**Lecture Notes**

**Themes from the History of Philosophy of Science**

**Stathis Psillos**

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**I. The epistemology and metaphysics of *episteme*: Aristotle’s *Posterior Analytics***

#### Explanation as Demonstration

Aristotle thought that causal knowledge is a superior type of knowledge, the type that characterises science—this is what he called *episteme*. He took it that there is a sharp distinction between understanding the fact and understanding the *reason* why. The latter type of understanding, which characterises explanation, is tied to finding the causes (*aitia*) of the phenomena. Though both types of understanding proceed via deductive syllogism, only the latter is characteristic of science because only the latter is tied to the knowledge of causes. He illustrated the difference between these two types of understanding by contrasting the following two instances of deductive syllogism:

(A): Planets do not twinkle; what does not twinkle is near; therefore, planets are near.

(B): Planets are near; what is near does not twinkle; therefore, planets do not twinkle.

(A), Aristotle says, demonstrates the fact that planets are near, but does *not* explain it, because it does not state its causes. In contrast, syllogism (B) is explanatory because it gives the *reason why* planets do not twinkle: *because* they are near.

Explanatory syllogisms like (B) are formally similar to non-explanatory syllogisms like (A). Both are demonstrative arguments of the form: All Fs are Gs; All Gs are Hs; therefore, all Fs are Hs. The difference between them lies in the “middle term” G. In (B), but not in (A), the middle term states a *cause*. As Aristotle says:

The middle term is the cause, and in all cases it is the cause that is being sought (90a5-10).

To ask ‘why F is H?’ is to look for a causal link joining F and H. More specifically, the search for causes, which for Aristotle is constitutive of science, is the search for middle terms which will link, like a chain, the major premise of an argument with its conclusion:

why is F H? Because F is G and G is H.

What Aristotle observed was that, besides being demonstrative, explanatory arguments should also be *asymmetric*: the asymmetric relation between causes and effects should be reflected in the relation between the premises and the conclusion of the explanatory arguments—the premises should explain the conclusion and not the other way around. The difference between (A) and (B), as Aristotle put it, is this: “It is not because the planets do not twinkle that they are near--rather because they are near they do not twinkle” (78a 35-38).

Though Aristotelian explanations are arguments— that is, ultimately, linguistic constructions—Aristotle favoured an *ontic* conception of explanation. This is because, as noted already, he tied explanation to causation: *it is the causes that do the explaining*. He distinguishes between four types of causes. The material cause is “the constituent from which something comes to be”; the formal cause is “the formula of its essence”’ the efficient cause is “the source of the first principle of change or rest”; and the final cause is “that for the sake of which” something happens (194b23-195a3). For instance, the material cause of a statue is its material (e.g., bronze); its formal cause is its form or shape; its efficient cause is its maker; and its final cause is the purpose for which the statue was made.

These different types of a cause correspond to different answers to why-questions. But Aristotle thought that, *ceteris paribus*, a complete causal explanation has to cite all four causes (that is, to answer all four why-questions): the efficient cause is the active agent that puts the form on matter for a purpose. The four causes do not explain the same *feature* of the object (e.g., the material cause of the statue—bronze—explains why it is solid, while its formal cause explains why it is only a bust), yet they all contribute to the explanation of the features of the very same object. All four types of cause can be cast as middle terms in proper causal explanations (cf. 94a20-25).

**Scientific knowledge**

The *ideal* of knowledge that has characterised science has been pretty much shaped by Aristotle’s conception of *episteme*, according to which scientific knowledge is demonstrative knowledge that starts from first principles. Of these first principles, Aristotle said that they are “true and primary and immediate, and more known than and prior to and causes of the conclusion” (71b19-25).

Aristotle calls the first principles “definitions”. Yet, they are not verbal: they do not just state what words mean; they also state the essences of things. In the example (B) above, it is of the essence of something’s being near that it does not twinkle. In the rich Aristotelian ontology, causes, i.e., middle terms of explanatory arguments, are essential properties of their subjects and necessitate their effects. Accordingly, causal explanation is explanation in terms of essences and essential properties, where “the essence of a thing is what it is said to be in respect of itself” (1029b14). He thought that the logical necessity by which the conclusion follows from the premises of an explanatory argument mirrors the physical necessity by which causes produce their effects.

Aristotelian first principles are general principles, as they involve relations among *universals* and they hold of everything to which the universals apply. For a universal P to hold of every object x (of a certain kind) it should be the case that P holds for all xs at all times and at all places. An Aristotelian universal is *an one over the many*, but (unlike Platonic forms) it is not one apart from the many. Universals are middle terms in a demonstration (and hence they capture the causes of whatever should be causally explained). So if there are no universals, there are no middle terms, there is no demonstration and hence there is no knowledge. Actually, for Aristotle, all scientific knowledge worthy of the name is *general* knowledge (of the universals) and not knowledge of particulars. A particular object c has property A (or belongs to the kind A) in virtue of the fact that it shares with other particulars attribute B and All Bs are A.

Aristotle also thought that first principles should be *necessary* principles in the sense that they are such that the property attributed to the subject (a principle has typically the form: All As are B; or better A is B) could not be otherwise: it is essentially possessed by the subject. So, episteme for Aristotle, the knowledge of the universal, is both general and necessary. “Demonstration” Aristotle says, “is a deduction which proceeds from necessities”.

Being an empiricist, Aristotle took it that experience is a source of knowledge and that, in particular, knowledge starts with perception. How then can first principles be known? Aristotle wants to exclude two possible answers to this question. The first is that the knowledge of first principles (of which he never doubts) is innate; the second being that first principles are known on the basis of prior knowledge (e.g., they are derived from other things known). Obviously, the second answer would lead to a regress. Another option, it seems, is experience.

**Experience and induction**

Aristotle takes experience to be quite a complex state which involves both perception and memory in such a way that, say, experience of x to be constituted by the stable and repeated memories of perceived instances of x. But how, if at all, can experience lead to knowledge of first principles?

Aristotle introduces *epagoge* (induction) at various places in his corpus. It seems he does not have a single view as to what this kind of inferential process is. But in the *Posterior Analytics* (where he presents the views we have been discussing), he takes it that induction depends on particulars (81b1). Aristotle seems to waver between two views (or to hold them both). The first is that induction is the process which produces a belief about the universal without producing certainty. The second is that induction is a process by means of which first principles come to be known (100b3); a process, that is, which is not deduction and yet produces knowledge (of first principles). In both cases, however, induction proceeds on the basis of particulars and is not possible without them (e.g., with direct insight). In (81a40), Aristotle presents an argument, which can be reconstructed as follows:

Learning is either by means of deduction or induction.

Deduction proceeds from universals, whereas induction proceeds from particulars.

It is impossible to view (theorisai) universals except through induction.

Hence, there is no knowledge without induction.

But, there cannot be induction without sense perception (since induction proceeds from particulars and particulars are apprehended via perception).

Hence, there is no knowledge without perception.

This, of course, does not imply that perception yields knowledge (episteme). Aristotle is adamant that episteme cannot be acquired through perception. But if perception of particulars is required for knowledge, and if induction proceeds on the basis of particulars aiming to “hunt” (as Aristotle 88a3-4 put it) the universal, it follows that *epagoge* plays a key role in acquiring knowledge of first principles, with the dual character of generality and necessity. Even though Aristotle does not quite tie induction with enumeration of instances, he does insist that is by viewing repeated instances that we view the universal: “it is from many particulars that the universal becomes evident”.

In the closing chapter (B19) of *Posterior Analytics*, Aristotle introduces the technical word ‘nous’ to capture the state (*hexis*) in which one is in when one knows first principles. Nous is to induction what episteme is to deduction. First principles become known via induction, and the “state which gets to know them” is nous: “it is by induction that we get to know the first principles, since this is the way perception instils universals” (100b3-4). So, strictly speaking there is no episteme (scientific knowledge) of first principles, even though the first principles are known (comprehended) via nous, which is the source of all knowledge. English translation of ‘nous’ include expressions like: intuition, rational insight—and these may create the impression that Aristotle had an irreducible rationalist element in his thought about science; that is that, after induction has operated some further process (intuition) is required for getting the general principle. This is not correct. Though this is hardly the place to go into Aristotelian exegesis, the prevailing view is that the method by means first principles are arrived at in induction, though the state of knowledge required by them is not episteme, but as Jonathan Barnes had translated ‘nous’, comprehension.

Be that as it may, Aristotelian induction involves movement from the particular to the general; it involves examining particulars, though Aristotle never tells us how many of those are enough for reaching the generalisation (which involves the universals). In *Topics*, Aristotle says that induction is “the progress [charge] from particulars to universals” (105a13). It would certainly be wrong to try to assimilate Aristotle’s thinking about induction to what we now think of induction. Bit it would be equally wrong to think that Aristotle’s induction is totally disconnected from what we now take it to be. The key point relevant to what we have been discussing, however, is this: Aristotle saw in induction a process by means of which general and necessary principles are (but not only them, of course) are generated and adopted. Yet, it’s been never clear how this is possible. Perhaps, Aristotle thought that it must be possible, since otherwise episteme would not be possible. Recall that the first principles (being general and necessary) are neither innate nor demonstrable. And though they are not derived from experience either, they are process by which they are formed (induction) has its basis (but not its ground) on experience.

Aristotle set the stage for what came to be known as the *problem* of induction, since his endeavours generated the following question: How possibly can experience lead to first principles which are universal and necessary (and certain and state the ultimate causes of things)? I am not claiming that Aristotle thought that experience can quite do this. And yet, he did think that human reason based on experience and induction does achieve this and hence makes knowledge possible. But the problem bequeathed by Aristotle to his successors was precisely to explain how the method of science can bring under one roof generality and necessity on the one hand and justification on the other.

**Some early criticism**

Sextus Empiricus, a famous sceptic, realised that this kind of accommodation is perhaps doomed. He took it that induction is a reasoning process which returns a generalisation of the form All As are B on the basis of instances of the form a is A and a is B (his example: ‘All humans are animals’ is induced by instances such as Socrates is an animal; Plato is an animal etc.) But he was adamant that this method (of establishing the universal from the particulars) “totters” because it faces a dilemma. It will either progress on the basis of some but not all particulars, but then it is possible that there may be exceptions among those particulars not surveyed. Or, it will progress on the basis of surveying all (relevant) particulars, but this task is impossible, since the particulars are “indefinite and indeterminate”. Hence, induction will be either uncertain or impossible.

Sextus’s scepticism about induction was clearly part of his overall or global scepticism about any type of reasoning (including deduction). But it is noteworthy that he took it that induction is a mode of reasoning which purports to yield knowledge of the universal (something that we have already seen in Aristotle too) by enumerating particulars (something which Aristotle did not quite ascertain). The dilemma that Sextus poses is then quite forceful. For the transition from the (many) particulars to the (one) universal that they presumably share will always be ‘shaky’ (as Sextus put it) unless there is reason to believe that the particulars already surveyed are like the ones not yet surveyed. But what can the source of this reason be? There is a sense, however, in which Sextus shifts the issue to the lack of *certainty* of induction—admitting, as Aristotle before him also did, that complete induction would be fine.

**A note on Universals**

From Plato and Aristotle on, many philosophers thought that a number of philosophical problems (the general applicability of predicates, the unity of the propositions, the existence of similarity among particulars, the generality of knowledge and others) required positing a separate type of entity—the *universal*—along side the particulars. Philosophers who are realists about universals take universals to be really there in the world, as constituents of states-of-affairs. Universals are the features that several distinct particulars share in common (e.g. redness or triangularity). They are the properties and relations in virtue of which particulars are what they are and resemble other particulars. They are also the referents of predicates. For instance, whiteness is the universal in virtue of which all white things are white (the property they share); it is also the referent of the predicate ‘is white’; and together with a particular, e.g., a piece of chalk, it constitutes the state-of-affairs this chalk being white. Universals are taken to be the repeatable and recurring features of nature. When we say, for instance, that two apples are both red, we should mean that the very same property (redness) is instantiated by the two particulars (the apples). Redness is a repeatable constituent of things in the sense that the very same redness—*qua* universal—is instantiated in different particulars. The very idea that universals are entities in their own right leads to the problem of how they are related to particulars and how they bind with them in a state-of-affairs. Philosophers have posited the relation of instantiation: universals are instantiated in particulars. But this all-important relation has not been properly explicated and has often been taken as primitive. Some realists (like Plato) thought that there can be uninstantiated universals (the Platonic forms or ideas) while others (like Aristotle) argued that universals can only exist when instantiated *in* particulars.

**II. Theory, experience and scepticism: From the problem of scientific method in the ancient Greek medicine to the scientific revolution**

'Let the *phainomena* be said [to be] first *(prota),* even if they are not first. '

**Herophilus**

**Empirics vs dogmatists**

The ancient empirics (*εμπειρικοί/empirici*) were a group of doctors in the latter part of the third century BC who took it that in practicing the art of medicine, doctors should rely on experience (*empeiria*) alone. The founder of the sect (αίρεσις), as it came to be known, was Philinus of Cos (around 260BC), but the school spread well into the first few centuries AD. The main proponents of empiricism were Serapion (fl 225 BC) and later on Menodotus, Theodas and Heraclides. Our knowledge of their writings comes mostly from Galen, Sextus Empiricus (who was a sceptic philosopher and an empiricist doctor) and Celsus. Empiricists were far from a monolithic school and their views evolved considerably over time, especially when they became associated with sceptical philosophy.

Empiricism was developed, at least partly, as a reaction to the proliferation of theories in medical practice. They attacked what they took it to be the dominant school in medicine—the so-called Rationalists or dogmatists (λογικοί/δογματικοί)—which took it that reliance on reason was indispensable in medicine. The rationalists took their cues from the stoic theory of signs and argued that there is a special kind of rational inference—called *indicative inference*—which enables the transition from an effect to its invisible cause. In particular, the rationalists thought that medicine should be based on understanding and finding the causes of a disease and that this required development of theories about the nature of things and the powers of the causes and of the remedies. This knowledge of *powers* would warrant a conclusion that “something that has such and such a power, if applied to this kind of cause, naturally produces that kind of effect” (Galen, SB; 3). Indicative inferences were supposed to be grounded on relations of “rational consequence”, as they put it, among distinct existences—relations which were discoverable by means of reason only. The rationalists might well be taken to make good on Aristotle’s claim that science should aim to the knowledge of why things are the way they are (that is, knowledge of causes) and not to the knowledge that they are the way they are (that is, knowledge of facts).

Against all this, empiricists were putting forward the *sola experientia* account of medical knowledge and practice. But what exactly was experience?

**What is experience?**

The empiricists had a rather rich conception of experience, which was reminiscent of the Aristotelian conception. In *Posterior Analytics*, Aristotle takes perception (αίσθησις) to be awareness of particulars common to all animals. But for experience, memory (i.e., the ability to retain a percept) is also required. Actually, for Aristotle, experience requires the presence of many memories of the same thing. And beyond this, experience involves a universal, which as Aristotle says, “comes to rest in the soul”. This is perhaps hard to understand but for Aristotle, experience is already *general* in that through it a universal (a concept, one might say) is lodged in the mind.

Interestingly, the empirics’ conception of experience is similarly complex. It involves observation and memory. Observation is of three types: *incidental* (that is, casual or accidental observations); *extemporary* (where deliberate manipulation is involved); and *imitative* (where something that has worked in the past is tried again). The results of repeated observations are lodged into memory and lead to general principles, the so-called *theorems* (of the form: same disease, same effects). Medicine *qua* art, the empiricists said, is the accumulation of theorems. These accumulation is based on experience and more specifically on *autopsy* (that is, on one’s own observations) and *history* (that is, reports on other practitioners’ observations). Medicine was then taken to be solely based on experience, where experience involves observation, memory and repetition that yields generalisations.[[1]](#footnote-1)

**Transition to the similar**

The hard-liners among empiricists took it that this was enough for medicine. But the problem faced was how this account of knowledge could possibly lead to novelty and innovation. How that is, could new medicines be developed, or how could new diseases be treated? The thought that prevailed was that there is a kind of scheme which allows novelty and this was taken to be the *transition to the similar* (*την του ομοίου μετάβασιν/ de similis transitione*). This was taken to be a heuristics or a method of invention (*οδός ευρεύσεως*) (SB, 2;4). It was based on the idea that when a drug has worked in a case of type A in the past, it will also work in a new type of case B, which is similar to A. But there was some active debate about the status of this principle, whose justification is not obvious. The dogmatists were quick to point out that this kind of transition could be justified if it was accepted that the nature of things were such that they resembled to each other. So they thought that transition to the similar can only have a rational basis, viz., indication (OE, 9;70). They also pointed out that it is hard to make judgements of similarity on the basis of experience only, since these judgements require a prior account of relevance (ME, 4;89).

