The Scientific Revolution

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Was there a scientific revolution of the 17th century? The standard narrative starts with Copernicus, then goes through with Kepler, Galileo and culminates with Newton whose mathematical theory of gravitation heralded the Enlightenment, for which he became the shining beacon and icon and provided the impossible ideal all science should strive for. This story is masterly, if tendentiously, told by Koestler in his 'Sleepwalkers'. It certainly has romantic appeal as it celebrates the outstanding men of geniuses breaking through prejudice and ignorance with revolutionary insights internally driven. But the author is a sociologist, or at least presents a sociological view point and is as such more concerned with the society at large, which encouraged or at least facilitated scientific endeavors, than with individuals. Now to explain science from a sociological perspective is to provoke suspicions, not to say fears, of post-modernistic reductionism, reducing truth to a mere social construct, and Western science as only one possible alternatives among many and whose predominance is due to endowed power rather than intrinsic merits. But such fears are mislaid. Just to place science and scientific ambitions in a social context, does not necessarily explain it as much as describing it. Popper famously claimed that science itself is a social undertaking and cannot be pursued by an individual in isolation, because it thrives on criticism and such is only possible in a social setting. And then it could very well be the fact that sociology is more transparent than psychology, and that it is more accessible to the inquiring mind and hence a more fruitful avenue of exploration than the opaque recesses of the individual human mind[1].

First there is no real opposition between religion and science contrary to the vulgar view, in which science breaks through the veil encompassing superstition and falsehood. Organized religion was if anything hostile to superstition and considered the belief in it heresy, because it rivaled the teaching of the Church as well as the miracles it upheld[2]. Catholicism not only incorporated many Pagan practices, including that of idolatry (of the Virgin Mary among others); but also much of Greek Pagan philosophy. Aristotle became the preferred philosopher and his abstract ideas about God became the orthodoxy in abstract Catholic theology as elaborated on by the much maligned scholastic philosophers, driven by an ambition of rationally underpinning faith. Aristotelian philosophy came under attack at the advent of the 17th century, not because it supported religious belief, but its ways of reasoning imbued the material world with animism and purposeful motives, such as theological explanations, and in that way undermined the exclusivity of the

[1] Popper also claims that sociology is a prerequisite for psychology rather than the other way around, because our identities are shaped by our interactions with other humans, and human psychology is just a further development of proto-human ones.

[2] One may on the other hand recall that any creed is jealous of its rivals and needs to exterminate them. Thus somewhat cynically, there should only exist one superstition.

spirituality of religion, focused on the special relationship between God and Man. What came instead was mechanical explanations, involving mindless matter in intricate but yet intelligible relationships with each other. A logical argument and a piece of machinery has much in common, in fact they are almost indistinguishable, except that things are more solid than mere thoughts, meaning more consistent and less liable to error. Machinery is admittedly not natural but artificial, and there is a deep distrust still noticeable to this day of the man-made and artificial as opposed to the natural. The great leap forward was to overcome this distinction and thus to be able to think of nature as a machine and hence make it intelligible. The fact that it was intelligible did not make it less natural or less divine, because behind every machine there is a design and hence a designer, a creator. There is no conflict between rational thought and faith, at least that was what the scholastic philosophers thought, and so while the scriptures were filled with contradictions and confusion, nature promised, when seen as a machine, to offer clarity and coherence by virtue of it being intelligible. Thus to understand God it was better to do away with the specious authority of the written word and instead read the Book of Nature as a much more reliable route to understanding God. This is what lies behind Francis Bacon's exhortation to observe and read nature, where truth was manifest and easy to understand, given a fresh unprejudiced outlook. Descartes too, the most consistent of all the mechanically minded philosophers wanted to do away with all the learned rubbish he had been taught and start afresh from first principles, to which one was guided by systematic doubt relentlessly pursued. Thus this scientific awakening was not a rejection of God but a revived affirmation. And Descartes having come to the end of all his doubts, exclaimed in French and not Latin 'je pense, donc je suis', from which he first at all derived the existence of God.

