Kepler, Galileo, Newton and the Constructive Ideas of Modern Science[1]

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Abstract

Nowadays science and Christianity are mainly seen as two completely separate contributions to our daily life and culture. In this paper I intend to argue that historically and conceptually, science and Christianity should in fact be seen as very closely related entities. The new kind of science, which was introduced about 400 yeas ago, was very much inspired by the Christian world-view which all the important pioneers in science accepted.

The main attitude today on the restricted relation between science and Christianity has its roots in problems which arose more than one hundred years ago. When we in this paper shall go even further back, it will be somewhat strange for us to see how close Christianity and science were linked together at that early time.

But the fact is that modern science grew up in Europe around the beginning of the 17th century, and Christianity had the function of being some of the soil from which it grew. In the last twenty years we have witnessed a reorientation among scholars in the question of the relation between religion and science [Merton & Trenn 1979, Lindberg & Numbers 1986, Brook 1991, Henry 1997]. Investigations in the history of science have contributed to casting new light upon the relationship between religion and science after the Middle Ages. The American sociologist Robert Merton, for instance, claims

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to find evidence that the Protestant ethics in the English culture had created a positive attitude to scientific work in the 16th and the 17th century. Merton interpreted this religious mandate as a necessary condition for the origin of modern science. For him there was a causal connection between Christianity and science. The old conflicts have thereby gradually lost their dominance in favor of other ways of understanding the relationship between religion and science.

Why did the scientific revolution happen in Europe only, and why did it occur in the 17th century? From where did the new ideas develop? What is the origin of the new challenges, and all the new scientific knowledge? - These questions will probably never be answered completely. Historians of science should be content if they will be able to identify the principal factors, which they will then have to evaluate relative to more or less subjective considerations. However, it appears to be evident that in order to discuss these questions in a proper way we have to involve considerations on topics outside of the subject of traditional science and history of science. Only a precise analysis of cultural ideas of the East and the West will eventually clarify why modern science and technology arose just in Europe, and not in other cultures.

Even if relations of philosophical and intellectual character have played the main role for the growth of science, we must not forget that there without any doubt also exist important social and economical causes. Only given a certain cultural level of advancement (penmanship, book printing, school system and so on) is a scientific revolution possible. Most cultures perished prior to its possibility to start developing a scientific revolution at all.

Some have attempted to explain the scientific revolution as a result of interplay between the demands and progress in technology (where technology again is a function of the social requirements). Such attempts, however, have never been particular convincing. Social structures and technological development may be necessary as prerequisites for a scientific revolution, but they are far from sufficient prerequisites. Chinese culture is a very interesting example. In the 16th century, China was in many respects far ahead of Europe. Joseph Needham, who has a comprehensive knowledge of China, says in the beginning of his book *The Grand Titration*:

> "The more you know about Chinese philosophy, the more you realize its profoundly rationalistic character ..... I believe that the more you know about Chinese civilization, the more odd it seems that modern science and technology did not develop there." [Needham 1969, p. 154]

In his attempt to give an explanation Needham writes:

> "There was no confidence that the code of Nature's laws could ever be unveiled and read, because there was no assurance that a divine being, even more rational than ourselves, had ever formulated such a code capable of being read." [1969, p.327]

Gradually it looks as if the Chinese, as people of many other large cultures, lost their interest in science. When Albert Einstein was asked to analyse the development behind Western science, he answered in a well-known letter:

> Dear Sir,
>
> The development of Western science has been based on two great achievements: the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility of finding out causal relationships by systematic experiment (at the Renaissance). In my opinion one need not be astonished that the Chinese sages did not make these steps. The astonishing thing is that these discoveries were made at all.
>
> Sincerely yours, Albert Einstein.
> [*Letter to J. E. Switzer* 1953, quoted from Needham 1969, p. 43]

The Middle Ages (500-1500)

When modern humans today look back to the Middle Ages, with its cultural and religious life, we may either be filled with a longing after the unified culture that gave life stability and safety, or with an abhorrence for the suppression that existed to maintain the same cultural unity. Science and world view in the Middle Ages were bound to the Roman Catholic teaching, without any great stress on the significance of studying the real world around ourselves. The church had such a great influence and power over life, that it did not tolerate any other authority than its own spiritual authority. It actually lifted itself up in God's place. Meditation instead of action got the greatest importance in human life. The world was seen as a picture of divine goodness only to show man the possibility of salvation upon doing good deeds. But with such a separation between daily existence and the real world-to-come, what existed now had no true interest. Life and the universe were only considered areas for moral test.