In response to all this, the empiricists insisted that any justification of this principle, that is of the principle ‘similar affections, similar treatments’, which is simply a version of the dictum ‘similar cause, similar effect’, should be based on experience. Hence, “we know from experience that similar things are like this” (OE, 9;70). So they thought that this is a kind of a second-order principle which can be accepted only after it has been “tested by practical experience”; that is only after evidence for it has been collected. They therefore wanted to make it clear that there is no experience-independent justification of the principle that underwrites the transition to the similar.

But the exact status of the transition to the similar divided the empiricists, partly because it was recognised that there is a tension in its employment. As Galen (OE, 4; 50) reports, Serapion took the transition to the similar to be part of experience alongside autopsy and history. Menodotus thought that it was *not* part of experience (and hence of medicine), but that the doctors could still make use of it. Theodas, who more generally thought that medicine should be based on experience plus an account (that is an explanation) of it, argued that the transition to the similar constitutes reasonable experience (*rationabilem experientiam*). Whereas others, took it that the transition is more like an instrument (*organum*) and not anything like a rational procedure.

**The issue of justification of indicative inference**

At stake, clearly, was the issue of the status and justification of methods and principles that seem to take us beyond experience and which are, arguably, necessary for doing science. This issue came into sharp focus in the debate about the status of indicative inference. The key problem was the knowledge of non-apparent things (*άδηλα*), which the dogmatists thought was necessary for medicine, but was going beyond experience. The empiricist doctors joined forces with the sceptic philosophers (in fact, some were both) in order to curtail the rashness of reason, as Sextus Empiricus (PH, 1;20) put it.

According to Sextus (PH, ΙΙ;97-98), the Dogmatists (the Stoic philosophers) divide entities into two epistemological categories: (a) pre-evident things (πρόδηλα) and (b) non-evident things (άδηλα). The former are immediately evident in experience without recourse to inference; they come of themselves to our knowledge, as Sextus put it, e.g. that it is day. The non-evident things are divided into three sub-categories. (b1) those which are non-evident once and for all (καθάπαξ άδηλα), e.g., that the stars are even in number; (b2) those which are non-evident for the moment (προς καιρόν άδηλα); (b3) those that are non-evident by nature (φύσει άδηλα). The real issue is between b2 and b3, Sextus thought. Temporarily non-evident things have an evident nature but are made non-evident for the moment by certain external circumstances (e.g., for me now, the city of Athens). Naturally non-evident things are those whose nature is such that we cannot grasp them in experience, e.g. Sextus says, imperceptible pores – for these are never apparent of themselves but would be deemed to be apprehended, if at all, by way of something else, e.g. by sweating or something similar (PH ΙΙ;97-98).

The case of pores in the skin was widely used as an example of a rational transition from an effect (sweating) to its non-evident cause (pores in the skin). This is a paradigm case of an indicative inference. Indicative inference was taken to be based on the Stoics theory of signs.

**The theory of signs**

As Sextus puts it, evident things are known by themselves, that is non-inferentially; but non-evident things are known by means of signs, apart from the once-and-for-all non-evident, which are not known at all. So things which are temporarily non-evident and things which are naturally non-evident are apprehended through signs. There are two kinds of sign. Recollective or commemorative (υπομνηστικά) signs, and indicative (ενδεικτικά) signs; and correspondingly, two kinds of inference. The difference between the two concerns the types of things involved in the two inferential procedures. Temporarily non-evident things are known by recollective signs, whereas naturally non-evident things are apprehended via indicative signs (PH, II;100)

The standard ancient example of a recollective sign is smoke, as in the case: if there is smoke, there is fire. The fire is temporarily non-evident, but knowing that there’s no smoke without fire, we can infer that there’s fire. So recollective sign-inferences take us from an evident entity to another entity which is temporarily non-evident, but which can be made evident. Indicative-sign inferences take us from an evident thing to another thing which is naturally non-evident. As Sextus (PH, II;101) put it: “An indicative sign is an antecedent statement in a sound conditional, revelatory of the consequent”.

**Two kinds of inference**

But the difference between the two modes of inference was not just the kinds on non-evident entities implicated in their antecedent and consequent. The idea was that the conclusion of an indicative inference was licensed by the fact that the effect (the sign) was necessarily connected with the cause (the signified) and flew out of its “proper nature and constitution”, (as bodily movements are signs of the soul) as Sextus put it. Sextus stresses this point by noting that the alleged warrant for the indicative inference is not related to the fact that the effect and the cause have been repeatedly observed together in the past (since the cause is non-evident anyway). So the alleged warrant can only come from reason unaided from experience. Reason is supposed to provide apprehension of the nature and constitution of non-evident things. What then of the commemorative sign-inference? This is based on the recollection of the past co-occurrence of the evident effect and the temporarily non-evident cause. So upon the observation of the evident effect, we are led to recall “the thing which has been observed together with it and is not now making an evident impression on us (as in the case of smoke and fire)”. So the commemorative inference is supposed to be grounded on past experience and to implicate the memory. Sextus assented to recollective signs, because they “are found convincing by everyday life: seeing smoke, someone diagnoses fire; having observed a scar, he says that a wound was inflicted” (PH, II;102).

**Analogism vs epilogism**

The issue of the distinction between indicative inferences and commemorative ones was centrally disputed among the ancient doctors. The empiricists employed special technical terminology to map this distinction. They called indicative sign-inference ‘analogism’; and commemorative sign-inference ‘epilogism’. The difference, as above, was related to the things involved in the conclusion of the two kinds of inference (non-evident vs evident-to-the-senses things). But empiricists also took issue with the Dogmatists’ claim that analogism leads to the acceptance of non-evident things. For empiricists, there were no non-trivial relations of consequences among distinct existences.

Like in the case of Sextus, the key argument of empiricists in favour of epilogism was that the kind of inference involved in it, being directed towards visible things, is “an inference common and universally used by the whole of mankind” (Galen, ME 24;133).[[2]](#footnote-2) Analogism, on the other hand, was not universally accepted, because of the invisibility of the things involved in it (ME 25;139).

**Arguments against analogism**

1. **Theoretical disagreement**

An important argument empiricists put forward against analogism and rationalism in general was the existence of theoretical disagreement in medicine. As Galen presents the debate between Asclepiades and Menodotus in his *On Medical Experience*, the empiricist case against rationalism can be summarised as follows.

If the inference from the visible to the invisible (analogism; indication) were rationally compelling, there would be neither theoretical proliferation nor disagreement among the doctors concerning the causes of a disease (ME, 9;103).

In fact, the empiricists point to an argument that later on came to be known as underdetermination of theories by evidence, in that the evidence together with logical inferential procedures cannot uniquely determine a theory that accounts for it. In fact, the empiricists readily pointed to competing theoretical explanations of various facts (e.g., that vinegar enables digestion) (ME, 13;108).[[3]](#footnote-3)

1. **Against an a priori operation of reason**

It’s fair to say, however, that this complaint was mostly motivated by an account of the theoretical use of reason according to which reason can have a rational insight into the nature of things, independently of experience (cf. ME 10;102). This is quite close to what later on came to be known as the a priori function of reason. Indeed, when Galen presents the rationalist alternative he notes that they give credence also to “those things which are discovered by reason independently of observation, on the basis of the natural relationship of consequence which holds among things” (OE, 7; 63), which implies an acceptance of an a priori operation of reason—whereas the empiricists strongly contested this, by claiming that we should never “make any assertions based on logical consequence but only assertions based on evident observation and memory”. It is therefore quite consistent with the empiricism advocated by the ancient doctors to allow for a theoretical use of reason which is not independent of experience, but allows experience to test various theoretical assumptions and hypotheses. Hence, it is quite consistent with empiricism to look for an alternative experience-based justification of indicative inference.

1. **Ampliative inferences**

More telling is the further (relatively undeveloped) objection that indicative inference cannot be both deductive and ampliative.[[4]](#footnote-4) The challenge, I take it, is that the very idea of a rational inference which is deductive and yet yields new content (it points to the existence of things not already included in the information made available in the premises) is doomed; only experience can lead to fresh claims of existence. But here again, the key empiricist point, viz., that analogism should be taken to be an ampliative mode of inference can be accepted without also accepting that this kind of inference should justifiable on the basis of reason only.

1. **Knowledge of nature of things**

Finally, empiricists protested against the very idea that the knowledge of the nature of things is necessary for science. They pointed out that a) this knowledge is not needed for knowledge of the regular behaviour of things; and b) even if this knowledge of nature could be had, we could not infer what things will do (what kind of behaviour they have) on its basis (e.g., knowing that mushrooms are poisonous, we cannot infer which ones actually are). Empiricists were making the point that theoretical knowledge of non-evident things was either useless or superfluous (ME, 9; SB, 6). But here a distinction should be drawn on the basis of the fact that empiricists were not opposed to anatomy and the knowledge of the inner workings of the bodies. The nature of an entity can be seen in a dual way. On the one hand, talk about the nature of a thing is talk of the invisible parts of a thing and their properties in virtue of which it behaves the way it does. On the other hand, talk about the nature of a thing implies a certain conception of the properties *qua* powers or potencies such that things are disposed to behave in certain ways in virtue of their natures. It is this latter conception of ‘nature’, loaded as it is with a certain metaphysical conception of the world as constituted by necessary connections and regularity-enforcers, that is at odds with empiricism.

**The dogmatists’ rebuttals**

The dogmatists (as represented by Asclepiades) were not without serious rebuttals. The key objections to empiricism were two. The first was that, as they put it, experience is lengthy, indefinite and un-methodical (SB, 5;9) and hence reason is required to introduce systematicity in the findings of experience and to render medicine an art.[[5]](#footnote-5) The second objection concerned the empiricists’ reliance on repetition. With hindsight, we may say that empiricists were relying on induction on the basis of observations to arrive at the theorems. But this reliance, which was taken to be indispensable to the empiricist epilogism, was subject to a sorites-type of objection: How many times are enough for the generalisation to be accepted? (ME 6; 94-95)[[6]](#footnote-6)

**Empiricism and scepticism**

It is, of course, no accident that there was an alliance between the empiricists and the sceptics against the prevailing conception of Reason. As Hankisnon has noted, the ancient conception of reason took it to be a “power or faculty in the soul which allowed one to go beyond the immediate data of experience in order to formulate general, universal principles” (73-74). The sceptics took it that if reason cannot offer compelling arguments to adopt various beliefs about the evident things, it is bound to be unable to do so when it comes to non-evident things.[[7]](#footnote-7)

By the time of Sextus, however, empiricism had become quite liberal. Experience was taken in a wide sense, as Michael Frede has stressed, to include the life-world and whatever is conducive to an ordinary life, which the sceptics took it to consist in guidance by nature, necessitation by feelings, handing down of laws and customs, and teaching of kinds of expertise (PH, I, 236-237). This reformed empiricism was not dogmatic.[[8]](#footnote-8) The non-dogmatic empiricism admitted analogical reasoning and commemorative inference, but was critical about the role of explanatory hypotheses, especially those that rely on the natures of things and posit internal relations of consequence among things and their powers.

So a rather refined view was developed: inferential knowledge of non-evident things is permissible if it is subjected to empirical confirmation. There were various voices among the empiricists, most notably Theodas, who took empiricism to rely on experience and an account of it—what Galen called (referring to Theodas) “reasonable experience” (*rationi empiria*). Incidentally, as Cardinal Mercier noted, the Latin word ‘ratio’ means literally an ‘account’ and “if we avail ourselves of an English translation it should then mean the reason why any given being is such a being”.

The empiricist Heraclides went even further and argued that there is room for hypotheses about non-evident things. The case he discussed concerned dislocated hip-bones and the dogmatists’ view (expressed by Hegetor) that they cannot be reset because the tendon that holds them in place is disrupted when the bone is dislocated. Heraclides noted that past experience shows that dislocated bones have been reset. But he did not stay there. He added: ‘Since the hip-bone sometimes also does stay in place, one does have to assume that the tendon does not tear invariably, but that it sometimes also just loosens and then tightens up again. For to inquire into such matters is useful, though not absolutely necessary’. This is, clearly, a piece of indicative reasoning—the formation and adoption of an explanatory hypothesis. Heraclides, unlike Hegetor, insists that a medical question (about the resetting of a dislocated hip-bone) can never be settled by indicative reasoning only; experience is always required. But it is consistent with the reformed empiricism he advocated that explanatory hypotheses are formed and adopted.

This attitude to theoretical reasoning, it should be noted, is compatible with the Pyrrhonian sceptical critique of reason. As Sextus described scepticism, it is not the case that sceptics do not hold beliefs at all, but that they do not hold beliefs “in the sense in which some say that belief is assent to some non-evident object of investigation in the sciences; for Pyrrhonists do not assent to anything non-evident”. So, Pyrrhonists held beliefs (in a non-dogmatic way) about ordinary life and practice. At the same time, these beliefs are also subject to a radical sceptical critique. The sceptical suspension of judgement is a suspension of judgement about everything (εποχή περί πάντων), if all beliefs are seen as aiming to a kind of truth and security that cannot possibly be subjected to doubt. The distinction between appearances and reality (or better, the distinction between how things appear to us and how they are) holds sway, in a certain sense, also among ordinary evident things. In the eighth of his sceptical modes, of the relativity of perception, Sextus makes this very clear by noting that a thing’s being relative implies the suspension of judgement as to what this thing is independently and in its nature (PH, I, 135).[[9]](#footnote-9) Hence, that evident things appear as they are can be doubted. Philosophical doubt concerning the nature of evident things is possible.

What this suggests is the following. From a genuinely sceptical philosophical point of view, knowledge of evident and non-evident things is in the same boat. Hence, if true sceptics do not affirm that knowledge of evident things is impossible, they should not affirm that knowledge of non-evident things is impossible. The issue of the possibility or impossibility of knowledge of non-evident things should be left open. Similarly, from the point of view of ordinary life, that is from a point of view which allows undogmatically held beliefs and brackets philosophical doubt (suspension of judgement about everything), indicative and commemorative inferences can be in the same boat, since the difference between the evident and the non-evident is a matter of degree. Recall that medical empiricists took agreement as the source of the security of judgements concerning evident things. And Sextus (*qua* representative of Pyrrhonian scepticism) defended commemorative inference on the grounds of its universal acceptance. This suggests that it should at least be an open option that indicative inferences get licensed on the basis of a universal acceptance.

**Theory vs Reason**

Empiricists came in a position to distinguish between the role of theory and the role of reason. They refused to accommodate reason in its a priori function, but they found room to accommodate theory. Galen reports that empiricists were happy to develop accounts of invisible entities (like stones in the bladder) provided they “are tested empirically” (by anatomical procedures, for instance) (ME, 24; 134). In fact, as Frede has argued, Pyrrhonian empiricism was moving towards a new way to employ use of reason, viz., theorising, which is compatible with their call for “moderation”. Galen himself might well be seen as providing a synthesis of the views of the two sects—a *via media*—in claiming that empiricism should be open to theory but theory should be open to empirical testing. Reporting his own views, Galen suggested a need for a “reasoned account” to be added to what is known from experience. This reasoned account (a theory) should be tested in experience either by finding confirming instances or by disconfirming it “by what is known in perception” (OE, 12; 89).[[10]](#footnote-10) Being also of the view that agreement “which is free from doubt” is a sign of truth, he noted that there can be agreement on reasoned accounts of experience (that is, on theories) in a lot more cases than strict empiricists might have allowed, thereby arriving “at the same conclusions on some matters, as the geometers, the calculators and the arithmeticians do” (OE, 12; 90).

This reaction to a priori and unrestricted theorising is perhaps the lasting message of the reformed medical empiricism. It was a reaction against the a priori use of reason to develop theories by means of relations of rational consequence. Against this, medical empiricism opened up space for an ineliminable use of experience in scientific theorising, by insisting that theories should be empirically tested.

**A note on Hippocratic medicine**

Hippocrates: humours existed as liquids within the body and were identified as blood, phlegm, black bile and yellow bile. These were associated with the fundamental elements of air, water, earth and fire. Each of the humours was associated with a particular season of the year, during which too much of the corresponding humour could exist in the body, for instance blood was associated with spring. Health was conceived of a good balance between the four humours. The treatments for disease within humoural theory were concerned with restoring balance.

**The transition to the seventeenth century**

# Aristotelianism

By the 1250s, Aristotle’s works had been translated into Latin, either from the original Greek or through Arabic translations, and a whole tradition of writing commentaries on these works had flourished. Aristotle’s *Organon* was the main source on issues related to logic and knowledge. At about the same time, the first Universities were founded in Paris and Oxford and natural philosophy found in them its chief institutional home. Aristotelianism was the dominant philosophy throughout the Middle Ages, though it was enriched by insights deriving from religious beliefs and many philosophical commentaries. The new Aristotelianism, especially at Paris, put secular learning at almost equal footing with revealed truth.

Thomas Aquinas (ca. 1225-1274) argued that science and faith cannot have the same object: the object of science is something seen, whereas the object of faith is the unseen. He found in Aristotle’s views the mean between two extremes. One was Plato’s view, which demeaned experience and saw in it just an occasion in the process of understanding the realm of pure and immutable forms. The other was the Democretian atomist view, which reduced all knowledge to experience. Aristotelianism, Aquinas thought, was the golden mean. Experience is necessary for knowledge, since nothing can be in the mind if it is not first in the senses. But thought is active: it extends beyond the bounds of sense and states the necessary, universal and certain principles on which knowledge is based.