Men were not stupid back then, in fact one suspects that they actually were smarter, and the arguments they brought forward were ingenuous, as were the counterarguments. But while traditionally debate had been rhetorical, the new modern men of science, as we can denote them retrospectively, abhorred purely verbal contests as leading nowhere, they preferred things to words doing away with medieval disputations. But how to be certain of truth, how to be able to read the book of nature correctly? Who would be the ultimate judge of veracity? The Church had fulfilled that function in the past and for that it was important that it was monolithic and spoke with one voice, after all there is but one truth. Matters of truth and faith hence were decided on by congresses (so called councils(, in what seems to have been a rather democratic way. Dissent could thus be tolerated provisionally, but when all was said and done, you had to stick to your decisions, right or wrong. There is nothing particular dogmatic about that, as any functioning power has to be unified and make a clear stand between right and wrong. The clue to the establishing the right and wrong of science lay in putting down a right method. If following the rules of a method, truth would be revealed, thus both Bacon and Descartes put great store in developing a method. Then of course this begs the question of what is a right method. Is there any method to find the right method, and so on?

Descartes was committed to finding mechanical explanations, while Newton transcended the purely mechanical point of view by asserting the inverse square law of mutual gravitational attraction without in any way trying to explain it. It was just so, and out of this mathematical axiom he could deduce physical consequences, which turned out to be in beautiful accordance with observed facts. He did not in any way prove that the gravitational laws where universal, as is often claimed, as little as Copernicus proved that the Earth moved around the Sun, after all how can such things be proved; what he did, as did Copernicus, was to show that following from this simple principle, consequences emerged by deductive necessity, which accorded with what is, i.e. with empirical observations. If you try to understand gravitation by proposing mechanical models for it, chances are that those will run into problems and just result in confusion. But if you just shut down this urge and compute, everything will work out beautifully, just as in the case of quantum mechanics, where every attempt to make it intelligible has failed so far, but if you just calculate, you will be happy.

Now if we return to Bacon's dictum about reading the Book of Nature with open eyes, rather than to trust to the spurious authority of human scripts, what does it all mean really? What new authority will enter? In fact whatever it must be, must be the human reliance upon sense data. What is before your eyes cannot be doubted. This is, the author notes, the basis for the empirical tradition in British philosophy, or more to the point, the empiricism of the modern scientific practice. But this simple attitude soon runs into problems. Can we really trust our senses and in how wide a field can they be applied? When Galileo asked people to look into his telescope to see the craters of the Moon, as well as the satellites of Jupiter, some people refused to do so. This instrument, may actually distort the testimony of the sight, they argued. True, when directed at terrestrial objects, well-known to each and sundry, they could check that it merely enlarged the image, and that the image did correspond to what was the case, as independent ocular inspection could confirm. But when directed to the heavens, there were no such confirmation to be had. True, against relentless skepticism there is no argument, the skeptic will always have the last word. But it did point to a necessary development, unaided senses could not penetrate far enough, many things were just too small or too faint to be visible to the naked eye, instruments had to come into play and mediate. In fact nowadays we may make a direct ocular inspection of a meter or a digital display, but what guarantees do we have that those readings and displays are relevant at all? In the long run modern science would divorce itself more and more from common sense and make it impossible for laymen to confirm their claims by direct observations, they simply had to take the word for it. And of course this is how people in the modern age typically look upon science as something that has to taken on trust, on the premise that scientists are honest and that they are trained in something referred to as the scientific method, by which they get access to truth. Of course such a state of affairs did not happen overnight but as a result of a long process. And of course something like the inverse square law of gravitation cannot be seen, as little by scientists themselves as the lay public, their confirmation has to be achieved indirectly, mediated by processes, such as sophisticated mathematical deductions, incomprehensible to most people. When all is said and done, it is the applications of science that eventually earns it authority and legitimacy among the lay public, and such did not exist at the time of the so called Scientific revolution, but needed centuries to trickle down to the masses. Thus one needs to distinguish between the understanding of a thin elite and that of people in general. In the phrase 'we now know' who is 'we' and what is it really what we 'know'.

The process that makes science diffuse properly, is one of a legitimate sociological concern.

