δόξα)? Indeed, the present endeavour is largely that of finding a means to tell mere δόξα apart from science (or philosophy), which is still the same task Plato grappled with. Plato ended up with the construction of a realm of eternal truths (his ‘ideas’) which we can attain in philosophy and mathematics. This ideal was to be very persis-

²² Sarton (1927–1948: 1:3–4). It may be noted in passing that defining science using the word ‘knowledge’ is not an option in Latin, as both these concepts are expressed by the one word *scientia*.

²³ Sarton (1927–1948: 1:7) points out: ‘I have attached much importance to the study of philology. The discovery of the logical structure of language was as much a scientific discovery as, for example, the discovery of the anatomical structure of the body.’

²⁴ Van der Waerden (1966: 9); this volume was originally published in German.

tent, but it is very hard today to share in its strict sense (although some would claim that mathematics constitutes this eternal ideal realm).²⁵ Above (chap. 3), it was shown that for Greek and Latin authors, a foundation of certain and timeless explanatory reasoned force was central in differentiating *ἐπιστήμη/scientia* from mere opinion. Insights in the twentieth century in many fields, however, have made full certainty rather illusory (even in the paradigmatic a priori science of mathematics); but the greatest possible, often statistical, certainty would still seem to be part of science’s goals. So, although we have had to become more modest, the basic drive for certainty is still central to science.²⁶

§4 A matter that certainly complicates a definition of science is the rift between natural and human sciences that has become increasingly palpable over the past century.²⁷ Above (chap. 2), it became clear that this problem is especially acute in English, a language that would no longer call *Geisteswissenschaftler* scientists. But as means of acquiring reasonably certain and testable knowledge outside the realm of ‘nature’ do not seem to be categorically different from the natural sciences – which, by the way, differ a lot among themselves – it would not seem wise to exclude all non-natural or non-exact sciences from science. Several traditionally ‘humanist’ fields (such as linguistics, computational linguistics, archaeology) are mingling more and more with the natural sciences in the twenty-first century.²⁸ Indeed, they all seek patterns, symmetries, or other in some way invariant structures.²⁹ As sciences progress, they tend to move from description to ever deeper explanatory patterns ‘behind’ the observational data, as Feynman pointed out. A good example is Galois theory.³⁰ This field, inaugurated by the genius Évar-

25 Such as Penrose (2004: §34.6).

26 See Gambino Longo (2015) on certainty in science.

27 The paradigmatic text for this is Snow (1963). See now Leavis (2013). Staal (1996: chap. 29) tries to refute the ‘myth of the two cultures’.

28 Mainzer followed similar lines of thought and found a ‘unity of methods’: ‘Allerdings ist diese neue Einheit von Methoden in Mathematik, Kunst und Naturwissenschaft von grundsätzlich anderen Absichten getragen, als im pythagoräischen Quadrivium. Es kann nicht mehr darum gehen, Tonskalen und Harmonien als Ausdruck bestimmter Naturgesetze zu verstehen. Philosophisch gesprochen handelt es sich also heute um eine Einheit der Methoden und keine ontologisch begründete Einheit wie bei den Pythagoräern’ (‘However, this new unity of methods in mathematics, art, and natural science is based on fundamentally different intentions than in the Pythagorean *quadrivium*. The point can no longer be to understand tonal scales and harmonies as an expression of some laws of nature. Philosophically speaking, then, we are dealing today with a unity of methods and not with an ontologically based unity as with the Pythagoreans’; 1988: 180).

29 Showing this is one of the main goals of Mainzer (1988).

30 See Mainzer (1988: 185–196). A good introduction to Galois theory is Artin (1944).

iste Galois (1811–1832), who tragically died in a duel, approached both traditional geometry and the problem of solving polynomial equations with root expressions from a deeper structural level (viz. group theory), and was thus able to offer solutions for centuries-old problems: in constructive geometry, Galois theory proves the impossibility of the trisection of angles, and in the field of polynomial equations, it proves that the solutions of equations of the fifth degree and higher are, in general, not root expressions.

Of course, the more ‘abstract’ and deeper our scientific structures get, the greater the danger that they may not reflect inherent characteristics but accidental ones. This can be seen historically in astrology or humoral theory in Antiquity and the Middle Ages: these very abstract superstructures far removed from observable facts were so complex that it was hardly possible to falsify them – until a new paradigm removed their very foundations and they finally lost credence. This makes ‘testability’ in some form crucial in order not to get stuck in what has been aptly termed a ‘null field’.³¹