Aquinas inherited (and suitably modified) much of the rich Aristotelian metaphysics. Aristotle had drawn a distinction between matter and form and had argued that, when a change takes place, something (the matter) perdures whilst something else (the form) changes. Change was conceived of as the successive presence of different (even opposing) forms in the substratum. Scholastic philosophers differentiated this substratum from the ordinary matter of experience and called it prime matter (*materia prima*). They called *substantial form* the form that gives prime matter its particular identity (making it a substance of a particular kind). Substantial forms were individuating principles: they accounted for the specific properties of bodies (which all shared the same prime matter). Aquinas added that prime matter is pure potentiality, incapable of existing by itself. Having adopted the view that change (and motion) was the passage from potentiality to actuality, and given that a thing could not be in both actuality and potentiality at the same time, he took it to be obvious that motion always requires a mover: no thing could be the active source of its own motion. Aquinas found solace in the Aristotelian doctrine of the first unmoved mover (the source of all motion) that immediately lent itself to an identification with God.

# The Problem of Motion

The status of motion was heavily debated among the Scholastics. Besides the central Aristotelian axiom that everything that moves requires a mover, another one was that the mover is in contact with the thing moved. This might be borne out in ordinary experience, but there were cases that created problems. One of them was projectile motion, while another concerned natural motion, that is motion towards a thing’s natural place. In both cases, it is not obvious that something does the moving, let alone by being in contact with the thing moved. There was no easy way out of these problems. What underlay them was the very issue of what kind of thing motion is. Is motion merely the terminus (or form) momentarily attained by the moving object at any instant or is it something in addition, a flux or transformation of forms? In medieval terminology, is motion *forma fluens* or *fluxus formae*? The radical answer to this question was sharpened by William of Ockham (ca.1280-1349), who argued that motion is nothing over and above the moving body and its successive and continuous termini. He was a nominalist who thought that only particulars exist. He denied the existence of universals and claimed that general terms or predicates refer to concepts that apply to many particulars. He therefore argued that the key to the problem of motion was held by the abstract noun ‘motion’. It is wrong, he claimed, to thing that this (and other) abstract nouns refer to distinct and separately existing things. Nothing other than individual bodies, places and forms are needed to explain what motion is. Another view, however, came from Jean Buridan (ca.1295-1358). He argued that local motion involves *impetus*, a motive force transmitted from the mover to the moving body, which acts as an internal cause of its continued motion.

## Secundum Imaginationem

In March 7 1277, the Bishop of Paris, Etienne Tempier issued an act, which condemned 219 propositions drawn from the works of Aristotle and his commentators (including Aquinas). These propositions were supposed to be in conflict with Christian faith and in particular with the omnipotence of God. They included claims such that the world is eternal, that God could not make several worlds, that God could not make an accident exist without a subject, that God could not move the entire cosmos in straight line. The irony was that this act opened up new conceptual possibilities that were hitherto regarded closed. If Aristotle could err in matters theological, why couldn’t he err in matters philosophical too? Given the premise that only the law of non-contradiction constrains God’s actions, it was argued that anything that can be thought of without contradiction is possible. This led to a new type of argumentation: *secundum imaginationem*—according to the imagination. If something could be consistently imagined, then it was possible. New ideas were pursued on this basis, unconstrained of claims according to the actual course of nature (*secundum cursus naturae*). Central elements of the Aristotelian doctrine were placed under close logical scrutiny. For instance, within the Aristotelian scheme of things, where there was no void and the entire cosmos had no place, it made no sense to say that the entire cosmos could move. But what if, Buridan asked, God made the whole cosmos rotate as one solid body? Freed to inquire into the logical possibility of this rotation, Buridan argued that since we can imagine it, there must be something more to motion than the moving body, its forms and the places it acquires. For if this was all there were to motion, then, contrary to our assumption, the entire cosmos could not move, simply because there would be no places successively acquired.

Ockham pushed *secundum imaginationem* to its limits by arguing that there is no a priori necessity in nature’s workings: God could have made things other than they are. Hence, all existing things are contingent. He forcefully denied that there are necessary connections between distinct existences and argued that there cannot be justification for inferring one distinct existence from another. Accordingly, all knowledge of things should come from experience. He claimed that there could never be certain causal knowledge based on experience, since God might have intervened to produce the effect directly, thereby dispensing with the secondary (material) cause. Ockham, then, gave a radical twist to empiricism, putting it in direct conflict with the dominant Aristotelian view.

# First Principles

The status of scientific knowledge was heavily debated in the thirteen and fourteenth centuries. John Duns Scotus (ca.1265-1308) defended the view that first principles were knowable with certainty, as they were based only on the natural power of the understanding to see that they were self-evident by virtue, ultimately, of the meanings of the terms involved in them. For him, the understanding does not have the senses for cause, but only for occasion. Once it has received its material from the senses, the understanding exercises its own power in conceiving the first principles. Interestingly enough, Scotus thought that there could be certain causal knowledge coming from experience. He advocated as self-evident a principle of induction: “Whatever happens frequently through something that is not free, has this something as its natural *per se* cause”. He thought that this principle is known by the intellect a priori since the free cause leads by its *form* to the effect that it is ordained to produce. It was then an easy step for him to extend this principle from free causes (that is, acts of free agents) to natural causes.

Ockham disagreed with Scotus’s account of the first principles, but his central disagreement with his predecessors was about the *content* of first principles. Since he thought there was nothing in the world that corresponded to general concepts (like a universal), he claimed that the first principles are, in the first instance, about mental contents. They are about concrete individuals only *indirectly* and in so far as the general terms and concepts can be predicated of concrete things. Ockham has been famous for a principle that he instigated, known as Ockham’s razor: entities must not be multiplied without necessity. In fact, this principle of parsimony was well-known in his time. Robert Grosseteste (ca. 1168-1253) had put it forward as the *lex parsimoniae* (law of parsimony).

It was Ockham’s most radical follower, Nicolas of Autrecourt (ca.1300-after 1350), who rejected the demand for certainty altogether and claimed that only probable knowledge was possible. He endorsed atomism, claiming that it is at least as probable as the rival Aristotelianism. But the fourteenth century Parisians masters (Buridan, Albert of Saxony (ca. 1316-1390) and others) claimed that empirical knowledge can be practically certain and wholly adequate for natural science. For Buridan, if we fail to discover an instance of A that is not B, then it is warranted to claim that all As are B. Based on this principle, he defended on empirical grounds the Aristotelian claim that there is no vacuum in nature, since, he said, we always experience material bodies.

# The Prerogatives of Experimental Science

Despite their engagement with philosophical issues in the natural science, thinkers such as Ockham and Scotus were little concerned with natural science itself. They saw little role for mathematics, the science of quantity, in physics. They neglected experiment altogether. This was drawback in relation to some of the earlier medieval thinkers. Grosseteste was one of the first to place emphasis on the role of mathematics in natural science. Roger Bacon (1214-1292) went further by arguing that all sciences rest ultimately on mathematics, that facts should be subsumed under mathematical principles and that active experimentation was required. Bacon put forward three prerogatives of experimental science. First, it criticises by experiment the conclusions of all the other sciences. Second, it can discover new truths (not of the same kind as already known truths) in the fields of the other sciences. Third, it investigates the secrets of nature and delivers knowledge of future and present events.

The emphasis on the mathematical representation of nature did exert some important influence on the work of the masters of Merton College in Oxford, who in the fourteenth century, put aside, by and large, the philosophical issues of the nature of motion and focused on its mathematical representation. The Mertonians (Walter Burley (ca. 1275-ca.1345), Thomas Bradwardine (ca.1295-1349), William of Heytesbury (before 1313—1372/3), Richard Swineshead (died ca.1355), most of whom where nominalists, engaged in a project to investigate motion and its relation to velocity and resistance in an abstract mathematical way. A similar tendency, though more concerned with the physical nature of motion, was developed in Paris by Buridan, Albert of Saxony, and Nicole Oresme (ca. 1320-1382), known as the Paris terminists. The mathematical ingenuity of the Mertonians and the Parisians led to many important mathematical results that were diffused throughout Western Europe and germinated the thought of many modern thinkers, including Galileo. By the end of the fourteenth century, a proto-positivist movement started to spread, concerned as it was not with the ontology of motion, but with its measurement.

# The CopernicanTurn

In *De Revolutionibus Orbium Coelestium* (*On the Revolutions of the Celestial Spheres*), Nicolaus Copernicus (1473-1543) developed his famous heliocentric model of the universe. The unsigned preface of the book, which was published posthumously in 1543, firmly placed it within the saving-of-appearances astronomical tradition, that was favoured by Plato and endorsed by many medieval thinkers. As it turned out, the preface was written not by Copernicus himself but by Andreas Osiander, a Lutheran theologian. Copernicus emphatically refused to subscribe to this tradition. He had a *realist* conception of his theory, according to which, as Pierre Duhem put it, “a fully satisfactory astronomy can only be constructed on the basis of hypotheses that are true, that conform to the nature of things” (1908, 62).

Before Copernicus, the dominant astronomical theory was Claudius Ptolemy’s (ca. 85-ca.165). He had assumed, pretty much like Aristotle and Plato, a geocentric model of the universe. To save the appearances of planetary motion, Ptolemy had devised a system of deferents and epicycles. There were alternative mathematical models of the motion of the planets (e.g., one based on a moving eccentric circle), but Ptolemy thought that since all these models were saving the appearances, they were good enough. The issue of their physical reality was not raised (though at least some medieval philosophers understood these models realistically). Geometry was then the key to studying the celestial motions but there was no pretension that the world itself was geometrical (though Plato, in *Timaeus*, did advocate a kind of geometrical atomism). The Copernican heliocentric model did use epicycles, though it made the earth move around the sun. But Copernicus argued that his own theory was true. He based this thought mostly on considerations of harmony and simplicity: his own theory placed astronomical facts into a simpler and more harmonious mathematical system.

**The Book of Nature**

Galileo Galilei (1564-1642) famously argued that the book of nature is written in the language of mathematics. He distinguished between logic and mathematics. The former teaches us how to derive conclusions from premises, but does not tell us whether the premises are true. The latter (mathematics) is in the business of demonstrating truth. Though Galileo emphasised the role of experiment in science, he also drew a distinction between appearances and reality, which set the stage for his own, and subsequent, explanatory theories of the phenomena that posited unobservable entities. He accepted and defended the Copernican system and substantiated it further by his own telescopic observations, which spoke against the dominant Aristotelian view of the immutability of the heavens. But the very possibility of the truth of Copernicus’s theory suggested that the world might not be the way it is revealed to us by the senses. Indeed, Galileo took it that the senses can be deceptive, and hence that proper science must go beyond the mere reliance on the senses. The mathematical theories of motion he advanced were based on idealisations and abstractions. Experience provides the raw material for these idealisations (frictionless inclined planes or ideal pendula), but the key element of the scientific method was the extraction, via abstraction and idealisation, of the basic structure of a phenomenon in virtue of which it can be translated into mathematical form. Then, mathematical demonstration takes over and further consequences are deduced, which are tested empirically. So Galileo saw that understanding nature requires the use of creative imagination.

Galileo also issued a distinction between primary qualities and secondary ones. Primary are those qualities, like shape, size and motion, that are possessed by the objects in themselves, are immutable, objective and amenable to mathematical exploration. Secondary are those qualities, like colour and taste, that are relative, subjective and fleeting. They are caused on the senses by the primary qualities of objects. The world that science studies is a world of primary qualities: the subjective qualities can be left out of science without any loss. Galileo set upon modern science the task of discovering the objective and real mathematical structure of the world. But though mathematical, this structure was also mechanical: all there is in the world is matter in motion.

**Seventeenth century**

When the messages of ancient empiricism were re-discovered in the seventeenth century, via mostly the translation of Sextus’s works into Latin and Galen’s own writings, the need arose for making *reformed empiricism* a via media between hard-line empiricism and dogmatism. Francis Bacon saw this very clearly in his *Novum Organum*, (1620) when he contrasted his own empiricism with both the ancient empirics and dogmatists.[[11]](#footnote-11) Pierre Gassendi was even more explicit in seeking a *via media* when he borrowed the distinction between indicative inference and commemorative one, but argued in his *Syntagma Philosophicum*, (1658) for principles that can act as a bridge between the macroscopic and the microscopic world of the new mechanical philosophy. For Gassendi, there are circumstances under which the conclusion of indicative inference can be certain (e.g., when we infer the existence of pores from sweat). This happens, he said, when the sign can exist in one circumstance; that is, when there is only one explanation of the presence of the sign (hence, when there no competing explanations). Interestingly, this cuts through the visible/invisible distinction. Though Gassendi agreed with the ancient empiricists that indicative inferences differ from commemorative ones in the type of entities implicated in them—entities invisible by nature (*occultae as nature*) vs entities temporarily invisible (*res ad tempus occultae*)—he argued that probable knowledge of invisible by nature things (such as the atoms and void) is possible. Whereas knowledge of visible things might not be possible, if there are competing theoretical accounts of them (as Gassendi thought about the structure of the planetary systems and the competing explanations of it).

**III. The problem of scientific method renewed: Bacon, Descartes and the role of hypotheses in science**

The emerging new science was leaving Aristotelianism behind. But it needed a new method. Better, it needed to have its method spelled out so that the break with Aristotelianism, as a philosophical theory of science, was complete.

**Two conceptions of the new method**

Two basic assumptions:

1. Appearances vs reality
2. The reality ‘behind’ the appearances has a non-observable micro-structure

**Mechanical Philosophy**: The broad contours of the mechanical conception of nature were not under much dispute. The key ideas were that all natural phenomena are explainable mechanically in terms of matter in motion; that efficient causation should be understood, ultimately, in terms of *pushings* and *pullings*; and that final causation should be excised from nature. And yet, the specific principles of the mechanical conception were heavily debated. For instance, some mechanical philosophers (notably Pierre Gassendi) subscribed to atomism, while others (notably Descartes) took the universe to be a plenum, with matter being infinitely divisible.

The aim of new science is finding the laws of nature which govern the behaviour of mechanical particles. A broadly reductive conception of the world: the (mechanical) micro-structure of the world—together with the laws of nature—determine (and explain) the behaviour of macro-scopic objects.

Scientific knowledge is still associated with certainty. But two different roads to certainty.

**Bacon’s model**: knowledge starts with experience and requires a new type of induction. Knowledge via elimination.

**Descartes’s model**: Knowledge starts with reason. Experience can never lead to certainty. The empirical models of the world have to be ‘restricted from above’ via metaphysically necessary (and hence knowable a priori) principles—known as laws of nature.

# Francis Bacon: The Interpretation of Nature

In *Novum Organum* (*New Organon*, 1620) Francis Bacon (1561-1626) placed method at centre-stage and argued that the world is knowable but at the very end of a long process of trying to understand it, which begins with experience and is guided by a new method: the method of induction by elimination. This new method differed from Aristotle’s on two counts: on the nature of first principles and on the process of attaining them. According to Bacon, the Aristotelian method (what Bacon called anticipation of nature) starts with the senses and particular objects but then flies to the first principles and derives from them further consequences. He contrasted this method to his own, which aims at an interpretation of nature: a gradual and careful ascent from the senses and particulars objects to the most general principles.

Bacon was fully aware that the problem Aristotle bequeathed to his successors—the status of first or basic principles—was both serious and urgent. The basic principles of science cannot be demonstrated. And since, the only other road to them (Bacon thought) was via experience, “our only hope lies in true induction” (14).

**What then is this true induction?**

The problem, Bacon thought, lies with the way induction is supposed to proceed, viz., via simple enumeration without taking “account of the exceptions and distinctions that nature is entitled to”. Having Aristotle in mind, he called enumerative induction “a childish affair”: “its conclusions are precarious and exposed to peril from a contradictory instance; and it generally reaches its conclusions on the basis of too few facts—merely the ones that happen to be easily available” (105). His new form of induction differed from Aristotle’s (and Bacon’s predecessors in general) in the following:

it is a general method for arriving at all kinds of general truths (not just the first principles, but also at the “lesser middle axioms” as he put it);

it surveys not only affirmative or positive instances, but also negative ones;

it therefore “separate(s) out a nature through appropriate rejections and exclusions”.

Baconian induction proceeds in three stages. *Stage I* is experimental and natural history: A complete inventory of all instances of natural things and their effects. Here observation rules. Then at *stage II*, tables of presences, absences and degrees of comparison are constructed. Take, for example, the case of heat, which Bacon discussed in some detail. The table of presences is a recording of all things with which the nature under examination (heat) is correlated (e.g., heat is present in light etc.). The table of absences is a more detailed examination of the list of correlations of the table of presences in order to find absences (e.g., heat is not present in the light of the moon). The table of degrees of variation consists of recordings of what happens to the correlated things if the nature under investigation (heat) is decreased or increased in its qualities.