The real revolution that occurred was the shift from uncritical admiration of the achievements of the Old Greeks to the realization that those masters of the past could be improved on. A shift which may be attributed as a result of the Renaissance, which initially meant a rediscovery of the Classical Greek culture with a growing concomitant admiration of it, to eventually be replaced by a gradually acquired confidence to criticize it. Now the vulgar view is that Modern Science differed from the Classical Greek one by actually testing and observing, not being satisfied with only speculating and taking the word of previous speculation. Instead one was expected to see with your own eyes, an idea which if pursued leads to difficulties, but nevertheless serves as a fruitful attitude. Now the Greek also did observe, and as many philosophers of science has pointed out, many pf the claims of people like Galileo and Newton was not amenable to direct testing, such as that a body on which no forces act, may not only be at rest but follows a straight path with a fixed velocity, something which is of course both counter-intuitive and not possible to observe[3]. Yet one may with some confidence assert that regular experiments was something new, and that the Greeks had not really engaged in it, although historical claims are hard to verify, and as is often repeated: Absence of evidence is not the same as evidence of absence. Anyway regular experiments were experienced as something new, and not altogether unproblematic, because it involved putting nature into artificial situations in order to wrangle the truth out of it, and one had to have faith that nature behaved true to itself also in an artificial situation, i.e. one induced by man. As an example we may consider the notion of pressure. If you fill a tube with water and turn in quickly upside down, the water-level will not sink and produce a vacuum on top. The classical explanation for this was that Nature abhors the Viacom. That the water was so to speak sucked up to fill the void in its quest. However, if the pillar of water was above a certain height (about ten meters in modern measure) this would not occur. The Italian Torricelli did the same experiment with mercury, and in this case the height of the pillar was much lower, in fact of given pillars of the same area of cross section, the column of water an mercury turned out to weigh the same. From this it became natural to think in terms of pressure (which differed from mere weight), the liquid was not sucked up but pressed upwards of what must be the weight of the corresponding column of air. To this was added further credence when Pascal came into the picture and had the experiment repeated on top of a mountain, and lo and behold as suspected, the pillar of liquid turned out not to be as high anymore, the difference to be accounted for by the weight of the air between the two observation points. Now we see the real difference between the classical 'explanation' and the 'modern', the latter being much more fruitful when it came to suggesting and hence asking further questions. For one thing having a theory or at least a hunch of an explanation, such as the weight of a column of air, suggested that one bring up the apparatus to a sizable mountain and repeat the experiment, something one otherwise hardly would have thought of. In fact, as Popper claims, there is no such thing as a disinterested observation, any observation is provoked by a question.

[3] In fact this statement in the end becomes a definition of force replacing a vague and misleading intuitive one. This was also the reason that Mach later on at the end of the 19th century began to doubt the notion of force which inspired Einstein in his speculations that led up to general relativity

Everybody knows about Boyle's Law, although he never stated it, at least not in the succinct and universal form we are taught and hence teach. Boyle was one of the leading lights of the Royal Society an assembly not principally of university people but of gentlemen which accorded it higher social status, and hence influence, than it otherwise would have had. It was a reaction to the disputational gatherings of academics and hence the display of experiments took pride of place, and here Boyle was very active. Now such experiments did have something of the seance over it, after all it was a matter of asking nature questions and finding out the answers. Boyle accordingly kept extensive records of his experiments, listing the witnesses and all kinds of external circumstances that might conceivably have a bearing on the matter. While Newton, when he reported on an experiment, such that his masterly elucidation of how a prism disperses light into different colors, each of which do not disperse further, he kept to the essentials and, much to the dismay of Boyle dispensed with what he considered extraneous matter.