However, this worldview of the Middle Ages also had positive sides. From our modern point of view we should not automatically or uncritically despise it. A positive side was that during the Middle Ages, man understood himself to live in a personal universe. He did not primarily need to find his identity in the impersonal matter around himself. Humans knew that they existed in a personal universe that started with a personal creator: The God of the Church.

Moreover they had a uniform way of thinking, where everything was integrated in a unified and sensible understanding of the universe. They worked within a united philosophy, in contrast to the specialized and fragmented view on knowledge that modern humans often have to live with.

Further, they expressed their concepts through the wish of harmony, 'a harmony of the spheres.' The stars were not studied so much in order to understand how they moved, but more to discover some of the harmony in creation itself. Astrology was also studied to understand some of the deep harmony in the universe. It was supposed that the stars had influence on terrestrial incidents. This was not primarily regarded as destiny, such as Arab astrology taught when introduced into western thinking around one thousand years ago, but rather as an attempt to increase harmony between everything existing.

In fact, quite a complicated construction arose out of the synthesis of the early Middle Ages between Christian theology and Neo Platonic philosophy. Through the work of the church fathers, including Augustine's comprehensive theology, a framework was made uniting all forms of knowledge in a grand hierarchy with theology as 'The Queen of Sciences,' and the other sciences as companions and helpers to theology. The result was a united and integrated worldview that was religious all through.

However, the worldview of the Middle Ages also had several negative consequences. Since the Church demanded the right to dictate the correct teachings, it accepted no testing in the universe outside, and therefore made itself a deity. The church was often so occupied with the spiritual sides of existence, that it tolerated much cruelty in practical life. With reputable exceptions, such as the Franciscan monks, little was done to combat illness and better the health among people. This embracement of nature could only be sustained if part of reality, with its particularities and information, was kept down and given little meaning. This worldview broke down under the hard pressure which an irresistible reality exerted. It ended with a collapse of man's great idea of being the centre of the universe. In addition, the brutal Black Death raged in Europe around 1350 and raised the question of the actual harmony and unity in nature. All this contributed to abolishing the assumption - and it was nothing else than an assumption - of a harmonic nature and a harmonic management from the Church above reality.

A fresh ideal for science was gradually born. One could no longer let scientists stay passive with the knowledge they had. The knowledge had to be expanded into new areas, and the present situation should be changed for the better for the coming generations. The Renaissance in Southern Europe and The Reformation in the North both bore a philosophy that "made wonders of scientific progress."

When great breakthroughs take place in science, it often is the result of the effort of a few people. Science is - more so than other subjects - the workshop of the geniuses and pioneers. This fact points to the reasons for which we in the following take a closer look at three of the principal founders of modern science and their efforts.

Johannes Kepler (1571-1630)

Kepler is one of pioneers of the new science. He was borne in Weil der Stadt, a small town west of Stuttgart. Thirteen years old he entered the evangelical convent school in Adelberg. Two years later he moved to another convent school where he was to stay until he was ready for university. Bible studies had a central place in school, but also mathematics and astronomy were among the subjects. Eighteen years old, Kepler entered the university in Tübingen where he some years later passed the magisterial degree with honors. In 1594 he was called to be a teacher in mathematics at the protestant gymnasium in Graz. Life went on step by step for Kepler, and in 1601 he was appointed Imperial Court astronomer and mathematician in Prague.

Fig 1. Johannes Kepler

Kepler wanted to provide a philosophy or physics of celestial phenomena in place of the theology or metaphysics of Aristotle. In his 59 years of life, Kepler published about ten major scientific works. In the 15^{th} and 16^{th} century a profound change in the philosophical and scientific thinking was going on in Europe. Aristotle and his reigning philosophical system were falling down from the throne. Scientists began to look at reality and the facts to be concluded from these in a new way. Here Kepler made significant contributions both to astronomy, optics and mathematical analysis. He is best known for his three laws of planetary motion around the sun. These were found on the basis of data collected by the Danish astronomer, Tycho Brahe, roughly after 22 years of intensive calculations. They were the first *Natural Laws* in the modern meaning of word. The path Kepler went through towards his goal is considered a masterpiece in the history of science. With these laws he contributed to building a bridge from the old picture of the universe as an unalterable cosmos, to the new idea of a dynamic system subject to mathematical laws. Kepler's first law published in his work *New Astronomy* (1609), indicates as an example what the new laws looked like:

> "The planets move around the sun in elliptical orbits, with the sun in one of the focal points." [Kepler 1929, chap. 59]

Prior to Kepler's time, quantitative calculations by and large were used as a support for geometrical a priori assumptions. In Kepler's works, however, the quantitative aspect found a fundamental meaning, an attitude that has influenced the scientific method and comprehension of the world for all posterity. Kepler solved the problem of circular versus elliptical orbits by claiming that it was not the geometrical figures themselves that were to be conclusive for the harmonic regularities in nature, but the quantitative harmonies that could be deduced from nature itself. His vision was a solar system where the changing velocities of the planets formed a basis for a symphonic harmony to the honor of the Creator.