*Stage III* is induction. Whatever is present when the nature under investigation is present or absent when this nature is absent or decreases when this nature decreases and conversely, is the *form* of this nature. The crucial element in this three-stage process is the elimination or exclusion of all accidental characteristics of the nature under investigation. Based on this method, Bacon claimed that heat is motion and nothing else.

Here is how he put it:

“The first work, therefore, of true induction (as far as regards the discovery of forms) is the rejection or exclusion of the several natures which are not found in some instance where the given nature is present, or are found in some instance where the given nature is absent, or are found to increase in some instance when the given nature decreases, or to decrease when the given nature increases. Then indeed after the rejection and exclusion has been duly made, there will remain at the bottom, all light opinions vanishing into smoke, a form affirmative, solid, and true and well defined. This is quickly said; but the way to come at it is winding and intricate. I will endeavor, however, not to overlook any of the points which may help us toward it.” (NO, Book II, 16)

So Baconian induction proceeds by elimination; but this is not enough, for in the end, a positive conclusion should be drawn. As he put it: “The process of exclusion is the foundation of true induction; but the induction isn’t completed until it arrives at something affirmative”.

Here is a schematic presentation of Baconian induction:

Presences: heat is present in the sun’s rays, lightning, flames, boiling liquids, hot smoke, a body forcefully rubbed, animals, hot spices, and many other things.

Absences (What Bacon calls ‘contradictory instances’) Heat is absent is: moonlight and starlight, (like sunlight but different); liquids in a natural state, (which are like boiling liquids but different) etc

Covariation: seasons, some of which are hot and some cold; flames of different temperatures; etc.

The stage of ‘true and proper induction.’ To discover the essence or form of heat.

This has four stages.

One: identification of possible candidates and then exclusion of candidates refuted by some instance or instances. E.g. heat cannot be light etc. The exclusion leads to a candidate for the nature of heat: heat involves some kind of motion.

Second stage: after the identification of the genus, the species should be identified. What kind of motion is heat? (All instances of heat involve motion, but not all instances of motion involve heat). Looking for a *differentia*.

Stage three: proposal and exclusion of possible differentia.

Stage four: the differentia is found.

Bacon concludes that heat is a motion of small particles with certain qualifications involving direction, enclosure, speed, and force. The true and proper induction has been completed.

A schema for the pattern of Baconian induction

1. Natural history: observation and experiment
2. Arrange the results in tables

|  |  |  |
| --- | --- | --- |
| Presences | Absences | variation |
| X is hot | X’ is not hot | X’’ is seldom hot |
| Y is hot | Y’ is not hot | Y’’ is sometimes hot |
| Z is hot | Z’ is not hot | Z’’ is of variable heat |

1. Identify the form of the nature under investigation.

(a) By suggesting and excluding,

(b) identify the genus.

Heat is motion ...

(c) By suggesting and excluding,

(d) identify the differentia.

... of a certain type.

Here is a beautiful statement of the gist of Bacon’s method in relation to alternative conceptions:

“Those who have handled sciences have been either men of experiment or men of dogmas. The men of experiment (empirics) are like the ant, they only collect and use; the reasoners (dogmatists) resemble spiders, who make cobwebs out of their own substance. But the bee takes a middle course: it gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own. Not unlike this is the true business of philosophy; for it neither relies solely or chiefly on the powers of the mind, nor does it take the matter which it gathers from natural history and mechanical experiments and lay it up in the memory whole, as it finds it, but lays it up in the understanding altered and digested. Therefore from a closer and purer league between these two faculties, the experimental and the rational (such as has never yet been made), much may be hoped” (*New Organon*, Book I, aphorism XCV).

Bacon’s talk of forms is reminiscent of the Aristotelian substantial forms. Indeed, Bacon’s was a view in transition between the Aristotelian and a more modern conception of laws of nature. For he also claimed that the form of a nature is the law(s) it obeys. Here is how he put it: “In speaking of forms or simple natures, I’m not talking about abstract forms and ideas which show up unclearly in matter if indeed they show up in it at all. When I speak of ‘forms’ I mean simply the objective real-world laws of pure action that govern and constitute any simple nature—e.g. heat, light, weight—in every kind of matter and in anything else that is susceptible to them. Thus the ‘form of heat’ or the ‘form of light’ is the same thing as the law of heat or the law of light”.

Bacon, however, found almost no place for mathematics in his own view of science, though he did favour active experimentation and showed great respect for alchemists because they had had laboratories. In his instance of fingerpost, he claimed that an essential instance of the interpretation of nature by the new method of induction consists in devising a crucial experiment that judges which of two competing hypotheses accounts for the causes of an effect. Accordingly, Bacon distinguished between two types of experiments; those that gather data for the experimental natural history and those that test hypotheses.

Bacon also spoke against the traditional separation between theoretical knowledge and practical one and argued that human knowledge and human power meet in one.

# Descartes: The Metaphysical Foundations of Science

René Descartes (1596-1650)too aimed to provide an adequate philosophical foundation of science. But unlike Bacon, he felt more strongly the force of the sceptical challenge to the very possibility of knowledge of the world. So he took it upon himself to show how there could be certain (indubitable) knowledge, and in particular, how science can be based on certain first principles. Knowledge, he thought, must have the certainty of mathematics. Though Bacon was fine with some notion of moral certainty, Descartes was after metaphysical certainty, that is knowledge beyond any doubt. But in the end, Descartes accepted that in science a lot of things (other than the basic laws of nature) can be known with moral certainty only.

He distinguished all substances into two sorts: thinking things (*res cogitans*) and extended things (*res extensa*). He took the essence of mind to be thought and of matter extension. The vehicles of knowledge were taken to be intuition and demonstration: we can only be certain of whatever we can form clear and distinct ideas or demonstrate truths. Descartes tried to base his whole foundational conception of knowledge on a single indubitable truth, viz., *cogito ergo sum* (I think, therefore I exist). But having demonstrated the existence of God, he took God as a guarantor of the existence of the external world and, ultimately, of its knowledge of it.

Descartes was not a pure rationalist who thought that *all* science could be done a priori. But he was not, obviously, an empiricist either. He did not think that all knowledge stemmed from experience. In *Principia Philosophiae* (*Principles of Philosophy*, 1644), he argued that the human mind, by the light of reason alone, could arrive at substantive truths concerning the fundamental laws of nature. These, for instance that the total quantity of motion in the world is conserved, were discovered and justified a priori, as they were supposed to stem directly from the immutability of God. Accordingly, the basic structure of the world is discovered independently of experience, is metaphysically necessary and known with metaphysical certainty; for instance, that the world is a plenum with no vacuum (or atoms) in it, that all bodies are composed of one and the same matter, that the essence of matter is extension etc. But once this basic structure has been laid down, science can use hypotheses and experiments to fill in the details. This is partly because the basic principles of nature place constraints on whatever else there is and happens in the world, without determining it uniquely. The less fundamental laws of physics are grounded in the fundamental principles but they are not directly deducible from them. Hypotheses are then needed to ‘flesh out’ these principles. They are also needed to determine particular causes and matters of fact in the world, e.g., the shape, size and speeds of corpuscles. It is only through experience that the values of magnitudes such as the above can be determined. Accordingly, Descartes thought that the less fundamental laws could be known only with moral certainty. Descartes view of nature was mechanical: everything could be explained in terms of matter in motion.

**Descartes on Explanation**

In *Principles of Philosophy* (1644), Descartes expanded on the Aristotelian idea that explanation consists in demonstrations from first principles. But he gave this idea two important twists. The first, as noted already, is that the basic principles are the fundamental rules or laws of nature. The second was the idea that all explanations of natural phenomena is mechanical. Like Aristotle, Descartes thought that explanation amounts to the search of causes. But unlike Aristotle, he thought that all causation is efficient causation and, in particular mechanical. Though Descartes did not fully abandon the rich Aristotelian philosophical framework, (for instance, he too conceived of the world in terms of substances, natures, essences and necessary connections, the latter being, by and large, a priori demonstrable), he thought that the explanation of natural phenomena proceeds by means of mechanical interactions, and not by reference to violent and natural motions; nor in teleological terms. To be sure, he took God to be “the efficient cause of all things” (1985, 202). But in line with the scholastic distinction between primary cause (God) and secondary causes (worldly things), he claimed that the secondary and particular causes—“which produce in an individual piece of matter some motion which it previously lacked” (1985, 240)—are the laws of nature and the initial conditions viz., the shapes, sizes and speeds of material corpuscles.

Descartes thought that all natural phenomena are explained, by being ultimately deduced from the fundamental laws and principles, which are discoverable independently of experience. How is then empirical science possible? Descartes, as noted already, thought that once the basic nomological structure of the world has been discovered by the lights of reason, science must use hypotheses and experiments to fill in the details. This is because the initial conditions (the shapes, sizes and speeds of corpuscles) can only be determined empirically. That is, among the countless initial conditions that God might have instituted, only experience can tell us which he has actually chosen for the actual world. Besides, though grounded in the fundamental laws, the less fundamental laws of physics are not immediately deducible from them. Further hypotheses are needed to flesh them out. Hence, Descartes thought that the less fundamental laws could be known only with moral certainty.

Indeed, Descartes allowed for the possibility that there are competing systems of hypotheses which, though compatible with the fundamental laws, offer different explanations of the phenomena. He illustrated this possibility by reference to an artisan who produced two clocks that indicate the hours equally well, are externally similar and yet work with different internal mechanisms. In light of this possibility, Descartes wavered between two thoughts, which were to become the two standard responses to the argument from underdetermination of theories by evidence. The first (cf. 1985, §44) is that it does not really matter which of the two competing systems of hypotheses is true, provided that they are both empirically adequate, that is, they correspond accurately to all the phenomena of nature. The other (cf. 1985 §§44 and 205) is that theoretical virtues such as simplicity, coherence, unity, naturalness etc. are marks of truth in the sense that it would be very unlikely that a theory possesses them and be false. Interestingly, Descartes put a premium on novel predictions: when postulated causes explain phenomena not previously thought of, there is good reason to think they are their true causes.

Explanatory hypotheses, Descartes claimed, must be mechanical, that is cast in terms of “the shape, size, position and motion of particles of matter” (1985, 279), and that the selfsame mechanical principles should deductively explain the whole of nature, both in the heavens and on the earth. It wouldn’t be an exaggeration to claim that Descartes advanced an unificationist account of explanation, where the unifiers are the fundamental laws of nature.

**Descartes on causation**

We noted already that Descartes distinguished all substances into two sorts: thinking things (*res cogitans*) and extended things (*res extensa*). In particular, he took the essence of mind to be thought and of matter extension. Unlike Aristotle, he thought that matter was inert (since its essence is that it occupies space). Yet, there are causal connections between bodies (bits of matter) and between minds and bodies (that is, between different substances). Two big questions, then, emerge within Cartesianism. The first is: how is body-body interaction possible? The second is: how is mind-matter interaction possible? Briefly put, Descartes’ answer to the first question is the so-called *transference* model of causation: when *x* causes *y* a property of *x* is communicated to *y*. He thought that this view is an obvious consequence of the principle “Nothing comes from nothing”. As he put it:

For if we admit that there is something in the effect that was not previously present in the cause, we shall also have to admit that this something was produced by nothing (1985, Vol. 1, 97).

But Descartes failed to explain how this communication is possible. Indeed, by taking matter to be an inert extended substance, he had to retreat to some external cause of motion and change and ultimately to God himself. This retreat to God cannot save the transference model. Besides, the transference model makes an answer to the second question above (how do mind and matter interact?) metaphysically impossible. Being distinct substances, they have nothing in common which can be communicated between them. In a sense, Descartes was a failed interactionist: there is matter-matter and mind-matter causal interaction but there is no clear idea of how it works.

**Descartes on metaphysics and physics—some thoughts on *the Principles of Philosophy***

What is metaphysics?

“Thus, all Philosophy is like a tree, of which Metaphysics is the root, Physics the trunk, and all the other sciences the branches that grow out of this trunk, which are reduced to three principal, namely, Medicine, Mechanics, and Ethics.” (From the preface to the French translation)

First philosophy: the quest for the principles (and hence of the possibility) of knowledge.

But it is also an ontology: substance and attributes, some of which are essential while others are accidental.

Hence, physics has a double grounding on metaphysics. That is;

The possibility of scientific knowledge by physics presupposes principles which make this knowledge possible

**and**

the natural world (being knowable) has a deeper ontological structure: it is matter (qua substance) which is essentially characterised by extension (essential attribute). The world is inherently geometrical and inert. Motion comes from the outside.

God if the bridge between these two roles of metaphysics within physics

He guarantees the knowledge of the world and is the source of all motion in nature.

**Descartes’ philosophical God**

1. **God as what makes the system of the world coherent.**

What is the criterion of truth? Clear and distinct ideas. Descartes moves from this criterion to the claim that God necessarily exists—existence is contained in the idea of a perfect being (Principle 14), in the same way in which that the sum of the angles of a triangle is 180 degrees is ‘contained’ in the idea of triangle.

“Part I, Principle 14. That we may validly infer the existence of God from necessary existence being comprised in the concept we have of him. When the mind afterwards reviews the different ideas that are in it, it discovers what is by far the chief among them--that of a Being omniscient, all-powerful, and absolutely perfect; and it observes that in this idea there is contained not only possible and contingent existence, as in the ideas of all other things which it clearly perceives, but existence absolutely necessary and eternal. And just as because, for example, the equality of its three angles to two right angles is necessarily comprised in the idea of a triangle, the mind is firmly persuaded that the three angles of a triangle are equal to two right angles; so, from its perceiving necessary and eternal existence to be comprised in the idea which it has of an all-perfect Being, it ought manifestly to conclude that this all-perfect Being exists.”

But (principle 5), we may be wrong in mathematical proofs. Can we similarly err about the existence of God? Only if God deceives us systematically. But God (being a perfect being) does not deceive us. Hence, he guarantees the clarity and distinctness of our ideas, and hence of the criterion of truth.

This is a full circle! Or else, we soudl simply assume the existence of an external guarantor of knowledge as presupposition for the very possibility of knowing the world. But isn’t this arbitrary?

1. **God as the primary cause of everything but also as this which constantly and continuously concurs the existence of matter and of material things.** (concursus Dei)(principle 21) “some cause, (GOD) viz., that which first produced us, shall, as it were, continually reproduce us, that is, conserve us”

“21. That the duration alone of our life is sufficient to demonstrate the existence of God.

The truth of this demonstration will clearly appear, provided we consider the nature of time, or the duration of things; for this is of such a kind that its parts are not mutually dependent, and never co-existent; and, accordingly, from the fact that we now are, it does not necessarily follow that we shall be a moment afterwards, **unless some cause, viz., that which first produced us, shall, as it were, continually reproduce us, that is, conserve us**. For we easily understand that there is no power in us by which we can conserve ourselves, and that the being who has so much power as to conserve us out of himself, must also by so much the greater reason conserve himself, or rather stand in need of being conserved by no one whatever, and, in fine, be God.”

The inertness of matter and the problematic role of force in Cartesian physics.

“Part II, IV. That the nature of body consists not in weight hardness, colour and the like, but in extension alone”.

In any case, God warrants the fundamental laws of nature and their a priori knowability. From the immutability of God to the fundamental law of the conservation of the quantity of motion in the universe.

“Part III, Principle 36. God is the primary cause of motion; and he always

preserves the same quantity of motion in the universe.

So much for the nature of motion—now for its cause. This is a two-part story: as well as the universal and primary cause, the general cause of all the motions in the world, there is the particular cause that produces in an individual piece of matter some motion which it previously lacked. (...) As for the first: It seems clear to me that the general cause is no other than God himself. In the beginning he created matter, along with its motion and rest; and now, merely by regularly letting things run their course, he preserves the same amount of motion and rest in the material universe as he put there in the beginning.”

**The three fundamental laws of nature are metaphysically certain.**

“37. The first law of nature: each thing when left to itself continues in the same state; so any moving body goes on moving until something stops it.

From God’s unchangingness we can also know certain rules or laws of nature, which are the secondary and particular causes of the various motions we see in particular bodies. The first of these laws is that each simple and undivided thing when left to itself always remains in the same state, never changing except from external causes. A cubic piece of matter will remain cubic for ever unless something from outside it changes its shape.

39. The second law of nature: each moving thing if left to itself moves in a straight line; so any body moving in a circle always tends to move away from the centre of the circle.

The second law is that every piece of matter . . . tends to continue moving in a straight line. This is true despite the fact that particles are often deflected by collisions with other

bodies, and the fact that when anything moves it does so as part of a closed loop of matter all moving together. The reason for this second rule is the same as the reason for the first rule, namely the unchangingness and simplicity of the operation by which God preserves motion in matter.

40. The third law: (a) if one body collides with another that is stronger than itself, it loses none of its motion; (b) if it collides with a weaker body, it loses the same amount of motion that it gives to the other body.”

**Crucial question: What exactly is the role of science in this framework?**

3rd and 4th part of the *Principia*.