But experiments were isolated occurrences and how could one reliably generalize from the particular to the general? And how can one make sure that the facts on which the generalization was based were correct? This is the problem of induction which remains a major problem in the practice as well as the philosophy of science. As noted above, Bacon firmly believed in a method which would guarantee the facts, but this is just one part of the problem of induction. One solution was of course to replace induction, which allows you to draw conclusions, by deduction which forces you to (in the words of Collingwood). But this requires the premises of axioms, which may be far from intuitive. This was the road taken by Newton, who famously tried to model his Principia on Euclid's elements. The Greeks reasoned in a similar vein trying to find indubitable principles that could serve a deductive treatment. But those principles need to be universal, because you can never deduct universal conclusions from particulars, as in logic mere pure existence statements cannot imply for all statements. Thus in order to derive universal laws you must start with universal principles, which also tended to make those principles simple, injecting into science an element of aesthetics closely related to Occam's razor. Aristotle, supposedly argued that the Earth did not move, because an arrow shot upwards would return to the same place. But if they did the same experiment on a moving ship, would they not experience the same? Or could that be accounted for by the wind? But if you drop a stone in a rapidly moving object protected from winds? In retrospect it is easy to think of all kinds of simple experiments which would disprove naive intuition. Why were they not made by the clever Greeks? Of course it could have happened that they were made and even written down, but the documentation has been lost to posterity, as most of the ancient treasures. On the other hand if they were made, they may not have caused much of a stir, otherwise Aristotle would surely have mentioned them if they were part of the scientific culture at the time. The heliocentric worldview proposed by Aristarchus we know only about through the accidental survival of the manscript, clearly it did not infuse Greek culture being just one speculation among others. Thus if the entire scientific corpus of the Classical Greek civilization would have survived we would of course have had a much fuller appreciation of their achievements or at least their breadth of speculation. It is not enough that a thought is formed, formulated and even fitted on a piece of documentation, it also has to influence and become part of a larger culture, and here again we are reminded about the ways sociology comes to the fore in a crucial way. Anyway it reminds us how even obvious things may be missed by people, and in fact Aristotelian concepts of the elements of basic dynamics still dominate the imagination of people in general. One may argue that the real knowledge of modern people may not be much greater than that of the past, in many aspects probably much less, because most of what is known by the public is but by hearsay.

Now experiments were a controversial issue at the time. Although Descartes refers to experiments he had done he thought of them as basically superfluous and he took exception to those involving such details and irrelevant ingredients, so it became impossible to gauge their significance and core truth. Hobbes was even more dismissive, why do systematic experiments when one should suffice and the rest follow from deduction? Hobbes as a result was never invited to become a member of the Royal Society, although he shared their mechanistic conception of Nature.

Now there is a distinction to be made between fact and theory, i.e. a causal and intelligible explanation, or maybe as in the case of Newton one that allows manipulations. Facts are either true and false and in a sense accessible, although as we have seen, accessibility is in most cases not direct but mediated; while theories and explanations are speculative and their interest is tied up how well they accord with the facts on the ground, so to speak. In fact this survives in the attitude of practical people, who tend to conflate the notion of 'theoretical' with 'speculative'. Facts are particular and can in principle be asserted, while theories are general and hence provisional, and according to Popper never provable. And of course one fact can have many different explanations, just like one theorem in mathematics can have different proofs, and all are of course correct. However, in a mechanical setting, what causes the observed effects (the facts) can in one instance not allow any alternatives. The iconical metaphor at the time was the clock, and even if two clockworks could be very different, they may cause the same effects (after all functioning clocks show the same time, although the way they do so, may be very different). But there is only one Nature and hence the explanations should be unique. Of course when it comes to clocks, they can all be pried open and inspected, but Nature remains opaque and we are unable to ask the designer, namely God, explicit questions; thus the way of divining the underlying causes has to be done in a very circumspect way. It is notable that at the time the word *probable* had a different meaning than it has now. It implied a great deal of certainty, rather than a likely possibility. Boyle, in the spirit of Francis Bacon, claimed that he was not interested in theoretical explanations, and boasted that he wanted to purge himself on any such merely rhetorical approaches, thus disdaining continental such as that of Descartes, in order not to be confined and conditioned by them. But as the author remarks, be it in a mere footnote, and as we have also noted above, he must have had some theoretical notions, otherwise he could not have gauged the significance of an experiment, i.e. whether it was successful or not. But what he rightly stressed was that considerations of morality, politics, theology and even metaphysics had no place, only things mechanical, which do not engender strife and stoke the passions[4]. Part of his disdain for theory involved mathematics, and like many of his peers, he was suspicious of mathematical ide-