A concrete example of Kepler's quantitative understanding of harmony is found in his so-called second law, the area law. It was quite a shock for Kepler to discover that the planets did not move with even velocity in its orbit around the sun, but the velocity changed according to how close the planet was to the sun. Kepler was still capable of maintaining harmony because he found that in the same amount of time, *equal areas* was swept out by the movements of the planet. The area is defined by the line from focus in the ellipse, where the sun is located, and to the planet at the edge of the ellipse. Thereby the concept of harmony is still valid, although formulated in a more complex mathematical form. This was quite a new idea, with far-reaching consequences ahead.

Kepler's detection of elliptical planetary orbits undermined to some extent the ideal world that the contemporary scientist had inherited from the old platonic and Pythagorean worldview. Still Kepler found that he could maintain the basic idea in his worldview, namely that nature itself reveals regularity and constancy that may be acknowledged by humans. This idea was united with the Christian faith in God as the source of law and regularity, because God was the same from eternity to eternity. But he made progress in unifying Greek cosmology and Christian theology by pointing out that the law and constancy in nature was of a quantitative character.

The following quotation from 1597 indicates Kepler's own opinion of his scientific activities, and also expresses hope that humans in an even better manner might acknowledge the Creator in nature:

> "My God make it come to pass that my delightful speculation the *Mysterium Cosmographicum* have everywhere among reasonable men fully the effect which I strove to obtain in the publication, namely that the belief in the creation of the world be fortified through this external support, that thought of the creator be recognized in its nature, and that his inexhaustible wisdom shine forth daily more brightly. Then man will at last measure the power of his mind on the true scale, and will realize that God, who founded everything in the world according to the norm of quantity, also has endowed man with a mind, which can comprehend these norms. For as the eye is for color, the ear for musical sounds, so is the mind of man created for the perception not of any arbitrary entities, but rather of quantities." [*Letter to Masterlin*, April 19, 1597. See Caspar and Dyck 1930, band I, p. 44]

Here something more is involved than the pure platonic principle of God as the first cause in geometry. Kepler's God has given humans possibilities to communicate directly with its divine origin through recognizing the laws of nature. Recognition of the order of nature expressed in mathematical language with its possibility of quantitative calculation is to have a share in

God's own thoughts. Kepler's mathematical astronomy was a way to realize the thought that mathematics is a symbolic interpretation of the nature of the universe. The mathematical language 'reflects' realities in such a way that it is a basic correspondence between the human acknowledgment and nature itself. This understanding of the relation between reality and language turned out to be founding for science and later for the triumph in technology in the centuries to come.

Fig 2. The first page of Kepler's book 'New Astronomy'

Eight years later, when the theory in *Mysterium Cosmographicum* was rejected and the new book *New Astronomy* was under construction, he still has his aim clear in mind:

> "My aim is to show that the heavenly machine is not a kind of divine, live being, but a kind of clockwork (and he who believes that a clock has a soul, attributes the maker's glory to the work), insofar as nearly all the manifold motions are caused by a most simple, magnetic, and material force, just as all motions of the clock are caused by a simple weight. And I also show how these physical causes are to be given numerical and geometrical expression." [*Letter to Herwart von Hohenburg*, February 10, 1605. See Caspar and Dyck 1930, band I, p. 219]

If we shall try to sum up Kepler's basic ideas, we may find that his understanding varies somewhat through his life. But the following subsequent factors were of great importance to Kepler's science:

Firstly, his basic idea was that universe was an *ordered universe*. The universe had a God-given order for Kepler. He was enthusiastic upon the idea that God had created the world as beautiful as possible. The harmony and correspondence in nature was the 'signature' from the Creator himself: such he wanted it to be.

Secondly, Kepler held that this order could be expressed *mathematically*. He believed, as the Greeks, that the creator worked according to mathematical models when he created the world.