The possible empirical models of the worlds are restricted from above by a priori principles (the fundamental laws of nature) and from below by experience. Between these two levels there are various theoretical hypotheses, which constitute the proper subject of science.

The hypothetico-deductive method (the role of hypotheses in science).

Principle 46

“But unaided reason won’t tell us how big these pieces of matter are, how fast they move, or what kinds of looped path they follow. There are countless configurations that God might have chosen, and experience will have to tell us which ones he actually chose. So we’re free to make any assumption we like about this, provided that its consequences agree with our experience.”

Going beyond the senses

“201. That sensible bodies are composed of insensible particles.

But I allow many particles in each body that are perceived by none of our senses, and this will not perhaps be approved of by those who take the senses for the measure of the knowable. [We greatly wrong human reason, however, as appears to me, if we suppose that it does not go beyond the eye-sight];”

**Descartes’ wavering Part ΙΙΙ 43-46**

**Truth or mere hypotheses? What are the criteria?**

43. If there’s a causal story from which all the phenomena can be clearly deduced, then it’s virtually impossible for it not to be true.

If we use only principles that we see to be utterly evident, and all our subsequent deductions follow by mathematical reasoning, and what the deductions lead to are in precise agreement with all natural phenomena, wouldn’t we be doing God an injustice if we suspected that the causal explanations reached in this way were false? It would imply that God had endowed us with such an imperfect nature that even the proper use of our powers of reasoning allowed us to go wrong.”

“44. Still, I want the causes that I shall set out here to be regarded simply as hypotheses.

When philosophizing about such important matters, however, it would be downright arrogant to claim that I have discovered the exact truth where others have failed; so I choose not to make such a claim, and to offer everything that I’m going to write simply as a hypothesis. And if you think the hypothesis is false, I’ll still think that I have done something pretty worthwhile if everything deduced from it agrees with our observations; because in that case the hypothesis will be **as useful as if it were true**—useful, that is, in enabling us to manipulate natural causes so as to get the effects we want.”

The role of novel predictions

42. “... but we’ll know that we are right about those causes when we observe that serve to explain not only the effects that we were initially trying to explain but all these other phenomena that we hadn’t even been thinking about.”

Vs

‘conformity with the phenomena’ is enough

“as useful to life as if it were true”

Part IV

(Principle 204) “This method may enable us to understand how all the things in nature could have arisen, but we shouldn’t conclude that they were in fact made in that way.”

**The watchmaker example**

“204. It’s enough to explain what the nature of imperceptible things might be, even if their actual nature is different.

This method may enable us to understand how all the things in nature could have arisen, but we shouldn’t conclude that they were in fact made in that way. A craftsman could make two equally reliable clocks that looked completely alike from the outside but had utterly different mechanisms inside; so also, I freely concede, the supreme maker of everything could have produced all that we see in many different ways. I’ll think I have achieved enough just so long as what I have written corresponds accurately with all the phenomena of nature. That’s all that is needed for practical applications in ordinary life, because medicine and mechanics—and all the other arts that can be fully developed with the help of

natural science—are directed only towards the phenomena of nature, i.e. towards items that are sense-perceptible. Do you think that Aristotle achieved more than this, or at least

wanted to do so? If so, you are wrong. At the start of his Meteorology 1:7 he says explicitly, regarding his reasons and demonstrations concerning things not manifest to the senses, that he counts them as adequate so long as he can show that such things could occur in accordance with his explanations.”

And yet (Principle 205)

Moral/Practical certainty

“205. That nevertheless there is a moral certainty that all the things of this world are such as has been here shown they may be.

But nevertheless, that I may not wrong the truth by supposing it less certain than it is, I will here distinguish two kinds of certitude. The first is called moral, that is, a certainty sufficient for the conduct of life, though, if we look to the absolute power of God, what is morally certain may be false. (...) But they who observe how many things regarding the magnet, fire, and the fabric of the whole world, are here deduced from a very small number of principles, though they deemed that I had taken them up at random and without grounds, **will yet perhaps acknowledge that it could hardly happen that so many things should cohere if these principles were false**.”

Unification and empirical sucess.

**The end point (207)**

I submit all my views to the authority of the Church.

**Cartesianism**

Descartes’ successors were divided into two groups: the occasionalists and those who, following Leibniz reintroduced *activity* into nature. Occasionalism is the view that the only real cause of everything is God and that all causal talk which refers to finite substances is a sham. Nicholas Malebranche drew a distinction between real causes and natural causes (or occasions). As he put it:

A true cause as I understand it is one such that the mind perceives a necessary connection between it and its effect. Now the mind perceives a necessary connection between the will of an infinite being and its effect. Therefore, it is only God who is the true cause and who truly has the power to move bodies (1674-5/1997, 450).

Natural causes are then merely the occasions on which God causes something to happen. Malebranche pushed Cartesianism to its extremes: since a body’s nature is exhausted by its extension, bodies cannot have the power to move anything, and hence to cause anything to happen. What Malebranche also added was that since causation involves a necessary connection between the cause and the effect (a view that Descartes accepted too), and since no such necessary connection is perceived in cases of alleged worldly causation (where, for instance, it is said that a billiard ball causes another one to move), there is no worldly causation: all there is in the world is regular sequences of events, which strictly speaking are not causal. For Malebranche, all causal explanation must ultimately refer to God and his powers.

**Boyle, Robert** (1627-1691) English scientist, one of the most prominent figures of the seventeenth century England. He articulated the **mechanical philosophy**, which he saw as a weapon against Aristotelianism, and engaged in active experimentation to show that the mechanical conception of nature is true. He defended a corpuscular approach to matter. In his *About the Excellency and Grounds of the Mechanical Hypothesis* (1674) he outlined his view that all natural phenomena are produced by the mechanical interactions of the parts of matter according to mechanical laws. He also wrote about methodological matters. For instance, he favoured consistency, simplicity, comprehensiveness and applicability to the phenomena as virtues that theories should possess and argued that his own corpsuscularian approach was preferable to Aristotelianism because it possessed these virtues.

**IV. The problem of induction: before and after Hume**

**David Hume** (1711-1776) was a Scottish philosopher, author of the ground-breaking *A Treatise of Human Nature* (1739-40). The subtitle of this book was: *Being an attempt to introduce the experimental mode of reasoning into moral subjects*. This was a clear allusion to Isaac Newton’s achievement and method. Hume thought that the moral sciences had yet to undergo their own Newtonian revolution. He took it upon himself to show how the Newtonian rules of philosophising were applicable to the moral sciences.

**Hume’s empiricism**

All ideas should come from impressions. Experience must be the arbiter of everything. Hypotheses should be looked at with contempt. His own principles of association by which the mind works, resemblance, contiguity and causation, were the psychological analogue of Newton’s laws. As he put it: ‘they are really *to us* the cement of the universe’.

The cornerstone of this epistemology is the thought that

all our ideas, or weak perceptions, are derived from our impressions, or strong perceptions, and that we can never think of any thing we have not seen without us, or felt in our own minds (A, 647-8; cf. also T, 4).

Let’s call this the Basic Methodological Maxim. Put in a nutshell, it asserts: *no impressions in, no ideas out*. Ideas are nothing but “fainted images” of impressions “in thinking and reasoning” (T, 1).

In his *An Enquiry Concerning Human Understanding* (1748), Hume drew a sharp distinction between relations of ideas and matters of fact. He took relations of ideas to mark a special kind of truths (those that came to be known an analytic truths), which are necessary and knowable a priori. Matters of fact, on the other hand, capture empirical (or synthetic) and contingent truths that are known a posteriori. This bifurcation leaves no space for a third category of synthetic *a priori* principles, the existence of which Hume firmly denied. Being an empiricist, Hume argued that all factual (and causal) knowledge stems from experience. He revolted against the traditional view that the necessity which links cause and effect is the same as the logical necessity of a demonstrative argument. He argued that there can be *no* a priori demonstration of any causal connection, since the cause can be conceived without its effect and conversely. He argued that there was no perception of the supposed necessary connection between cause and effect. When a sequence of events that is considered causal is observed, e.g., two billiard balls hitting each other and flying apart, there are impressions of the two balls, of their motions, of their collision and of their flying apart, but there is *no* impression of any alleged necessity by which the cause brings about the effect. Hume went one step further. He found worthless his predecessors’ appeals to the power of God to cause things to happen. So Hume secularised completely the notion of causation. He also found inadequate, because circular, his predecessors’ attempts to explain the link between causes and effects in terms of powers, active forces etc. As he put it: “[T]he terms *efficacy*, *force*, *energy*, *necessity*, *connexion*, and *productive quality*, are all nearly synonymous; and therefore ’tis an absurdity to employ any of them in defining the rest” (1739, 157).

But his far-reaching point was that the alleged necessity of causal connection cannot be proved empirically either. As he famously argued, any attempt to show, based on experience, that a regularity that has held in the past *will* or *must* continue to hold in the future will be circular and question-begging. It will presuppose a principle of uniformity of nature. But this principle is *not* a priori true. Nor can it be proved empirically without circularity. For any attempt to prove it empirically will have to assume what needs to be proved, viz., that since nature has been uniform in the past it *will* or *must* continue to be uniform in the future.

This Humean challenge to any attempt to establish the necessity of causal connections on empirical grounds has become known as his scepticism about induction. But Hume never doubted that people think and reason inductively. He just took this to be a fundamental psychological fact about human beings which cannot be accommodated within the confines of the traditional conception of Reason. Indeed, Hume went on to describe in detail some basic rules by which to judge of causes and effects.

**Hume on causation**

Hume focused on causation and aimed to dissolve the issue of its metaphysical nature. Before Hume, here is how Malebranche had characterised the metaphysical state of play:

There are some philosophers who assert that secondary [i.e., worldly] causes act through their matter, figure, motion (...) others assert that they do so through a substantial form; others through accidents or qualities, and some through matter and form; of these some through form and accidents, others through certain virtues or faculties different from the above. (...) Philosophers do not even agree about the action by which secondary causes produce their effects. Some of them claim that causation must not be produced, for it is what produces. Others would have them truly act through their action; but they find such great difficulty in explaining precisely what this action is, and there are so many different views on the matter that I cannot bring myself to relate to them (1674-5/1997, 659).

Malebranche found in this situation a reason to advocate occasionalism. Hume, on the other hand, presenting the situation in a way strikingly similar to the above, found in it a reason to bury the metaphysical issue altogether, to secularise causation completely and to challenge the distinction between causes and occasions. As he put it, there is “no foundation for that distinction (...) betwixt cause and occasion” (1739, 171). In effect, Hume made the scientific hunt for causes possible, by freeing the concept of causation from the metaphysical chains that his predecessors had used to pin it down. For Hume, causation, as it is in the world, is regular succession of event-types: one thing invariably following another. His *first* definition of causation runs as follows:

We may define a CAUSE to be ‘An object precedent and contiguous to another, and where all the objects resembling the former are plac’d in like relations of precedency and contiguity to those objects, that resemble the latter’ (1739, 170).

But Hume faced a puzzle: what is the impression of the idea of causation? According to his empiricist theory of ideas, there were no ideas in the mind unless there were prior impressions (perceptions) (cf. 1739, 4). Yet, he (1739, 77) did recognise that the ordinary concept of causation involved the idea of *necessary connection*. Where does this idea come from, if there is no perception of necessity in causal sequences? It is essential to his project to show that *there is* such an impression of necessary connection. For if there was not, and if the Basic Methodological Maxim was accepted, then the whole idea of causation would become vacuous (it could not exist, or in modern terms, it would be meaningless). But he does not doubt that we have this idea (cf. T, 74-5). Hume notes that this idea cannot stem from a quality (or property) of an object. Being a cause is not a particular quality of an object. It’s not like being red, or being square. So to say that *c* is a cause is simply a way to describe *c* (in relation to an effect *e*) and not a way to ascribe a property to *c*. Hence, the idea of causation *cannot* derive from the impression of a property (quality) of an object. It follows that the idea of causation “must be derived from some *relation* among objects” (T, 75). What are the “essential” characteristics of this relation? They are at least two:

* spatial *contiguity* (or the presence of “chains of causes” if the two objects are not contiguous, cf. T, 75)
* temporal *succession*: “that of PRIORITY of time in the cause before the effect” (T, 76).

Hume, however, thinks that contiguity and succession are *not* sufficient for causation: they cannot “afford (...) a complete idea of causation” (T, 77). For, “an object may be contiguous and prior to another, without being consider’d as its cause” (ibid.). If *contiguity* and *succession* cannot afford the basis for a distinction between a causal sequence and a coincidental one, what can? Hume is adamant in claiming that when we restrict ourselves to *particular* sequences, there is nothing beyond *contiguity* and *succession* to be discovered: “We can go no *farther* in considering this particular instance” (ibid.). So, when it comes to examining a particular instance (such as the collision of two billiard balls), there is nothing which can distinguish between this instance’s being a causal sequence and its being merely coincidental. We “would say nothing”, Hume (T, 77) adds, if we were to characterise a causal sequence in terms of expressions such as *c* *produces* *e*. For, the idea of “production” is synonymous with the idea of causation, and hence it would offer no further illumination.

Hume acknowledges that what is taken to distinguish between causal sequences and coincidental ones is that only the former involve some kind of necessary connection between events *c* and *e*. Hence, since *contiguity* and *succession* do not exhaust the characterisation of causation, “NECESSARY CONNEXION” should also “be taken into consideration” (T, 77). So,

* *necessary connection* (“and that relation is of much greater importance, than any of the other two above-mention’d” (T, 77)).

But what is the source of this idea? Hume argued that the *source* of this idea is the perception of “a new relation betwixt cause and effect”: a “constant conjunction” such that “like objects have always been plac’d in like relations of contiguity and succession” (1739, 88). The perception of this constant conjunction leads the mind to form a certain habit or custom. As he put it:

after frequent repetition I find, that upon the appearance of one of the objects, the mind is *determin’d* by custom to consider its usual attendant, and to consider it in a stronger light upon account of its relation to the first object (1739, 156).

And he adds:

’Tis this impression, then, or *determination*, which affords me the idea of necessity.

So Hume *does* explain the idea of necessary connection in a way consistent with his empiricism. But instead of ascribing it to a feature of the natural world, he takes it to arise from *within* the human mind, when the latter is conditioned by the observation of a regularity in nature to form an expectation of the effect, when the cause is present. Indeed, Hume went on to offer a *second* definition of causation:

A CAUSE is an object precedent and contiguous to another, and so united with it, that the idea of the one determines the mind to form the idea of the other, and the impression of the one to form a more lively idea of the other (1739, 170).

Hume took the two definitions to present “a different view of the same object” (1739, 170). The idea of necessary connection features in none of them. In fact, he thought that he had unpacked the “essence of necessity”: it “is something that exists in the mind, not in the objects” (1739, 165). He went as far as to claim that the supposed objective necessity in nature is *spread* by mind onto the world (1739, 167).

Hume placed causation firmly within the realm of experience: all causal knowledge should stem from experience. He revolted against the traditional view that the necessity which links cause and effect is the same as the logical necessity of a demonstrative argument. He argued (1739, 86-7) that there can be *no* a priori demonstration of any causal connection, since the cause can be conceived without its effect and conversely. But, as noted already, his far-reaching observation was that the alleged necessity of causal connection cannot be proved empirically either. As he (1739, 89-90) argued, any attempt to show, based on experience, that a regularity that has held in the past *will* or *must* continue to hold in the future too will be circular and question-begging. It will presuppose a *principle of uniformity of nature*, viz., a principle that “instances, of which we have had no experience, must resemble those, of which we have had experience, and that the course of nature continues always uniformly the same” (1739, 89).

A central target of Hume’s criticism is the view that causal action (and interaction) is based on the powers that things have. This view was resuscitated by Leibniz and was, partly, criticised by Newton. Hume spends quite some time trying to dismiss the view that we can meaningfully talk of powers. His *first* move is that an appeal to “powers” in order to understand the idea of necessary connection would be no good because terms such as “*efficacy*, *force*, *energy*, *necessity*, *connexion*, and *productive quality*, are all nearly synonimous” (1739, 157). Hence, an appeal to “powers” would offer no genuine explanation of necessary connection. His *second* move is to look at his opponents’ theories: Locke’s, Descartes’, Malebranche’s and others’. The main theme of his reaction is that all these theories have failed to show that there are such things as “powers” or “productive forces”. In the end, however, Hume’s argument was that we “never have any impression, that contains any power or efficacy. We never therefore have any idea of power” (1739, 161). He endorsed what might be called the *Manifestation Thesis*: there cannot be unmanifestable “powers”, i.e., powers which exist, even though there are no impressions of their manifestations. This thesis should be seen as an instance of *Ockham’s Razor*: do not multiply entities beyond necessity. For Hume, positing unmanifestable powers would be a gratuitous multiplication of entities, especially in light of the fact that he can explain the origin of our idea of necessity without any appeal to powers and the like.