§5 The rôle of language within science is often underestimated: in what follows, a tentative list of criteria (including linguistic ones) will be proposed that an activity should fulfil in order to be called scientific. This is more circumscribing the phenomena that have passed as scientific over the millennia than actually defining them, which may well be better avoided.³² In line with Wittgenstein’s ‘family resemblance’, it will not be advisable to demand that all criteria be completely fulfilled for an activity to be termed ‘science’ – even contemporary model sciences may fail to meet some of them. Rather, it will be sufficient if they are fulfilled mostly and in general. First, non-linguistic criteria for scientific activities abstracted from the above discussion are proposed. As will become clear below, point (IV) has the consequence that some disciplines or activities may at one time have been scientific but are no longer so (e.g. astrology). In short, the proposed criteria for a *Denkstil* to pass as scientific are

- (I) a systematic methodology and well-defined topic,
- (II) finding patterns and explaining them step-by-step,
- (III) unbiased seeking of confirmation or refutation.

31 This term is used by Ioannidis (2005) to denote ‘fields with absolutely no yield of true scientific information, at least based on our current understanding’. He points out that in such fields, the positive results one gets correspond only to bias. It is often not a trivial matter to see that a field is a null field, as the long-persisting examples mentioned show.

32 After all, definitions are used *within* scientific activities.

The following criteria may be added, but they seem less central:

- (IV) coherence and non-sterility,
- (V) community effort,
- (VI) formalisation of results.

The final point (VI) is linked to the criteria scientific language should fulfil. But before dealing with such linguistic criteria, those in the above list need some clarifications, including relevant Greek and Latin concepts from science's past.

(I) A systematic method for solving certain kinds of questions (a μέθοδος, *methodus sciendi*).³³ Heuristically, scientific knowledge is gained by a procedure or method³⁴ that is in some way reproducible: one that can be followed again by others, leading to comparable results. It should at least in part be possible to retrieve new insights systematically from those already possessed. The importance of the term 'system' can be traced back to the Scientific Revolution.³⁵ In the present context, 'systematic' is only meant to imply that knowledge is not collected haphazardly. This is often stressed as fundamental, for instance in the quotation from Störig in §6 below. According to von Weizsäcker (1991: 176), *Wissenschaft* can be boiled down to 'planmäßiges Fragen' ('the methodical asking of questions'). Kuhn already saw 'normal science as problem solving'.³⁶ What method is to be used may be highly controversial, and may lead to Kuhnian paradigm shifts. From this it follows that every science, during 'normal' (non-revolutionary) development, tends to become demarcated in its own clearly defined topic (Aristotle's ὑποκείμενον), which determines to some extent the methods best used in its exploration. Thus, these cannot be independent of the topic under scrutiny,³⁷ leading to a dialectic process between the two. As Putnam puts it: 'It is not possible to draw a sharp line between the content of science and the method of science; [...] the method of science changes as the content of science changes' (1981: 191).

33 This 'scientific method' is mentioned by Sanches, *Quod nihil scitur* (1581), p. 100, where he resolves to write a book about it (which he never did). On his scepticism, see Caluori (2007).

34 μέθοδος, literally a 'path after something'; see chap. 3 §9 above.

35 See Ritschl (1906). Before that, the Greek and Latin term was used in many circumstances but not in epistemology. Forcellini writes: *compages, constructio. Solet in scientiarum studiis adhiberi pro ingeniose excogitata rerum dispositione, quo sensu tamen deest nobis Latini scriptoris exemplum* ('a joint structure, a joining together. It is employed in the studies of the sciences for an ingeniously contrived disposition of things, for which sense, however, we lack an example from an [antique] Latin writer'; s.v. *systema*).

36 Kuhn (1970: chap. 4 title). Kuhn's novel approach consisted in identifying, beside this slowly progressing development in science, the revolutionary, paradigm-shifting one.

37 Lakatos (1978) speaks of 'scientific research programmes'. Tambiah (1990: 68) characterises science as a 'self-conscious, reflexive, open-ended process of knowledge construction'.

(II) Spotting regularities, patterns, in something and trying to understand why they are the way they are, then explaining them step-by-step, is the second crucial point. This may be linked to the traditional attributes of scientific knowledge as *σαφέες*, *manifestum*, *certum*. Science means to find out step-by-step *how* something came about or happens, and is not content with the knowledge *that* it happens or its ultimate cause. But what counts as an explanation of something? For instance, aetiological myths also offer explanations. As Lloyd (1987: 287) points out:

The emergence of what can begin to be called fully fledged explanations of classes of natural phenomena is an important new development, though a hesitant one, in early Greek philosophy, with the practice of such explanations preceding the theory.

What exactly qualifies as a sufficient explanation depends a lot on time and scientific culture (*Denkstil*), but the important point is that science aims at the understanding of mechanisms. Different kinds of mechanisms may be allowed to be explanatory; during the heyday of the mechanical universe, for instance, only mechanical explanations – i.e. ones that entail actions through contact between pieces of matter – were accepted. In other times, the mere finding of a source quotation in an authoritative text will have sufficed as an explanation. Thus, a more precise narrowing down may be inadvisable, but mechanisms are further restricted by criteria III and IV.