Thirdly, Kepler thought that *man could acknowledge this mathematical order*. In his own words:

> "Those laws [which govern the material world] lie within the power of understanding of the human mind; God wanted us to perceive them when he created us in His image in order that we may take part in His own thoughts..." [*Letter to Masterlin*, April 19, 1597. See Caspar and Dyck 1930, band I, p. 44]

Furthermore, Kepler held that in order to grasp the right laws, man had to take the physical creation under investigation**.** *Physical observations* were necessary and decisive. Here Kepler differs consistently from the Greek way of thinking. The Greeks had postulated that the ideas in mathematics never could be implemented in full scale in matter - they only had a weak 'reflection' there. But Kepler considered matter as given directly from God's creative hand, and often talked about the necessity of "*reading the book of nature.*" Here an error of eight arc minutes between observations and computations for the orbit of planet Mars, made Kepler reject the two thousand years old postulate of circular planetary orbits, to introduce ecliptic orbits. The main thing was to be precise and absolutely true in the scientific work. All errors and simplifications would offend God's majesty.

Finally, we should mention that Kepler, like the famous composer J.S. Bach, always wanted to *give God the glory*. Science was a part of his worship.

Kepler represented a kind of 'praising scientist,' who together with the apostle Paul, could worship with his mind.

Galileo Galilei (1564-1643)

Galileo was born in the town of Pisa in Italy. After completing his studies, he was appointed professor in mathematics in 1589. Galileo was the first to use the telescope to study the sky. He also studied how bodies move here on Earth, and thereby he laid the foundation of experimental mechanics.

In Galileo's scientific theory, nature itself was presented as a *single, ordered system* - even stronger than in Kepler's mind. Secondly, Galileo maintained that nature itself was composed as a *mathematical language*:

> "Philosophy is written in that great book which ever lies before our eyes - I mean the universe - but we cannot understand it if we do not first learn the language and grasp the symbols, in which it is written. This book is written in the mathematical language, and the symbols are triangles, circles, and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wanders in vain through a dark labyrinth."
> [Drake 1957, Galilei: *The Assayer*, p. 237]

The universe was for Galileo a book written in a foreign language. Therefore it also had to be interpreted and explained in this language. After many misunderstandings humans now had begun to discover this language - which is the principles and concepts of mathematics. Any part of mathematics could always be applied in the material world. Physical bodies, for example, were always geometrical figures, even if they did not have a regular form as in geometry. When one was trying to understand an unknown aspect of nature, the method was to make use of the language of nature and thereby decompose the system in mathematical terms. The physical world, Galileo conjectured, was identical with Euclid's geometrical space. Thereby mathematics had validity in the material world.

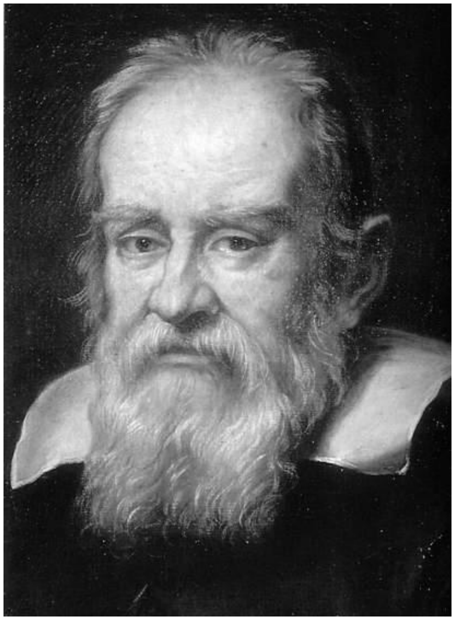

Fig 3. Galileo Galilei

Furthermore, according to Galileo, the validity of the theorems in mathematical language was guaranteed by the divine intellect:

> "Extensively, that is, with regard to the multitude of intelligibles, which are infinite, the human understanding is as nothing even if it understands a thousand propositions; for a thousand in relation to infinity is zero. But taking man's understanding intensively, in so far as this term denotes understanding some proposition perfectly, I say that the human intellect does understand some of them perfectly, and thus in these it has as much absolute certainty as Nature itself has. Of such are the mathematical sciences alone; that is, geometry and arithmetic, in which the Divine intellect indeed knows infinitely more propositions, since it knows all. But with regard to those few which the human intellect does understand, I believe that its knowledge equals the Divine in objective certainty, for here it succeeds in understanding necessity, beyond which there

> can be no greater sureness." [Galilei: *Dialogue concerning two chief World Systems*, 1967, p. 103].