Hume, however, articulated the principles on which causal explanation should be based. These are his well-known “rules by which to judge of causes and effects” (1739, 173). These principles include:

1. The same cause always produces the same effect, and the same effect never arises but from the same cause.
2. Where several different causes produce the same effect, it must be by means of some quality, which we discover to be common amongst them.
3. The difference in the effects of two resembling causes must proceed from that particular, in which they differ.
4. An object, which exists for any time in its full perfection without any effect, is not the sole cause of that effect, but requires to be assisted by some other principle, which may forward its influence and operation.

These principles are grounded in the first one noted above, viz., *same cause, same effect*. This, Hume thought, is an empirical principle derived from experience. The second and the third principles are early versions of Mill’s methods of agreement and difference. Hume’s point is that causal explanation (and causal knowledge) does not require the backing of a metaphysical theory of causation. It can proceed by means of principles such as the above. He is adamant that these principles are extremely difficult in their application. But this does not imply that they are inapplicable; nor that they do not yield causal knowledge. After all, Hume denied that knowledge requires certainty.

In Hume then we see the first important philosophical step away from the metaphysics of causal explanation and towards the epistemology or methodology of causal explanation. But Hume made possible what has come to be known as the *Humean* view of causation, viz. the *Regularity View of Causation*. According to this, whether or not a sequence of events is causal depends on things that happen elsewhere and elsewhen in the universe, and in particular on whether or not this particular sequence instantiates a regularity.

**Hume on Induction**

In the *Treatise*, as noted already, Hume aims to discover the locus of the idea of necessary connection, which is taken to be part of the idea of causation. One of the central questions he raises is this: “Why we conclude, that such particular causes must *necessarily* have such particular effects; and what is the nature of that *inference* we draw from the one to the other, and of the *belief* we repose in it?” (1739, 78).

When it comes to the *inference* from cause to effect, Hume’s approach is captivatingly simple. We have memory of past co-occurrences of (types of) events *C* and *E*, where *C*s and *E*s have been directly perceived, or remembered to have been perceived. This co-occurrence is “a regular order of contiguity and succession” among tokens of *C* and tokens of *E* (1739, 87). So, when in a *fresh instance*, we perceive or remember a *C*, we “infer the existence” of an *E*. Although in all past instances of co-occurrence, both *C*s and *E*s “have been perceiv’d by the senses and are remember’d”, in the fresh instance, *E* is not yet perceived, but its idea is nonetheless “supply’d in conformity to our past experience” (ibid.). He then adds: “Without any further ceremony, we call the one [*C*] *cause* and the other [*E*] *effect*, and infer the existence of the one from that of the other (ibid.)”. What is important in this process of causal inference is that it reveals “a new relation betwixt cause and effect”, a relation that is different from *contiguity*, *succession* and *necessary connection*, viz., *constant conjunction*. It is this “CONSTANT CONJUNCTION” (1739, 87) that is involved in our “pronouncing” a sequence of events causal. Hume says that *contiguity* and *succession* “are not sufficient to make us pronounce any two objects to be cause and effect, unless we perceive, that these two relations are preserv’d in several instances” (ibid.). The “new relation”—constant conjunction—is a relation among sequences of events. Its content is captured by the claim: “like objects have always been plac’d in like relations of contiguity and succession” (1739, 88). So, ascriptions (“pronouncements”) of causation cannot be made of single sequences: we first need to see whether a certain sequence is part of a constant conjunction of resembling sequences.

The reason why constant conjunction is important (even though it *cannot* directly account for the idea of necessary connection by means of an impression) is that it is the *source* of the inference we make from causes to effects. Then, looking more carefully at this inference might cast some new light on what exactly is involved when we call a sequence of events causal. As he (1739, 88) put it: “Perhaps ‘twill appear in the end, that the necessary connexion depends on the inference, instead of the inference’s depending on the necessary connexion”.

Let us then take a closer look at causal inference. The inference of which Hume wants to unravel the “nature” is this: “after the discovery of the constant conjunction of any objects, we always draw an inference from one object to another” (1739, 88). This, it should be noted, is what might be called an inductive inference. If we paraphrased a bit what Hume says, we can say that its form is:

(I)

(CC): A has been constantly conjoined with be (i.e., all As so far have been followed by Bs)

(FI): a is A (a fresh instance of A)

Therefore, a is B (the fresh instance of A will be followed by a fresh instance of B).

That this inference is *inductive* is something that Hume wants to establish! In other words, his target are all those who think that this kind of inference is demonstrative. In particular, his target is all those who think that the fresh instance of A must *necessarily* be followed by a fresh instance of B.

What, he asks, determines us to draw this inference (I)? If it were Reason that determined us, then this would have to be a demonstrative inference: the conclusion would to have to follow necessarily from the premises. But then another premise would be necessary, viz., “*instances, of which we have had no experience, must resemble those, of which we have had experience, and that the course of nature continues always uniformly the same”*.

Let’s call this the Principle of Uniformity of Nature (PUN). If indeed this principle were added as an extra premise to (I), then the new inference

(PUN-I)

(CC): A has been constantly conjoined with be (i.e., all As so far have been followed by Bs)

(FI): a is A (a fresh instance of A)

(PUN): The course of nature continues always uniformly the same.

Therefore, a is B (the fresh instance of A will be followed by a fresh instance of B).

would be demonstrative and the conclusion would necessarily follow from the premises. Arguably, then the logical necessity by means of which the conclusion follows from the premises would mirror the natural necessity by means of which causes bring about the effects (a though already prevalent in Aristotle). But Hume’s point is that for (PUN-I) to be a sound argument PUN need to be provably true. There are two options here. The first is that PUN is proved itself by a demonstrative argument. But this, Hume notes, is impossible since “we can at least conceive a change in the course of nature; which sufficiently proves that such a change is not absolutely impossible” (1739, 89). Here what does the work is Hume’s principle that if we can conceive A without conceiving B, then A and B are distinct and separate objects and one cannot be inferred from the other. Hence, since the idea that past constant conjunction is *distinct* from future constant conjunction, one can conceive the former without the latter. So, *PUN* cannot be proved *a priori* by pure Reason. It is not a principle of Reason.

The other option is that PUN is proved by recourse to experience. But, Hume notes, experience (in the form of *past* constant conjunctions) is not enough to guide Reason in proving PUN. Any attempt to rest the *Principle of Uniformity of Nature* on experience would be circular. From the observation of *past* uniformities in nature, it cannot be inferred that nature is uniform, unless it is assumed what was supposed to be proved, viz., that nature *is* uniform, i.e., that there is “a resemblance betwixt those objects, of which we have had experience [i.e. past uniformities in nature] and those, of which we have had none [i.e. future uniformities in nature]” (1739, 90). In his first *Enquiry*, Hume (E, 35-6) is even more straightforward: “To endeavour, therefore the proof of this last supposition [that the future will be conformable to the past] by probable arguments, or arguments regarding existence, must evidently be going in a circle, and taking that for granted, which is the very point in question”. As he explains in his *Treatise*, “the same principle cannot be both the cause and effect of another”. PUN would be the ‘cause’ for the “presumption of resemblance” between the past and the future, but it would also be the ‘effect’ of the “presumption of resemblance” between the past and the future (where by ‘cause’ and ‘effect’ in this setting. Read ‘premise’ and ‘conclusion’).

What then is Hume’s claim? It is that (PUN-I) cannot be a demonstrative argument. Neither Reason alone, nor Reason “aided by experience” can justify PUN, which is necessary for (PUN-I) being demonstrative. Hence, causal inference—that is (I) above—is genuinely *non-demonstrative*.

Hume (1739, 91-92) summed up this point as follows: “Thus not only our reason fails us in the discovery of the *ultimate connexion* of causes and effects, but even after experience has inform’d us of their *constant conjunction*, ‘tis impossible for us to satisfy ourselves by our reason, why we shou’d extend that experience beyond those particular instances, which have fallen under our observation. We suppose, but are never able to prove, that there must be a resemblance betwixt those objects, of which we have had experience, and those which lie beyond the reach of our discovery”.

Note well Hume’s point: “we suppose but we are never able to prove” the uniformity of nature. Indeed, Hume goes on to add that there is causal inference in the form of (I), but it is not (cannot be) governed by Reason, but “by certain principles, which associate together the ideas of these objects, and unite them in the imagination” (1739, 92), that is general psychological principles of resemblance, contiguity and causation by means of which the mind works. Hume is adamant that the “supposition” of PUN “is deriv’d entirely from habit, by which we are determin’d to expect for the future the same train of objects, to which we have been accustom’d” (1739, 134).

**John Stuart Mill**

Mill took induction to be both a method of generating generalisations and a method of proving they are true. In his System of Logic (1848), he defined induction as “the operation of discovering and proving general propositions” (1911, 186). Being a nominalist he thought that “generals”—what many of his predecessors had thought of as universals—are collections of particulars “definite in kind but indefinite in number”. So induction is the operation of discovering and proving relations among members of kinds—where kinds are taken to be characterised by relations of resemblance “in certain assignable respects” among its members. The basic form of induction then is by enumeration: “ this and that A are B, therefore every A is B”. The key point behind enumerative induction is that it cannot be paraphrased as a conjunction of instances. It yields “really general propositions”, viz., a proposition such that the predicate is affirmed or denied of “an unlimited number of individuals”. Mill was ready to add that this unlimited number of individuals include actual and possible instances of a generalisation, “existing or capable of existing”. This suggests that inductive generalisations have modal or counterfactual force: if All As are B, then if a were an A it would be a B.

It is then important for Mill to show how induction acquires this force. His answer is tied with his attempt to distinguish between good and bad inductions and connects good inductions with establishing (and latching onto) laws of nature. But there is a prior question to be dealt with, viz., what is the “warrant” for induction? (1911, 201). Mill has no time for Hume, when he raises this issue. But he does take it the root of the problem of the warrant for induction is the status of the principle of uniformity of nature. This is a principle according to which “the universe, so far as known to us, is so constituted, that whatever is true in any one case, is true in all cases of a certain description; the only difficulty is, to find what description” (1911, 201).

This, he claims, is “a fundamental principle, or general axiom, of Induction” (1911, 201) and yet, it is itself an empirical principle: a generalisation itself based on induction: “this great generalisation is itself founded on prior generalisations”. If this principle were established and true, it could appear as a major premise in all inductions; hence all inductions would turn into deductions. But how can it be established? For Mill there is no other route to it than experience: “I regard it as itself [the Principle of Uniformity of Nature] a generalisation from experience” (1911, 203). Mill is not really upfront on this matter. But he does claim that the Principle of Uniformity of Nature emerges as a second-order induction over successful first-order inductions, the successes of which support each other and the general principles.

There may be different ways to unpack this claim, but it seems to me that the most congenial to his own overall strategy is to note that past successes of inductions offer compelling reasons to believe that there is uniformity in nature. In a lengthy footnote (1911, 378) in which he aimed to tackle the standard objection attributed to Reid and Stewart that experience gives us knowledge only of the past and the present but *never* of the future, he stressed: “though we have had no experience of what *is* future, we have had abundant experience of what *was* future”. Differently put, there is accumulated future-oriented evidence for uniformity in nature. Induction is not a “leap in the dark”.

Recall that in formulating the Principle of Uniformity of Nature, Mill takes it to be a principle about the “constitution” of the universe, being such that it contains regularities: “whatever is true in any one case, is true in all cases of a certain description”. But he meaningfully adds: “the only difficulty is, to find what description”, which should be taken to imply that the task of inductive logic is to find the regularities there are in the universe and that this task is not as obvious as it many sound since finding the kinds (that is the description of collections of individuals) that fall under certain regularities might is far from trivial and may require extra methods. Indeed, though Mill thinks that enumerative induction is indispensable as a form of reasoning (since true universality in space and time can be had only through it, if one starts from experience, as Mill recommends), he also thinks that various observed patterns in nature may not be as uniform as a simple operation of enumerative induction would imply. “To Europeans, not many years

ago, the proposition, All swans are white, appeared an equally unequivocal instance of uniformity in the course of nature. Further experience has proved (…) that they were mistaken; but they had to wait fifty centuries for this experience. During

that long time, mankind believed in a uniformity of the course of nature where no such uniformity really existed” (1911, 204).

The “true theory of induction” should aim to find the laws of nature. As Mill says: “every well-grounded inductive generalization is either a law of nature, or a result of laws of nature, capable, if those laws are known, of being predicted from them. And the problem of Inductive Logic may be summed up in two questions: how to ascertain the laws of nature; and how, after having ascertained them, to follow them into their results” (1911, 208). The first question—much more significant in itself—requires the introduction of new methods of induction, viz., methods of elimination

Here is the rationale behind these methods: “Before we can be at liberty to conclude that something is universally true because we have never known an instance to the contrary, we must have reason to believe that if there were in nature any instances to the contrary, we should have known of them” (1911, 204). Note the counterfactual claim behind Mill’s assertion: enumerative induction on its own (though ultimately indispensable) cannot yield the modal force required for empirical generalisations that can be deemed laws of nature. What is required are methods which would show how if there were exceptions, they could be found. These are Mill’s famous methods of agreement and difference, which Mill presents as methods of induction (cf. 1911, 276).

Suppose that we know of a factor *C* and we want to find out its effect. We vary the factors we conjoin with *C* and examine what the effects are in each case. Suppose that, in a certain experiment, we conjoin *C* with *A* and *B* and what follows is *abe*. Then, in a new experiment, we conjoin *C* not with *A* and *B* but with *D* and *F* and what follows is *dfe*. Both experiments agree only on the factor *C* and on the effect *e*. Hence the factor *C* is the cause of the effect *e*. *AB* is not the cause of *e* since the effect was present, even when *AB* was absent. Nor is *DF* the cause of *e*, since *e* was present when *DF* was absent. This is then the *Method of Agreement*. The cause is the common factor in a number of otherwise different cases in which the effect occurs. As Mill (1911, 255) put it: “If two or more instances of the phenomenon under investigation have only one circumstance in common, the circumstance in which alone all the instances agree is the cause (or effect) of the given phenomenon”. The *Method of Difference* proceeds in an analogous fashion. Suppose that we run an experiment and we find that an antecedent *ABC* has the effect *abe*. Suppose also that we run the experiment once more, this time with *AB* only as the antecedent factors. So, factor *C* is absent. If, this time, we only find the part *ab* of the effect, if that is, *e* is absent, we conclude that *C* was the cause of *e*. On the *Method of Difference*, then, the cause is the factor that is different in two cases, which are similar except that in the one the effect occurs, while in the other it doesn’t. In Mill’s (1911, 256) words: “If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance in common save one, that one occurring only in the former; the circumstance in which alone the two instances differ is the effect, or the cause, or an indispensable part of the cause, of the phenomenon”.

It’s not difficult to see that what Mill has described are cases of controlled experiments. In such cases, we find causes (or effects) by creating circumstances in which the presence (or the absence) of a factor makes the only difference to the production (or the absence) of an effect. The effect is present (or absent) if and only if a certain causal factor is present (or absent). Mill is adamant that his methods work only if certain metaphysical assumptions are already in place. *First*, it must be the case that events have causes. *Second*, it must be the case that events have a limited number of possible causes. In order for the eliminative methods he suggested to work, it must be the case that the number of causal hypotheses considered is relatively small. *Third*, it must be the case that same causes have same effects, and conversely. *Fourth*, it must be the case that the presence or absence of causes makes a difference to the presence or absence of their effects. Indeed, Mill (1911, 255) made explicit reference to two “axioms” on which his two Methods depend. The axiom for the *Method of Agreement* is this: “Whatever circumstances can be excluded, without prejudice to the phenomenon, or can be absent without its presence, is not connected with it in the way of causation. The casual circumstance being thus eliminated, if only one remains, that one is the cause we are in search of: if more than one, they either are, or contain among them, the cause [...]” (ibid.). The axiom for the *Method of Difference* is: “Whatever antecedent cannot be excluded without preventing the phenomenon, is the cause or a condition of that phenomenon: Whatever consequent can be excluded, with no other difference in the antecedent than the absence of the particular one, is the effect of that one” (1911, 256).

What is important to stress is that although only a pair of (or even just a single) carefully controlled experiment(s) might get us at the causes of certain effects, what, for Mill, makes this inference possible is that causal connections and laws of nature are embodied in regularities—and these, ultimately, rely on enumerative induction.

**V. Newtonianism, Kant and the rise of Conventionalism (Poincaré, Duhem)**

#### Newton

The real break with the Aristotelian philosophical and scientific tradition occurred with the consolidation of empiricism in the seventeenth century. Empiricists attacked the metaphysics of essences and the epistemology of rational intuition, innate ideas and infallible knowledge. Modern philosophical empiricism was shaped by the work of three important figures: Pierre Gassendi (1592-1655), Robert Boyle (1627-1691), and Sir Isaac Newton (1642-1727). Gassendi revived Epicurean atomism and stressed that all knowledge stems from experience. Boyle articulated the mechanical philosophy and engaged in active experimentation to show that the mechanical conception of nature is true. Newton’s own influence was two-fold.