(III) The criterion of the unbiased search for confirmation or refutation, that is, some general form of testability (*ἐμπειρία*, *experimentum*) is somewhat wider than the often-quoted ‘empiricity’. Scientific activity must be based on some kind of experience or observation (in a wide sense) shared by most human beings, possibly instructed beforehand.³⁸ Thus, it needs to be in concord with empiricity (*ἐμπειρία*); in Antiquity this is called *συμφωνεῖν*, its contrary *ἀντιμαρτυρεῖν*. Scientific constructs (‘theories’) should produce predictions that can be tested in some way proper to the topic. Besides, basic, generally acknowledged facts must not be contradicted, unless they can be debunked in a methodologically sound way. Thus, systematic doubt becomes the methodological foundation. As the old proverb has it: *Qui nihil scit, nihil dubitat* (‘He who knows nothing, doubts nothing’).³⁹ Modern definitions in the wake of Popper often narrow this criterion to

38 This may be what is intended by ‘objective’, but because of its history of dramatically changing meanings, it will be better to avoid this word. ‘Most human beings’: often the insane are excluded. ‘Instructed beforehand’: they may have to learn to read before they can, say, check a quotation, or to count before they can count events. So, they have to be initiated into a Fleckian *Denkstil*.

39 Mentioned in Ps-Bede, *Sententiae philosophicae collectae ex Aristotele atque Cicerone* PL 90.990C. Not in Jones (1939), Otto (1962), or Walther (1963–1986).

‘falsifiability’. For a historically applicable approach, it will be better to be content with a wide ‘minimal’ empiricism,⁴⁰ in which any kind of testing an outcome, including non-physical ones, is acceptable. Examples would be mathematics, where theorems can be ‘checked’ or ‘tested’ (by proof) although they are not usually upheld by attempts at empirical falsification, or mediaeval scholastic theology, whose conclusions drawn from harmonising authorities could be ‘checked’ in the authoritative source texts.⁴¹ To put it differently: the scientist should lack credulity but be of a curious nature.⁴² This curiosity is the famous θαυμάζειν that lies at the root of philosophy according to Aristotle (*Metaphysica* A2, 982b12–13):

διὰ γὰρ τὸ θαυμάζειν οἱ ἄνθρωποι καὶ νῦν καὶ τὸ πρῶτον ἤρξαντο φιλοσοφεῖν.
‘Men begin today and began first to philosophise through marvelling.’

The very contrary of testability is authoritarianism. Already in Antiquity, the Pythagoreans used to finish arguments with an authoritarian αὐτὸς ἔφα (‘He said it’).⁴³ Pseudo-science is still often characterised today by blindly following what someone has proclaimed to be the truth.⁴⁴

As a subcategory one can mention impartiality, or the lack of bias. Often a scientist sets out to prove something but through ‘testing’ ends up with a completely different result. Thus, no undue priority should be given to one’s favoured points of view in science. These may be based on prejudices such as nationalism or personal preference for one theory over its competitors. Max Weber called this *Wertfreiheit* (‘the lack of value-statements’).⁴⁵ Of course, this criterion is always difficult to attain, as it seems to be part of the human mind to cling to its previous knowledge and to become biased. It has been objected that science needs value statements of the kind ‘correct’ (e.g. $2 + 2 = 4$) and ‘wrong’ (e.g. $2 + 2 = 3$). Thus, ‘lack of bias’ may be a better term than *Wertfreiheit*; similarly, von Fritz (1971: 317) would only demand the absence of ideological propaganda. A step in this direction within scholasticism may be seen in the attempt to prove the existence of

40 See Schurz (2008: 14).

41 Modern people may object that such a scholastic ‘set of axioms’ made up of Holy Scripture is far from free of contradictions. But scholasticism grew out of the problem of having to deal with such – for its exponents – only apparent contradictions. See more on this topic below (chap. 11).

42 Augustine seems to agree with this (Tasinato 1994), but his personal conclusion was, nevertheless, to largely abandon worldly science in favour of Christianity in his later life (see chap. 9 §2 below).

43 e.g. in Diogenes Laertius, *De vita philosophorum* VIII.46, ed. Long, vol. 2, p. 414.

44 As examples today, un-scientific Marxists or Freudians may be mentioned.

45 Weber (1917/1918); he dealt with the social sciences.

God instead of merely taking it as revealed truth.⁴⁶ The claim of God's existence was, however, not seriously challenged, and the Christian dogmatic truths remained universally accepted 'axioms' among Christian writers until far into modern times.