[4] One may compare with a passage in Plato's dialogues Euthyphro (7b-7d) when Socrates points out that in certain areas you can settle disputes without strife by simply appealing to measurements

alizations, and thought of those who proceeded mathematically as dogmatists and guilty of making category mistakes. This incidentally explains why he never wrote down, as we noted above, the simple relationship which is now known as Boyle's law. The attitude has something to commend itself, nowadays, many theoretical physicists thinks of physics as just mathematical manipulations, and hence deprive themselves of a workable physical intuition as well as a proper attitude. But, as we noted above, Newton put a large store in mathematics, and claimed that any physical certainty must have a mathematical basis. As Newton gained a lot of prestige, his point of view prevailed, but at the time he was frustrated by the lack of assent from his peers, which may have contributed to his eventual withdrawal from natural philosophy as well as his vindictive temper[5]. And of course grand theories with wide explanatory power appealed to those with exalted conceptions of their work, while those who were more diffident as to their scope, were content with merely amassing concrete facts.

A crucial issue, on which we have touched, is the dissemination of scientific knowledge to a larger circle. In this respect applicability is of paramount importance; and not any applications, but such that speaks directly to the fears and wishes of people, such as personal health. Descartes made extravagant claims, that once the mechanism of the body would be sufficiently understood, diseases would be eradicated as well as the infirmities of old age. Applications also constitutes an important part of Bacon's vision, maybe the most, as he envisioned humans taking control over Nature, in order to make it serve their purposes, rather than being subjected to its whims. A vision which indeed has characterized the modern world.

As we have noted, the clockwork metaphor of Nature implied a designer, and that designer could only be God. Thus science ultimately had to bow to God and by its findings and explanations pay tribute to the supreme being. It also pointed to the ultimately unsatisfactory concept of pure materialism, going back to the Greeks. If the world was but matter in motion, yet the motion has to be started, and it could not have a material cause. In other words if we could explain the motion of a particular piece of matter as being imputed by some other moving matter, ultimately there had to be a first cause, which pointed to the Deity as being the ultimate cause, ideas which were of course very scholastic in their spirit. One logical consequence of this was to understand God as the first mover, who had constructed a perfectly running machine, but then been content to withdraw. Both Boyle and Newton took exception to such a view. In fact it is safe that no scientist at the time denied the existence of a deity, outright atheism being not only politically incorrect but downright impossible. Then it is another thing whether those services were of the lip or of the heart, this we can probably never know. Mechanical as they may have been in their outlook, the philosophers of the time were well aware of the limitations of the mechanical worldview and did indeed take into account such things as purpose which was bound to transcend the mere material realm. Descartes drew a line as we all know, namely the line at the human soul and consciousness, while everything else in Nature, including all animals, would very well fit into the mechanistic scope of explication. The issue of materialism and its intrinsic limitations would be part of the general discourse for centuries to come. The psychologist William James was careful not to be seen as a

[5] His treatment of Hooke is a sad example of this.

materialist, and in the modern quandary about material explanations of consciousness and the capabilities of computers to really think, the limitations of such phenomena are still being laid down with urgency and conviction. The attitude not having changed in its essentials since the 17th century. Another development going in the other direction, concerns human limitations. We cannot expect everything in Nature to be intelligible to us, ultimately we will have to be content with shutting up and compute, as we have already noted above. But within the mechanical universe, notions such as morality and politics has no right of admission, as we saw pontificated upon by Boyle, which according to the author led to a separation between science, as totally disinterested, and society at large, with a concomitant depersonalization of Nature. The British philosopher Collingwood is very clear about making a distinction between world of Nature and that of Man, the former being but a 'spectacle'. Of all scientific theories that of Darin was the unrelentingly most materialistic, as it did do away with the necessity of a designer, and made it intelligible that order could arise spontaneously out of chaos, guided by some simple, almost tautological principles. In this way Cartesian duality was given a serious blow, as the distinction between man and Nature, man being part of Nature and amenable to the same kind of materialistic explanations. But on this the author does not touch as it is not part of 17th century science. He concludes that his sociological viewpoint is not to be thought of a critique of science as such, let alone a disparagement of; such criticism is best left to the scientists themselves, but only a criticism of the stories which are being told about science.

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