On the one hand, his own scientific achievements, presented in his monumental ***Philosophiae Naturalis Principia Mathematica*** (*Mathematical Principles of Natural Philosophy*, 1687), created a new scientific paradigm. The previous paradigm, Cartesianism, was overcome. Down with it went the views that space is a plenum, that there are no atoms, that the planets are carried around by vortices, that the quantity of motion (as distinct from momentum) is conserved etc. Newton extended the mechanical view of nature by systematically using the category of *force* alongside the two traditional mechanical categories, *matter* and *motion*. Force was set in a mechanical framework in which it is measured by the *change* in the quantity of motion it could generate. But Newton insisted that his concept of force was mathematical (cf. *Principia*, Book I, Definition VIII). Mechanical interactions were enriched to include attractive and repulsive forces between particles (where again, these forces were considered not physically but mathematically). The concept *mass* was clearly defined for the first time, by being distinguished from weight. Motion and rest were united: they are relative states of a body. Space became the infinite container in which motion of corpuscles takes place. The mechanics of the earth and the heavens were united: a single, mathematically simple, law of gravity governs all phenomena in the universe.

On the other hand, Newton’s methodological reflections became the standard reference point for all subsequent discussion concerning the nature and aim of science and its method. Newton demanded certainty of knowledge but rejected the Cartesian route to it. By placing restrictions on what can be known and on what method should be followed, he thought he secured certainty in knowledge. As he explained, he used the term “hypothesis” “to signify only such a proposition as is not a phenomenon nor deduced from any phenomena, but assumed or supposed—without any experimental proof” (cf. Letters to Cotes, 1713 in Thayer, 1953, 6). And he proceeded with his famous dictum *Hypotheses non fingo* (I do not feign hypotheses), which was supposed to act as a constraint on what can be known: it rules out all those metaphysical, speculative and non-mathematical hypotheses that aim to explain, or to provide the ultimate ground of, the phenomena. As he said in the *General Scholium*, (*Principia*, Book III)

For whatever is not deduced from the phenomena is to be called a hypothesis, and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy.

Newton took Descartes to be the chief advocate of hypotheses of the sort he was keen to deny. His official suggestion for the method of science was that it is deduction from the phenomena. This was contrasted to the hypothetico-deductive method endorsed by Descartes. Newton’s approach was fundamentally mathematical-quantitative. He did not subscribe to the idea that knowledge begins with a painstaking experimental natural history of the sort suggested by Francis Bacon in his *Novum Organum* (1620). The basic laws of motion do, in a sense, stem from experience. They are not a priori true, nor metaphysically necessary. The empirically given phenomena that Newton starts with are laws (e.g. Kelper’s laws). Then, by means of mathematical reasoning and the basic axioms or laws of motion further conclusions can be drawn, e.g., that the inverse square law of gravity applies to all planets.

Undoubtedly, Newton thought that the explanation of natural phenomena consists in finding the most general principles that account for them, where this relation of ‘accounting for’ is deductive. These general principles are the fundamental laws of nature. As he stated:

Natural Philosophy consists in discovering the frame and operations of Nature, and reducing them, as far as may be, to general Rules or Laws—establishing these rules by observations and experiments, and thence deducing the causes and effects of things (…).[[12]](#footnote-12)

But his views led to considerable controversy in connection, in particular, with his account of gravity. Leibniz, for instance, denounced Newtonian gravity as being an occult quality. Indeed, as Newton himself claimed: “But hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses” (ibid.). In his second letter to Richard Bentley, he notes:

You sometimes speak of gravity as essential and inherent to matter. Pray do not ascribe that notion to me, for the cause of gravity is what I do not pretend to know and therefore would take more time to consider of it (in Thayer, 1953, 53).

Newton’s thought was that an explanation cannot be faulted on the grounds that it does not unveil the ultimate causes of the phenomena. On the contrary, since explanations must have empirical content, they must be independently testable. Consequently, the employment of general explanatory hypotheses that transcend the limits of what is observed and inductively generalised in laws is futile and has nothing to do with the mathematical principles of natural philosophy. Newton’s defence against Leibniz was that, though he had not explained the cause of gravity, he had established that gravity *is* causal (and hence that it can offer adequate causal explanations of the phenomena). As he stressed (*General Scholium*, *Principia*, Book III):

And to us it is enough that gravity does really exist and act according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies and of our sea.

And in Query 31 of *Optics*, he noted:

To tell us that every species of things is endowed with an occult specific quality by which it acts and produces manifest effects is to tell us nothing, but to derive two or three general principles of motion from the phenomena, and afterward to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered.

Consequently, it suffices for explanation to subsume the phenomena under universal laws, even if the underlying causal mechanisms are not known. In a recent piece, McMullin (2001) has claimed that Newton offered a dynamical account of explanation placed between an agent-causal account (in terms of the powers of agent to produce effects) and a simple law-based account (in terms of subsumption under a law). Though Newton did emphasise the role of laws in explanation, he also stressed that nomological explanation should be unifying: it should subsume all phenomena under a “single sort of underlying causal agency” (2001, 298)—even if, I should add, this underlying causal agency (e.g., gravity) is not further causally explainable.

#### Kant’s Awakening

It was Hume critique of necessity in nature that awoke Immanuel Kant (1724-1804) from his “dogmatic slumber”, as he famously stated. Kant thought that Hume questioned the very possibility of science and took it upon himself to show how science was possible.

Kant rejected strict empiricism (which denied the active role of the mind in understanding and representing the world of experience) and uncritical rationalism (which did acknowledge the active role of the mind but gave it an almost unlimited power to arrive at substantive knowledge of the world based only on the lights of Reason). He famously claimed that although all knowledge starts with experience it does not arise from it: it is actively shaped by the categories of the understanding and the forms of pure intuition (space and time). The mind, as it were, imposes some conceptual structure onto the world, without which no experience could be possible. There was a notorious drawback, however. Kant thought there could be no knowledge of things as they were in themselves (*noumena*) and only knowledge of things as they appeared to us (*phenomena*). This odd combination, Kant thought, might well be an inevitable price one has to pay in order to defeat empiricist scepticism and to forgo traditional idealism. Be that as it may, his master thought was that some synthetic a priori principles should be in place for experience to be possible. And not just that! These synthetic a priori principles (e.g., that space is Euclidean, that every event has a cause, that nature is law-governed, that substance is conserved, the laws of arithmetic) were necessary for the very possibility of science and of Newtonian mechanics in particular. If we were to sum up, somewhat sketchily, Kant’s conception of a priori knowledge, this would be helpful: it is knowledge

a. universal, necessary and certain;

b. whose content is formal: it establishes conceptual connections (if analytic); it captures the form of pure intuition (if synthetic);

c. constitutive of the form experience;

d. disconnected from the content of experience; hence, unrevisable.

Like Hume before him, Kant does not claim that reason alone can discover, in a *a priori* manner, the connection between any specific cause and any specific effect, nor understand its necessity (cf. 1787, A195; B240-41). Kant and Hume both insist that particular causal connections can be discovered only empirically. But unlike Hume, Kant *denies* that the concept of causation arises from experience and in particular that it arises in the same way as the knowledge of the causes of particular events. In his *Second Analogy of Experience*, Kant tried to demonstrate that the principle of causation, viz., “everything that happens, that is, begins to be, presupposes something upon which it follows by rule”, is a precondition for the very possibility of objective experience. He took the principle of causation to be required for the mind to make sense of the temporal irreversibility that there is in certain sequences of impressions. Whereas we can have the sequence of impressions that correspond to the sides of a house in any order we please (e.g., by going around the house clockwise or anti-clockwise), the sequence of impressions that correspond to a ship going downstream cannot be reversed: it exhibits a certain temporal order (or direction). This temporal *order* by which certain impressions appear can be taken to constitute an objective happening *only if* the later event is taken to be necessarily determined by the earlier one (i.e., to follow by rule from its cause). For Kant, objective events are not ‘given’: they are constituted by the organising activity of the mind and in particular by the imposition of the principle of causation on the phenomena. Consequently, the principle of causation is, for Kant, a synthetic a priori principle.

Ingenious though Kant’s answer to Hume was, it was ironic in three respects. Firstly, Kant safeguarded the concept of causation but at the price of making it applicable only to the *phenomena* and not to the unknowable things-in-themselves (*noumena*). Secondly, recall that Hume argued that the supposed necessity of causal sequences cannot be observed in the sequences themselves, but is projected by the mind onto the world. Kant agreed with all this, but took this projection by the mind onto the world to be presupposed for the distinction between causal and non-causal sequences. Thirdly, Kant identified causation with the rule of natural law: causal sequences of events are lawful sequences of events. This became the main plank of the *Humean* philosophical tradition. Stripped from objective necessity, natural laws boil down to worldly regularities.

In *Metaphysical Foundations of Natural Science* (1786), Kant claimed that

Only that whose certainty is apodeictic can be called science proper; cognition that can contain merely empirical certainty is only improperly called science.

Besides, natural science proper relies on laws that are known a priori and hold with necessity (they are not merely laws of experience). Kant thought all natural science should derive its legitimacy from its pure part, that is the part that contains “the a priori principles of all remaining natural explications”. He took as his task to show that these a priori principles of pure natural science are certain and necessary for the very possibility of science and experience. This, he thought, was the task of the metaphysics of nature. Unlike Newton, Kant thought that there could not be proper science without metaphysics. Yet, his own understanding of metaphysics was in sharp contrast with that of his predecessors (Leibniz in particular). Metaphysics, Kant thought, was a science, and in particular *the science of synthetic a priori judgements*. Mathematics was taken to be the key element in the construction of natural science proper: without mathematics no doctrine concerning determinate natural things was possible. On these grounds, he argued that the chemistry of his age, in its pre-Lavoisier state, was more of an art than a science. The irony, Kant thought, was that though many great past thinkers (and Newton in particular) repudiated metaphysics and had relied on mathematics in order to understand nature, they failed to see that this very reliance on mathematics made them unable to dispense with metaphysics. For, in the end, they had to treat matter in abstraction from any particular experiences. They postulated universal laws without inquiring into their a priori sources.

As Kant argued in *Critique of Pure Reason* (1781), the a priori source of the universal laws of nature was the transcendental principles of pure understanding. These constitute the object of knowledge in general. Thought (that is, the understanding) imposes upon objects in general certain characteristics in virtue of which objects become knowable. The phenomenal objects are constituted as objects of experience by the schematised categories of quantity, quality, substance, causation and community. If an object is to be an object of experience, it must have certain necessary characteristics: it must be extended; its qualities must admit of degrees; it must be a substance in causal interaction with other substances. In his three Analogies of Experience, Kant tried to prove that three general principles hold for all objects of experience: that substance is permanent; that all changes take place in conformity with the law of cause and effect; that all substances are in thoroughgoing interaction. These are synthetic a priori principles that make experience possible. They are imposed a priori by the mind on objects.

Yet, these transcendental principles make no reference to any experienceable objects in particular. It was then Kant’s aim in *Metaphysical Foundations of Natural Science* to show how these principles could be concretised in the form of laws of matter in motion. These were metaphysical laws in that they determined the possible behaviour of matter in accordance with mathematical rules. Kant thus enunciated the law of conservation of the quantity of matter, the law inertia and the law of equality of action and reaction and thought that these laws were the mechanical analogues (cases *in concreto*) of his general transcendental principles. They determine the pure and formal structure of motion, where motion is treated purely mathematically *in abstracto*. It is no accident, of course, that the last two of these laws are akin to Newton’s law and that the first law was presupposed by Newton too. Kant’s metaphysical foundations of (the possibility of) matter in motion was precisely meant to show how Newtonian mechanics was possible. But Kant also thought that there are physical laws that are discovered empirically. Though he held as a priori true that matter and motion arise out of repulsive and attractive forces, he claimed that the particular force-laws, even the law of universal attraction as the cause of gravity, can only be discovered empirically.

His predecessors, Kant thought, had failed to see this hierarchy of laws that make natural science possible: transcendental laws that determine the object of possible experience in general; metaphysical laws that determine matter in general and physical laws that fill in the actual concrete details of motion. Unlike the third kind, the first two kinds of law require a priori justification and they are necessarily true.

Overall, then, Kant was mostly concerned with the metaphysical foundations of causal explanation, viz., that causal explanation presupposes necessary connections. Given that causation is nomological, Kant’s thought amounted to the claim that all causal explanation is nomological explanation. But, especially towards the end of *Critique*, he highlighted another important dimension of explanation, viz., unification. He claimed it to be a “regulative idea” that nature is unified and uniform. He took it that reason aims to systematise its body of knowledge, that is “to exhibit the connection of its parts in conformity with a single principle” (A645/B673). It is this systematic unity of knowledge that shifts it from being “a mere contingent aggregate” to being “a system connected according to necessary laws”. This “systematic unity of knowledge” is “*the criterion of the truth* of its rules” (A647/675). As an example of this, he offered the subsumption of more specific (causal) powers under more fundamental powers. This subsumption, he thought, “claims to have an objective reality, as postulating the systematic unity of the various powers of a substance (…) (A650/B678). This, to be sure, is a regulative idea (an idea of Reason) and not a principle constitutive of experience. Still, as he put it:

In all such cases reason presupposes the systematic unity of the various powers, on the ground that special natural laws fall under more general laws, and that parsimony in principles is not only an economical requirement of reason, but is one of nature’s own laws (A650/B678).

By calling “regulative” the idea that nature has an objectively valid and necessary systematic unity (cf. A651/B679), he wanted to stress that it is indemonstrable. Yet, without it, Kant thought, there would be no criterion of empirical truth. Besides, it can be confirmed in view of their empirical success in science. As he stressed:

(I)t is evident that the laws contemplate the parsimony of fundamental causes, the manifoldness of effects, and the consequent affinity of the parts of nature as being in themselves in accordance both with reason and with nature. Hence these principles carry their recommendation directly in themselves, and not merely as methodological devices (A661/B689).

Unification of all phenomena under universal laws of nature, then, emerges both as the ultimate goal of the explanation of natural phenonema and as the criterion for truth. Besides, as Philip Kitcher (1986) has noted, unification confers necessity on certain principles, thereby rendering laws of nature.

Though philosophically impeccable, Kant’s architectonic suffered severe blows in the nineteenth and the early twentieth centuries. The blows came, by and large, by science itself. The crisis of the Newtonian mechanics and the emergence of the special and the general theories of relativity, the emergence of non-Euclidean geometries and their application to physics, Gottlob Frege’s (1848-1925) claim that arithmetic, far from being synthetic a priori, was a body of analytic truths and David Hilbert’s (1862-1943) arithmetisation of geometry which proved that no intuition was necessary created an explosive mixture that, in the end of a long process, led to the collapse of the Kantian synthetic a priori principles.

# Conventionalism

The inductivist tradition that was dominant in England in the nineteenth century was challenged by the rise of the French conventionalism. Henri Poincaré’s (1854-1912) work on the foundations of geometry raised the following question: is physical space Euclidean? In *La Science et l'Hypothese* (*Science and Hypothesis*, 1902), Poincaré took this question to be meaningless, because, he suggested, one can make physical space possess *any* geometry one likes, provided that one makes suitable adjustments to one’s physical theories.

To show this, Poincaré (1902) told vividly the story of a possible world in which the underlying geometry is indeed Euclidean but, due to the existence of a strange physics, all attempts to find out empirically the geometry of this world would lead its inhabitants to assume that the geometry is non-Euclidean. This world is the interior of a sphere *S*. Viewing this world from “the outside”, we can easily infer that its geometry is Euclidean. Things are not so simple for the locals, however. For, unbeknownst to them, there is a medium permeating *S* such that the temperature at each point is variable, being a function of the distance of each point from the centre of the sphere. In particular, the temperature at each point is *R2-r2*, where *R* is the radius of the sphere and *r* is the distance of the point from the centre. The freely-moving inhabitants of this world cannot notice any difference because the laws of physics ensure that, wherever they move, thermal equilibrium is immediately restored. But the laws of physics also ensure that all bodies, including measuring rods, contract uniformly as they move away from the centre of *S* and towards the periphery.

Imagine that the inhabitants of *S* try to determine the geometry of their world. They will soon find out that they live in a Lobatchevskian world of infinite extent. One of their relevant empirical findings will be that they can draw an infinite number of ‘parallel’ lines from a point outside any given line. The only operational procedure at their disposal will be enough to persuade them of this: they extend the lines indefinitely and they never meet. So, they will find irresistible the conclusion that their world is Lobatchevskian. Yet, an eccentric mathematician of *S* suggests to his fellow scientists that the geometry of *S* is really Euclidean but that, due to a universal force (the temperature field) which makes everything contract as it moves, the geometry appears to be non-Euclidean. Now, the inhabitants of *S* are faced with two empirically equivalent alternatives. How are they to choose between them? Poincaré says that whatever their choice be, it is not dictated by their empirical findings. The latter can be written into any of the two geometrical languages, with suitable adjustments in the relevant physics.