Criteria (II) and (III) are the fundamental ones: by unbiased observation, then capturing patterns with theories, then renewed unbiased observing and testing, science can and does begin to 'walk' on these 'two legs', as Galen puts it.⁴⁷ As it 'walks' on, ever greater rigour is necessary to counter fallacies that are uncovered and to render methodology more adequate to the topic in question.

The three final criteria may be seen as optional: some sciences were not yet coherent with the other accepted sciences of their times, in some times and places there were not enough scientifically minded people for much of a community effort, and some sciences have largely withstood formalisation to this day.

(IV) Coherence and non-sterility: results and theories within a science and between sciences should be coherent and should meaningfully fit together in order to lead to wider theories, and not just end up as a patchwork of unrelated facts. A scientific approach should also have the potential for further heuristic development,⁴⁸ often ending up explaining phenomena that were in the beginning not even intended to be covered (which is what we intend with the term 'non-sterility' or 'fruitfulness'). An extreme 'theory' that does not meet this criterion could be 'God made everything the way He liked'. This 'explains' everything but is not at all fruitful for the generation of further knowledge and cannot be considered scientific.⁴⁹ A scientific theory should be open to modification by new insights. From

46 Anselm of Canterbury started this with his famous ontological proof of God's existence. Some two centuries later, Raimundus Lullus extended the idea and tried to prove the main Christian dogmas in order to be able to convert scientifically minded non-Christians. He was generally seen as having gone too far with this, possibly also because it rather failed to produce any result remotely convincing to non-Christians.

47 Galen described with this simile his understanding of scientific medicine: *De compositione medicamentorum secundum locos libri X*: εἰς τὸ βαδίζειν ἐκάτερον τῶν σκελῶν εἰσφέρεται, τοιαύτην «δύναμιν» ἐν ἰατρικῇ τὴν ἐμπειρίαν τε καὶ τὸν λόγον ἔχειν ('In order to walk, both legs contribute; in medicine experience and reason possess this force'; XIII.188, ed. Kühn, vol. 13, p. 188). A conciser form, ἔστι γὰρ ἐν τῇ ἰατρικῇ ὡς δύο σκέλη, ἐμπειρία τε καὶ λόγος ('for there are as if two legs in medicine: experience and reason'; XVI.81, vol. 13, p. 188), comes from a Renaissance forger (see Garofalo 2005: 445–447).

48 Gruenberger (1962: 3): 'fruitfulness is one of the attributes of science'. Mainzer rightly points out that the 'heuristische Möglichkeiten eines Wissenschaftsprogramms' ('heuristic capabilities of a research programme'; 1988: 68) are more important than falsification of some peripheral consequence.

49 See below (chap. 7 §4) for Plato's fruitful, albeit rather un-scientific approach to astronomy.

scientific openness follows a theory's ability to be further developed and a lack of dogmatic rigidity.

A certain coherence (*unitas scientiarum*)⁵⁰ with what is known from other scientific branches may be required so as to have a science fit into the accepted scientific *Denkstil*. In the extreme case, all sciences will form one hierarchically structured single body of non-contradictory, coherent knowledge. This is an idea that stood at the basis of the antique circle of education, the ἐγκύκλιος παιδεία (see chap. 9). Even before that, Aristotelianism emphasised an interconnected 'network of the sciences'.⁵¹ In early modern times, Descartes stressed this point as well.⁵² Clearly, taken strictly, this criterion narrows down what can pass as science considerably. For instance, astrology was usually considered a reputable science that fitted well into the Aristotelian *Weltbild* claiming that the relative positions of the planets affected the centre of the universe (the Earth), until the advent of heliocentricism and until new ways of understanding forces gained ground in the Scientific Revolution. This left astrology completely out of touch with the other sciences, and thus it came into disrepute as a science and is today considered a pseudo-science.⁵³

This criterion thus unites all sciences to some degree into a whole. The demarcating lines between various sciences may often be disputed, but at least some coherence among them should be expected: after all, we live in one unified whole (the 'universe'). On the other hand, this coherence also leads to 'paradigms' (as shown by Kuhn) that may become too rigid and in need of being broken apart in order to allow further progress in understanding. Edward Wilson (1998) called this criterion 'consilience'. The idea of the coherence of scientific theories and fields is also related to Lakatos's 'research programmes': scientific facts have to come in groups, not as small insights or facts. On the other hand, the

50 This phrase is already common in Spanish neo-scholasticism, for example in Francisco Suárez, *Disputationes metaphysicae* XLIV.11.55, ed. Berton, vol. 26, p. 711.

51 On which in the thirteenth century, see Fidora (2011).

52 Cf. Descartes, *Regulae*, ed. Wohlers, p. 4: *Credendumque est, ita omnes [scientiae] inter se esse connexas, ut longe facilius sit cunctas simul addiscere, quam unicam ab aliis separare* ('It is to be believed that all sciences are thus connected among one another such that it is much easier to learn all of them together than to separate a single one from the others').

53 On the details of this long process, see Lerch (2015). Strangely enough, Thorndike (1923–1958) is not aware of this and treats astrology as a pseudo-science already in Antiquity. This makes his outlook on scientifically minded people in Antiquity very thin, as even men such as Ptolemy and Galen failed to 'notice' astrology's fallacy. Our argumentation is shared by Kuhn (1970: 2): 'If, on the other hand, they [out-of-date beliefs] are to be called science, then science has included bodies of belief quite incompatible with the ones we hold today. Given these alternatives, the historian must choose the latter.'

greater the number of such uncontroversial facts in a scientific field, the less freedom (so to speak) it has and the more realistic the scientific approach is likely to become. This way, many theories become ruled out by facts that have become common knowledge. This can be observed well among the ‘pre-Socratics’; for instance, the sphericity of the Earth becomes common knowledge in the fourth century BC in Greece, ruling out all other older, often fanciful theories of its shape.⁵⁴

(V) Community effort. A community of scientists that is as large as possible and able and willing to share its results is clearly also of great importance: there is much too much to study for a single human life. Aristotle is the first known scientist who worked with a team, as we shall see below (chap. 7 §6). Albertus Magnus was also well aware of this scientific *societas*.⁵⁵ The scientific community’s knowledge is likely to grow with time.⁵⁶ For this to work well, external factors seem necessary: the possibility of fixing knowledge permanently, as in writing; some political stability to allow interchange; some but not too much competition between scientists, who might otherwise be reluctant to share their insights or fake results. Besides, they need to be able to understand one another: a mutually intelligible scientific language comes into play here, which in turn will have criteria of its own (to be discussed below). This community effort requires teachability: insight and methodology must be communicable and must be teachable and learnable, as Aristotle, quoted above (chap. 3 §4), already pointed out. The crucial rôle of the *Gemeinschaft* in shaping a scientific *Denkstil* is also pointed out by Fleck (2011: 470).

(VI) Formalisation of the results. The insight gained by a science should lend itself to description in a formal, rigorous way, which may make use of special symbols, diagrams, or a special type of language.⁵⁷ We have seen above that the *μαθήματα* from classical Greek times onward had a tendency to become more and more formalised (chap. 3 §3), reaching a first peak, for instance, in Euclid’s *Elementa*. The frequently invoked necessity of *rationalitas* in science can also be seen

⁵⁴ Described by Graham (2013); see also Gleede (2021: 2–10, and other sections treating later, mostly Syrian Christian, authors who did not accept the Greek consensus).

⁵⁵ e.g. Albertus Magnus, *Politica*, ed. Borgnet, vol. 4, p. 500: *in omni autem corpore humor fellum est, qui euaporando totum amaricat corpus, ita in studio semper sunt quidam amarissimi et felle uiri, qui omnes alios conuertunt in amaritudinem, nec sinunt eos in dulcedine societatis quaerere ueritatem* (‘but in every body there is bilious humour which when evaporating renders the entire body bitter, similarly in science there are always some very bitter and bilious men who turn everyone else into bitterness and do not let them seek truth in the sweetness of companionship’).

⁵⁶ Despite the now generally acknowledged fact of upheavals or revolutions in the history of science and their important rôle in its progress (see Kuhn 1970 [1st ed., 1962], and the vast literature his work sparked), there is still an overall progress to be observed, as pointed out above.

⁵⁷ Further on this topic, see chap. 14 §7 below.

in the light of formalisation, in this case of a logical kind. In early modern times, Galileo is so convinced of the importance of formal languages that he claims that mathematics (the most rigorous type of formalisation known) is God's language (see chap. 13 §§3–4). But clearly, not all sciences can produce their knowledge in mathematical form; indeed, even in mathematics itself human language is needed to explain at least what the symbols stand for. Thus, the need for a specific language of science that can neither be pure mathematics nor everyday language becomes obvious. This thought is pursued further in §7.

§6 Before this, first a few authors who have used similar approaches to 'define' science will be considered. This problem is tackled by Graham for similar and very practical reasons (he studies the emergence of Greek astronomy). The results in his appendix 2 are similar to our proposed wider set of criteria; he concludes with a definition, called S, of (natural) science as (Graham 2013: 256):

S. Science is a) a systematic study of the natural world, b) using accepted theory and methodology, c) allowing for open inquiry within (b), d) permitting elaboration and revision of (b), e) based on empirical evidence.