Consequently, Poincaré called the axioms of Euclidean geometry “conventions” (or definitions-in-disguise). However, in his address to the 1900 Paris International Congress of Philosophy, he extended his geometrical conventionalism further by arguing that the principles of mechanics are also conventions (cf. 1901, 556-557). His starting point is that the principles of mechanics are not synthetic a priori truths since they cannot be demonstrated independently of experience. For instance, one can conceive of worlds in which Newton’s first law would not hold. Nor is it the case, however, that the principles of mechanics are generalisations of experimental facts. The systems to which these principles apply, such as perfectly isolated systems, are not to be found in nature. Besides, no experience can conclusively confirm, nor even falsify, a mechanical principle. Poincaré offers two reasons. First, since the principles of mechanics apply to systems not encountered in experience, they can never be submitted to a rigorous and decisive test. Second, even if a mechanical principle could be submitted to a rigorous test, it could always be saved from refutation by some sort of corrective move.

Poincaréan conventions are general principles which are held true, but whose truth can neither be the product of a priori reasoning nor can be established on a posteriori grounds. But calling them ‘conventions’ did not imply, for Poincaré, that their adoption (or choice) was arbitrary. He repeatedly stressed that some principles were more convenient than others. He thought that considerations of simplicity and unity, as well as certain experiential facts, could and should ‘guide’ the relevant choice. Indeed, he envisaged a certain hierarchy of the sciences, according to which the very possibility of empirical and testable physical science requires that there are in place (as, in the end, freely chosen conventions) the axioms of Euclidean geometry and the principles of Newtonian mechanics.

Though Poincaré took scientific theories to be mixtures of conventions and facts, he favoured a, Kantian in origin, structuralist account of scientific knowledge. He took mathematics to offer a framework in which the empirical findings of science were embedded and organised. Though he took the basic axioms of geometry and mechanics to be (ultimately, freely chosen) conventions, he nonetheless thought that scientific hypotheses proper, even high-level ones such as Maxwell’s laws, were empirical. Faced with the problem of discontinuity in theory-change (the fact that some basic scientific hypotheses and law-statements have been abandoned in the transition from one theory to another), he argued that there is, nonetheless, some substantial continuity at the level of the mathematical equations that represent empirical as well as theoretical relations. From this, he concluded that these retained mathematical equations—together with the retained empirical content—fully capture the objective content of scientific theories. By and large, he thought, the theoretical content of scientific theories is structural: if successful, a theory represents correctly the *structure* of the world. In the end, the structure of the world is revealed by structurally-convergent scientific theories.

**VI. Revolutions in science and maths, neo-Kantianism and synthetic a priori knowledge**

A hundred years after the death of Kant, a major crisis swept across the reigning Newtonian physics. Classical mechanics, which had been seen as the ultimate foundation of all physics, crumbled. Two kinds of pressure were exerted on it.

The *first* came from Einstein’s Special Theory of Relativity in 1905. Drawing on important considerations of symmetry, Albert Einstein (1879-1955) suggested that understanding the electrodynamics of moving bodies requires a radical departure from classical mechanics. Where classical mechanics, and its extension to the electrodynamics of moving bodies by Hendrik Antoon Lorentz (1853-1928), had relied on the existence of absolute space and time, Einstein showed that no such commitment was necessary. Indeed, by taking the concept of simultaneity to be relative to a frame of reference, based on the postulate that the speed of light is constant and identical to all reference frames, he showed that there was no such thing as *the* time in which an event happened. And, by postulating that laws of nature must remain invariant in all inertial frames, he showed that there was no need to posit an absolute frame of reference, typically associated with the absolute space (and the aether). In the able hands of the mathematician Hermann Minkowski (1864-1909), space and time where united in a four-dimensional spacetime framework. He also suggested that Einstein’s theory could be best understood in a non-Euclidean space. In 1915, Einstein advanced his General Theory of Relativity, according to which the laws of nature are the same in *all* frame of reference. This was captured by the Principle of Equivalence: a reference frame falling freely in a gravitational field is indistinguishable from an inertial frame.

The *second* kind of pressure came from Planck’s quantum of action in 1900. He showed that the explanation of a number of phenomena which were within the explanatory purview of classical mechanics, such as the black body radiation, required admitting a radical discontinuity: energy comes in fundamental quanta. In 1905, Einstein used Planck’s idea to explain the photoelectric effect, suggesting that light radiation comes in quantised photons, while many other physicists employed it to develop an alternative to classical mechanics, known as (old) quantum theory. Its culmination came in 1913, where Neils Bohr (1865-1962) explained the structure and the stability of atoms, based on the thought that electrons orbit the nucleus in discrete orbits. By the 1920s, Newtonian mechanics had given its place to Quantum Mechanics and the General Theory of Relativity.

It had been already known, from the work of Nikolai Ivanovich Lobachevsky (1792-1856), János Bolyai (1802-1860) and Bernhard Riemann (1826-1866) in the nineteenth century, that there could be consistent *geometrical* systems which represented non-Euclidean geometries. Euclid’s fifth postulate, that from a point outside a line exactly one line parallel to this can be drawn, can be denied in two ways. Lobachevsky and Bolyai developed a geometry which assumed that an infinite number of lines could be drawn, and this (hyperbolic) geometry was shown to be consistent. Riemann developed a (spherical) geometry which assumed that no parallel lines could be drawn, and, here again, this geometry was proved consistent. These non-Euclidean geometries were originally admitted as interesting mathematical systems. The Kantian thought that the geometry of physical space had to be Euclidean was taken as unassailable. Yet, Einstein’s General Theory suggested that this Kantian thought was an illusion. Far from being flat, as Euclidean geometry required, space—that is *physical* space—is curved. Actually, it’s a space with variable curvatute, the latter depending on the distribution of mass in the universe. This was a far-reaching result. All three geometries (Euclidean, Lobachevkyan and Riemannian) posited spaces of constant curvature: zero, negative and positive respectively. They all relied on a fundamental axiom: the Helmholtz-Lie axiom of free mobility, which, in effect, assumes that space is homogeneous. Einstein’s General Theory called this axiom into question: objects in spacetime move along geodesics whose curvature is variable.

A key Kantian thought that came under pressure was that space and time were the a priori forms of pure intuition. Kant thought that arithmetic relied essentially on temporal intuition (the possibility of iteration in time) and that geometry relied essentially on spatial intuition (in the sense that a geometrical proof required a schematic demonstration in space). Accordingly, he thought that both arithmetic and geometry were bodies of synthetic a priori knowledge. In *The Foundations of Arithmetic* (1884), Gottlob Frege (1848-1925) challenged the Kantian thought in relation to *arithmetic*. He suggested that arithmetical truths are analytic: they are provable on the basis of general logical laws plus definitions. No intuition was necessary for establishing, and getting to know, arithmetical truths: rigorous deductive proof was enough. Arithmetic, to be sure, was still taken to embody a corpus of a priori truths. But being, in effect, logical truths, they make no empirical claims whatsoever. Frege, however, agreed with Kant that geometrical truths were synthetic a priori: they were a priori because their proof depended only on general laws which needed no, and admitted of no, proof, but they were synthetic because the required general laws (the axioms of geometry) were *not* logical truths. Frege went on to advance a hierarchical view of knowledge. At the top stand the truths of logic and arithmetic. They are *analytic a priori* truths and have universal scope of applicability. Then, there are the truths of geometry. These are *synthetic a priori truths* in that spatial intuition is required for their knowledge while their scope is not universal, since they apply only to whatever is in space. Finally, at the bottom as it were, stand the truths of empirical sciences. They are synthetic a posteriori truths: knowing them requires empirical investigation and they apply only to whatever is empirically given.

It was David Hilbert (1862-1943) in *The* *Foundations of Geometry* (1899) who excised all intuition from geometry. He advanced an axiomatisation of geometry and showed that the proof of geometrical theorems could be achieved by strictly logical-deductive means, without *any* appeal to intuition. Hilbert’s result was far-reaching because, among other things, it made available the idea of an *implicit definition*. A set of axioms implicitly defines its basic concepts in the sense that it specifies their interpretation collectively: any system of entities that satisfies the axioms is characterised by these axioms. There is no need to have an ‘independent’ or intuitive grasp of the meanings of terms such as ‘point’, ‘line’, or ‘plane’: their meaning is fully specified collectively by the relevant axioms.

These developments in physics and mathematics, mixed up with the dominant Kantian tradition, created an explosive philosophical brew. The inherent instability of the Kantian synthetic a priori principles became evident. Principles that were neatly and permanently classified in light of the three Kantian categories (analytic a priori; synthetic a priori; synthetic a posteriori) started to move about. In particular, the category of synthetic a priori truths was being drained away. The crisis in the sciences made possible the claim that the basic principles of classical mechanics and of Euclidean geometry were not a priori since they were revis*able* (since they were revis*ed*). And the crisis in arithmetic suggested that arithmetical truths, alongside the logical ones, were analytic. It wouldn’t be an exaggeration to claim that much of philosophy of science in the first half of the twentieth century was an attempt to come to terms with the apparent collapse of the Kantian synthetic a priori and to re-cast (even cast to the wind) the concepts of a priority and analyticity in such a way that justice is done to the developments in the sciences. Here is how Hans Reichenbach (1891-1953) described the key item of the philosophical agenda, in relation to the theory of relativity: “(…) there are two possibilities: either the theory of relativity is false, or Kant’s philosophy needs to be modified in those parts which contradict Einstein. (…) The first possibility appears to be very doubtful (…) (1921, 4).

# The Rise of Atomism

The beginning of the twentieth century was marked by a heated debate over an emergent scientific theory, atomism. Atomism posited the existence of unobservable entities—the atoms—to account for a host of observable phenomena (from chemical bonding to Brownian motion). Though many scientists, including Max Planck (1858-1947) and Ludwig Boltzmann (1844-1906), adopted atomism rightaway, there was some strong resistance to it by other eminent scientists. Ernst Mach (1838-1916) resisted atomism on the basis of the concept-empiricist claim that the very concept of ‘atom’ was problematic because it was radically different from ordinary empirical concepts. Poincaré was initially very sceptical of the atomic hypothesis, but towards the end of his life came to accept it based on the results of the French physicist Jean Perrin (1870-1942). In his renowned book *Les Atomes* (1913), Perrin summarised his experimental work and the evidence for the reality of molecules and atoms. He cited thirteen distinct ways to calculate the precise value of Avogadro’s number, that is the number of molecules contained in a mole of a gas. This spectacular developments suggested to Poincaré a rather irresistible argument in favour of the reality of atoms: we can calculate how many they are, therefore they exist. Yet, resistance still persisted and was best exemplified in the writings of Pierre Duhem. In *La théorie physique, son objet, sa structure* (*The aim and structure of physical theory*, 1906), he put forward an anti-explanationist form of instrumentalism which rested on a sharp distinction between science and metaphysics and claimed that explanation belongs to metaphysics and not to science.

Science, for Duhem, is only concerned with experience, and as such it “is not an explanation. It is a system of *mathematical propositions deduced from a small number of principles, which aim to represent as simply as completely and as exactly as possible a set of experimental laws*” (1906, 19). The ‘autonomy’ of physics, as he put it, rests precisely on the fact that physics does not aim to explain the phenomena, nor to describe the reality ‘beneath’ them. It only aims to embed descriptions of the phenomena in a unified and comprehensive mathematical framework. But Duhem’s theory of science rested on a very restricted understanding of scientific method, which can be captured by the slogan: scientific method=experience + logic. On this view, whatever cannot be proved from experience with the help of logic is irredeemably suspect. To be sure, theories, qua hypothetico-deductive systems, help scientists classify and organise the observable phenomena. But, for Duhem, the theoretical hypotheses of theories can never be confirmed or accepted as true: at best, they can be appraised as convenient or inconvenient empirically adequate classifications of the phenomena. The irony is that Duhem himself offered some of the best arguments against the instrumentalist conception of view of theories. The most central one comes from the possibility of *novel* predictions: if a theory were just a “rack filled with tools”, it would be hard to understand how it can be “a prophet for us” (1906, 27).

Duhem was a strong critic of inductivism. He famously argued that observation in science is not just the act of reporting a phenomenon (whatever that means!). It is the interpretation of a phenomenon in the light of some theory and other background knowledge. Strictly speaking, a phenomenon is an already interpreted regularity (or event). This thesis, known as the theory-ladeness of observation, was resurfaced in the 1960s, this time drawing on a mass of empirical evidence coming from psychology to the effect that perceptual experience is theoretically interpreted. Duhem also stressed that there could not be crucial experiments in science, since no theory could be tested in isolation from other theories (and several auxiliary assumptions) and consequently, any theory could be saved from refutation by making suitable adjustments to collateral theories or auxiliary assumptions.

**The rise of Logical Positivism**

Poincaré’s and Duhem’s views, as well as the emergence of the new logic of Frege and Russell, Hilbert’s conception of implicit definitions, and Ludwig Wittgenstein’s theory of meaning, set the logico-philosophical background for the work of the school of Logical Positivism, in Vienna in the 1920s. The consolidation of modern physics lent credence to the view that a priori principles can be revised; hence, a new conception of *relativised* a priori emerged. The linguistic turn in philosophy (especially in Russell’s Britain) re-oriented the subject-matter of philosophical thinking about science to the *language* of science. The Logical Positivists took to heart Kant’s view that some principles (which, in the end, are the free creations of the mind) were necessary for experience. But they took them to be analytic truths: they are necessary for experience because they specify the formal structure of the meanings of concepts we use. In the 1930s, philosophy of science became the logic of science; it became synonymous to anti-psychologism, anti-historicism and anti-naturalism. At the same time, philosophy of science, in Vienna and elsewhere, was completing the project of the Enlightenment: the safeguarding of the objectivity and epistemic authority of science.

1. As Galen reports in his *An Outline of Empiricism*, experience does not always yield what we would now call universal generalisations. Rather, experience is “knowledge of those things which have become apparent so often that they already can be formulated as theorems, i.e., when it is known that they always have turned out his way, or only for the most part, or half of the time, or rarely” (OE, 2; 46). [↑](#footnote-ref-1)
2. Epilogism is “a logos which they all employ, and concerning which there is complete unanimity, and which refers to visible things alone” (Galen ME, 24;135). [↑](#footnote-ref-2)
3. Here is Sextus’s (M*,* 8;219-20) example: “in the case of fever patients, flushing and prominence of the vessels and a moist skin and increased temperature and quickening of the pulse and all the other signs of the same thing ... nor do they appear alike to all; but to Herophilus, for example, they seem to be definite signs of good blood, to Erasistratus of the transference of the blood from the veins to the arteries, and to Asclepiades of the lodgement of theoretical particles in the theoretical interstices”. [↑](#footnote-ref-3)
4. As Galen puts it, “the Dogmatists base their arguments on certain premises, and then they assert that these premises point to other things outside of themselves” (ME, 12;107) [↑](#footnote-ref-4)
5. More specifically, repetition is never exact; similarity is always a matter of respects; causes are always complex and perhaps with superfluous conditions. Hence, they claimed, Reason should be the source of the categorisation of experience. [↑](#footnote-ref-5)
6. The typical dogmatist argument was this. One instance of an A being B is not enough for the claim that All As are B. Suppose that n instances are enough. Suppose further that you have seen n-1 instances and you are about to see the nth. Then, in moving from the n-1th instance to the nth, one instance is enough for the general claim All As are B. This is a contradiction! The empiricists replied to this by an appeal to vagueness and by arguing that if the former argument would be valid there would be no nations, no armies, co cities etc. [↑](#footnote-ref-6)
7. Sextus asked: “if reasoning is such a deceiver that it all but snatches even what is apparent from under our very eyes, surely we should keep watch on it in non-evident matters, to avoid being led into rashness by following it?” (PH I, 20). [↑](#footnote-ref-7)
8. Sextus himself (PH Ι, 236) noted that insofar as empiricism asserts the incomprehensibility (*ακαταληψία*) of non-evident things, it becomes itself committed to a negative dogmatism and is not aligned with scepticism, which invited the suspension of judgement about the non-evident things. [↑](#footnote-ref-8)
9. Sextus says: “Further, some existing things are evident, others non-evident, as they [the Dogmatists] themselves say, and what is apparent is a signifier while what is non-evident is signified by something apparent (for according to them ‘the apparent is the way to see the non-evident’). But signifier and signified are relative. Everything, therefore, is relative (PH I, 139)”. [↑](#footnote-ref-9)
10. Galen, to be sure, allowed for the possibility of necessary connections in nature, but he also insisted that some claims which are taken to be necessary are, in fact, only contingent. [↑](#footnote-ref-10)
11. In aphorism 95, he likened the empiricists to ants which accumulate food and the dogmatists to spiders, which spin out their own web. His own view—the *via media*—was likened to bees, which extract pollen from the flowers, but transform it into honey. For Bacon, experience, in the form of natural history and memory, should work in tandem with the theoretical dimension of reason to find out the invisible causes of the phenomena. [↑](#footnote-ref-11)
12. Quoted by Richard Westfall, *Never at Rest* (Cambridge: Cambridge University Press, 1980, 632). [↑](#footnote-ref-12)