Typically for the narrower modern English meaning of 'science', the activities are restricted to nature in (a). Without this restriction, less formally but in some more detail, Störig (1965: 13–16) describes science thus:

Wissenschaftliches Wissen ist gewonnen durch planmäßiges, methodisches Forschen, und es ist systematisch in einem Zusammenhang geordnet. [...]

Wissenschaft als Inbegriff solchen Erkennens und seiner Ergebnisse können wir nunmehr vorläufig definieren: einerseits als Prozeß methodischer Forschung und zielbewusster Erkenntnisarbeit aus ursprünglichem sachlichen Wissenwollen und Fragen nach der Wahrheit; andererseits als Schatz methodisch gewonnener und systematisch geordneter Erkenntnisse, die mit dem Anspruch auf allgemeine Gültigkeit und zwingenden Charakter auftreten. 'Scientific knowledge is gained by systematic and methodological inquiry, and it is ordered systematically into context. [...]

We can now provisionally define science as the embodiment of such knowledge and its results: on the one hand as a process of methodological enquiry and progressive knowledge aware of its aim, born out of an initial wish to know the facts and an enquiry into truth, on the other hand as a stockpile of knowledge gained methodologically and ordered systematically which claims for itself general validity and a necessary character.'

It may be noted here in passing that the German language can use compounds and expressions that are quite untranslatable into English or Latin. For instance, the phrases *zielbewusste Erkenntnisarbeit* and *ursprüngliches sachliches Wissenwollen* are clear to any educated speaker of German (even though the compound *Erkenntnisarbeit* does not figure in any dictionary), but in order to translate them

into English or Latin one must use long circumlocutions; we see here a typically German scientific *Denkstil* at work (see further chap. 24).⁵⁸

Similarly, Vlastos (1975: 36) proposed three criteria, roughly corresponding to our II and III:

By 'scientifically ascertained facts' I understand facts satisfying three basic requirements:

- (i) They are established by observation or by inference from it: they are derived, directly or indirectly, by the use of the senses;
- (ii) They have theoretical significance: they provide answers to questions posed by theory;
- (iii) They are shareable and corrigible: they are the common property of qualified investigators who are aware of possible sources of observational error and are in a position to repeat or vary the observation to eliminate or reduce suspected error.

Staal (1996: 351–352) also proposed a descriptive list similar to ours. It is intentionally rather vague and to some extent repetitive. It can be condensed to (i) a body of statements, rules, and so on that can be tested; (ii) abstract statements that go beyond that data; (iii) consistency of the edifice built out of (i) and (ii); and (iv) the existence of some methodology of argumentation. Some sociologists, such as Robert K. Merton (1973: 270), demand ethical 'imperatives' for science that roughly correspond to our points (II) and (V): 'universalism, communism, disinterestedness, organized skepticism'.

The authors quoted in this section seem to agree with our approach that although science should not be defined outright, it can still be described reasonably well with a set of criteria. Thus, we agree with Staal that the exact list of criteria does not matter too much, as long as it covers the essential points that have been mentioned. But it seems that the language science uses should be more emphatically treated than in the proposals considered (hinted at in Staal's (iv)). Indeed, the importance of the precise and critical use of language for science will become evident when studying many of the so-called pre-Socratic philosophers, who by and large lacked it and should therefore, it would seem, not be called scientists (see chap. 7). Occasionally, this point was stressed in the past, for example by the physicist Léon Brillouin (1959: ix):

Science begins when the meaning of the words is strictly delimited. Words may be selected from the existing vocabulary or new words may be coined, but they all are given a new definition, which prevents misunderstandings and ambiguities within the chapter of science where they are used.

⁵⁸ There is a lexicon of such untranslatable, especially philosophical vocabulary: Cassin (2004), which however (somewhat disappointingly) treats almost exclusively specialised philosophical terminology.

The first three points in our proposed list are the most central ones; they resemble strongly the way Aristotle did scientific research. Indeed, science may be seen as a further development of the Peripatetic *Denkstil*,⁵⁹ although the results of Peripatetic science are nearly all rejected today and the methodologies in the various fields have also often changed radically. Aristotle laid the foundations of logic in his *Organon*, and started many empirical sciences more or less from scratch (such as zoology or the study of city constitutions). His school, the Peripatos, continued along these same lines. This will be considered further below (chap. 7 §5).

§7 The above criteria already suggest certain features of the language used to communicate what scientific research has found. These will pertain on the one hand to technical terminology, but also to syntax and in general the logic of linking thoughts. Like science itself, its language should be systematic and explain matters clearly; it should be coherent and mutually understandable by as many scientists working in similar research fields as possible. It has already been pointed out that such language criteria may be seen as by-products of a tendency in science to formalise insight (criterion VI). This leads to criteria such as the following ones (which are not exhaustive):

- (i) well-defined terminology,
- (ii) exactness and unambiguity,
- (iii) extendability and flexibility,
- (iv) perspicuity,
- (v) evidentiality and modality.

Latin quotations from authors in part 2 will show the importance of these criteria to what ‘scientists’ did and how they expressed it. First, though, some more details about these criteria are required.

(i) Well-defined and standardised terminology. Communication between scientists is seriously hampered if the scientific vocabulary is not clearly defined and free from contradictions in its terms. On the one hand, this just means that the same word should be used when speaking about the same phenomenon. This criterion was often, for instance, not met by mediaeval alchemists, who used terms such as *sulfur* very differently from one another; or, in Latin medicine, Celsus⁶⁰ criticised a lack of common terminology for tumours of the

⁵⁹ The significant difference between Aristotle’s own practical work and his theoretical basis in the *Analytica* is considered below (chap. 7 §5).

⁶⁰ *De medicina* VII.6.1, ed. Marx, p. 311.

head.⁶¹ On the other hand and more broadly, terminology and syntactic uses are often automatically understandable to speakers of a language and should not be used counter-intuitively. Thus, ‘life sciences’ study living organisms; it would be inappropriate to use this designation for, say, geology. Nonetheless, by historical accident such inaptly named terms may be coined and may even survive; for instance, we know today that despite its name, ‘oxygen’ has nothing to do with acids. As knowledge of Greek and Latin is more and more disappearing among scientists today, new terminology is sometimes erroneously formed from these languages. Some examples of this will be discussed below (chap. 21 §5).

(ii) Exactness (*exactum*, τὸ ἀκριβές) is a general feature of scientific study. Kurz (1970) followed its growing importance among Hippocratic doctors and sophists to Thucydides, Plato, and Aristotle. The word ἀκριβής seems to have been used first to designate a quality in crafts (τέχναι) as ‘nicht allgemein verbreiteter Sachverstand’ (‘not generally available expertise’; Kurz 1970: 11). For Plato, as for many later scientists, the greatest exactness is found in mathematical methods (105). Scientific terminology should also as far as possible be unambiguous (*univocum*, ἀναμφίβολον) in order not to reach conclusions about something by using a particular word in different meanings. This point is stressed emphatically by Aristotle when he finds that a term πολλαχῶς λέγεται.⁶² Indeed, he proposes an entire theory of the metaphorical versus literal meaning of terms.⁶³ For instance, Aristotle points out that Plato’s forms are mere poetic metaphors,⁶⁴ but he himself also uses potentially ambiguous terms, such as ὕλη or εἶδος, although the wide range of meanings that these terms cover for us may have represented a single concept for him (see Lloyd 1987: 175). This suggests that the unambiguity of terms is not a trivial concept in itself: although some words clearly have several clear-cut and non-overlapping meanings (e.g. ‘ear’ of an animal vs ‘ear’ of corn), often going back to different etymons (compare German *Ohr* vs *Ähre*), this is often not the case, yet their meaning can be very wide. We have seen, for instance, that the Greek term λόγος (introduction, §2) has to be translated by several words into Latin or English, depending on context. Aristotle’s criticism caught on, and analysing technical terminologies, keeping them as far as possible free from metaphor, became common in many fields, but it also became

⁶¹ More examples of synonymous medical terminology in Antiquity are collected by Fögen (2009: 42–43).

⁶² e.g. Aristotle, *Topica* I.18, 108a31–32: Τοῦτο δ’ οὐκ ἐπὶ πάντων δυνατόν, ἀλλ’ ὅταν ἤ τῶν πολλαχῶς λεγομένων τὰ μὲν ἀληθῆ τὰ δὲ ψευδῆ (‘This, however, is not possible in all cases but only when some of the various meanings are true and others false’).

⁶³ Studied by Lloyd (1987: chap. 4).

⁶⁴ *Metaphysica* A9, 991a.

a rhetorical weapon against one's opponents.⁶⁵ Quintilian rightly stresses that syntactic *ambiguitas* is also to be avoided.⁶⁶

(iii) Extendability and flexibility: a language of science must be able to express newly discovered facts. Thus, a certain flexibility and clear rules for producing new words or syntagms for new content are required. In some languages, such as Greek or German, new terminology that is at once understandable to the audience can be introduced tacitly. In Latin this is usually done explicitly, for instance by adding *quod x vocatur/vocamus/vocari potest*. In chapters 21 and 24, it will be seen that in Latin the main linguistic tool for forming new terms was suffixation, while Greek more often uses compounding and nominalisation with the article. Classically minded Latin humanists usually avoided the coining of new words altogether and had to resort to syntagms, often nouns modified by adjectives, to express new concepts, such as *bilis atra* (see further chap. 21 §3). It has already been pointed out that German is in this respect closer to Greek (using grammatical features) and English closer to Latin (both are of a rather more analytical nature and tend to shun new words).

(iv) Perspicuity or clarity: scientific language should be easily and unambiguously understood by experts in a field. Ancient rhetoric often stresses the importance of *perspicuitas*, in Greek σαφήνεια, and that its opposite *obscuritas* should be shunned.⁶⁷ Quintilian⁶⁸ points out that regional, archaic, or obscure terminology should be avoided. Other terms often used in Latin for this aim in scientific texts are that they should be written *articulatim*, *distincte*, and *dilucide* ('appropriately structured', 'distinctly', 'clearly'). Again, this holds true not only for vocabulary but also for syntax. Concision (*brevitas*, συντομία)⁶⁹ is also often mentioned as a means for perspicuity, although, of course, exaggerated concision would lead to *obscuritas*. This implies that scientific language avoids not only inconsistencies but also redundancy. Scholastic authors such as Thomas Aquinas follow this rhetorical⁷⁰ approach; he sums it up as (*Summa theologiae* proem., Leonina edition, vol. 4, p. 5):

65 'Aristotle's invention of the metaphorical/literal dichotomy involved the stipulation of criteria for truth that at one stroke downgraded – even ruled out – poetry, most traditional wisdom, and even much of earlier philosophy' (Lloyd 1987: 210).

66 *Institutio oratoria* VIII.2.14, ed. Rahn, vol. 2, p. 144. He does this in general, not specifically for *Fachsprache*. His examples are from Vergil.

67 More details in Fögen (2009: 28–29).

68 *Institutio oratoria*, esp. VIII.2, ed. Rahn, pp. 139–149.

69 Fögen (2009: 30).

70 Already stressed in the earliest Latin text on rhetoric we have, *Ad Herennium* I.27, ed. Achard, p. 28: *Sedulo dedimus operam, ut breviter et dilucide, quibus de rebus adhuc dicendum fuit, dicemus* ('We endeavoured diligently to speak briefly and clearly about the remaining topics').

breviter ac dilucide prosequi, secundum quod materia patietur.
 ‘proceed with brevity and clarity, as far as the matter allows.’

(v) Evidentiality and modality: where does the evidence for an assertion come from?⁷¹ Are modes of statements, such as reality, conditionality, potentiality, or counter-factuality, distinguished in a clear way? Both these related points are important for scientific language; usually, particles and/or verbal tenses are used in this function. Greek, Latin, and English use both these devices. Logical nexuses in science are often expressed by conditional clauses. If-clauses are especially developed in the Indo-European languages of science considered above (chap. 1); they all have tense rules applying exclusively to them (e.g. not allowing ‘*if I would do ...’). In general, it seems that subordinate clauses are important for precise scientific expression. In Greek, thoughts/sentences are usually linked by sentence-modifying adverbs or particles, a trait that scientific Latin sometimes copies; thus, *δέ* may become *autem*, *vero*, or *tamen*; *γάρ* *enim* or *nam*; *γέ* *quidem*; *δή* *igitur*.⁷² It will also be advantageous for scientific expression to be able to differentiate between different degrees of certainty, especially before the advent of modern statistical tools that can quantify probabilities. It would seem that German has especially rich possibilities for this,⁷³ but this would have to be studied in further depth.

In passing, it may be noted that interestingly (and unintentionally), all these terms for linguistic desiderata of a language of science are based on Latin words. Many of the above, non-linguistic, criteria are too, and the three first and most important ones bear Greek names in modern English. We will return to this topic in chapter 23, where it will become apparent how deeply scientific English depends on the two antique languages. It would be very hard indeed to formulate such criteria using, say, Old English words only (in so-called English).⁷⁴

71 Aikhenvald (2006) discusses languages in which the evidence of a statement must be grammatically expressed. This would seem to be a very useful feature for a language of science. Unfortunately, none of the languages of science has this potentially very useful feature well developed.

72 On Latin adverbs expressing the certainty of the speaker, see Schrickx (2011). She studies especially *nempe*, *quippe*, *scilicet*, *videlicet*, and *nimirum*.

73 In moods (subjunctives), auxiliaries (e.g. *mögen*), and especially adverbs (*ja*, *doch*, *wohl*, *anscheinend*, etc.).

74 There are people who try to use reconstructed Anglo-Saxon to communicate; cf. e.g. the Anglo-Saxon Wikipedia entry on *Witancræft*: ‘Witancræft (on Niwenglisce hätte science) is fandung tō aspyrienne, þurh fandungfæstnesse (“empirical method”)’ (‘*Witancræft* (in modern English called “science”) is seeking to discover by the empirical method’); <https://ang.wikipedia.org/wiki/Witancr%C3%A6ft>, 5 December 2017).