The development of mathematical physics showed that mathematics is far more than just a tool. This insight led to the main turning point between old and new science. The quantification of nature was the key to understanding the world, and without this mathematical approximation of reality, modern science would have been unthinkable. With Galileo, science therefore took the great leap towards the implementation of the mechanistic worldview. Furthermore, Gary Deason [cf. Lindberg & Numbers, p. 167-191] has argued that there is a connection between the theological underlining of God as the absolute and sovereign majesty, and the growth of a mechanical interpretation of the world. As an aside, we may mention that the famous conflict between Galileo and the Catholic Church was not a collision between two opposite worldviews. The trial was rather the result of personal conflicts and provocations (cf. Arthur Koestler: *The Sleepwalkers*). The philosophical confrontation had to do with the relation between Galileo's physics and Aristotle's physics. Aristotle's was at this time the authorized tutoring at the universities, and it was in reaction to this that Galileo stated the following:

> "They wish never to raise their eyes from those pages - as if this great book of the universe had been written to be read by nobody but Aristotle, and his eyes had been destined to see for all posterity." [Drake 1957, Galilei: *Letters on Sunspots*, p. 127].

Therefore, it is a misunderstanding and a twist of the historical relations, to give a picture of a Galileo who never was able to get the Pope to take a look in his telescope; and a Copernicus who waited till after his death to publish his work, because he was afraid of reactions from the church. The historical fact is that Copernicus met little or no resistance from the church against his theory. Even Galileo had friends high up in the church hierarchy sympathizing with his ideas. Galileo's first publication and following visit in Rome was an immediate success, and the Jesuits at the Vatican's public bureaucracy mentioned his discovery and the new equipment, the telescope, in inspiring words. The first dispute with the censors was not at all on his scientific discovery, but on the theology he used to legitimate his scientific activity.

The principle of "neutrality of hypotheses" was a basic and important part of the position which the ecclesiastic authorities held. Galileo's book, *Dialogue concerning two chief World Systems*, was approved by Pope Urban in 1630 and printed two years later. To keep the claim of neutrality Galileo had consequently included the central words, dictated by the Pope himself, that the Copernican theory was no categorical or ultimate truth. He had, however, laid these words in the mouth of a person named Simplicio, who in the book is a rather weak equipped character. Censors of course discovered this, and when the Pope was notified, he took it as a personal offence. But it was hardly the Pope himself Galileo had in mind when he created the Simplicio character. The historian Stillman Drake asserts that it rather was Galileo's first opponent, Lodovico delle Colombe, an autodidactic and otherwise amateur in scientific affairs, who was portrayed as Simplicio.

It may also be of interest to mention that Galileo often used an atomic theory of matter. Galileo found it useful to suppose that matter was decomposable in "*infinite small, indivisible atoms*" (cf. *Two New Sciences*, p. 40). Perhaps this theory has connection to the mathematical indivisibles, but otherwise they may also derive from the Greeks. Galileo's student, the monk Bonaventura Cavalieri (1598-1647), applied this concept frequently in mathematics.

With such visions of a mathematical reading of the material world, Galileo could state one of the well-known headlines:

> Let us measure everything that is measurable, and let us make measurable everything that not yet is measurable. [cf. Drake 1957]

Isaac Newton (1642-1727)

Sir Isaac Newton is considered to be among the very greatest in the history of science. He stands forth as one of the driving forces forming the whole of our western science and culture. During his own lifetime he reached such an authority and influence that he challenged and defeated even Aristotle.

Posterity has, so to speak, unanimously chosen him as the greatest scientific intellect that has ever lived. According to an interesting anecdote, his contemporary competitor Leibniz said:

> "Taking mathematics from the beginning of the world to the time when Newton lived, what he did was much the better half." [Brewster 1965, vol. 2, p.406]

In contrast to all this stands Newton's own words towards the end of his life:

> "I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." [Quoted in Brewster, 1965, vol 2, p.407]

The University of Cambridge early became aware of Newton's capacity, and in 1669 he took over a professorship. The years 1684-86 are among the most important in the history of science. Then Newton finally had been convinced by a friend to publish his astronomical and physical discoveries. Working almost day and night with this for two years, the project *Philosophia Naturalis Principia Mathematica* (in short: *Principia*) was realized. This book at once had a great influence in the whole of Europe. The presentation is elegant. It is characterized by an enormously systematic, and impressive penetration and width in the problems dealt with. He starts with the laws for the motion of bodies, and from this he explains a whole row of phenomena (among other things the tides) known for the Earth, the moon and the rest of our solar system. The work was a synthesis of Kepler's and Galileo's theories, and it represents the first and greatest triumph for the new mathematical analysis (the calculus) that Newton himself had discovered. Here Newton marks the introduction of a completely new epoch of science.

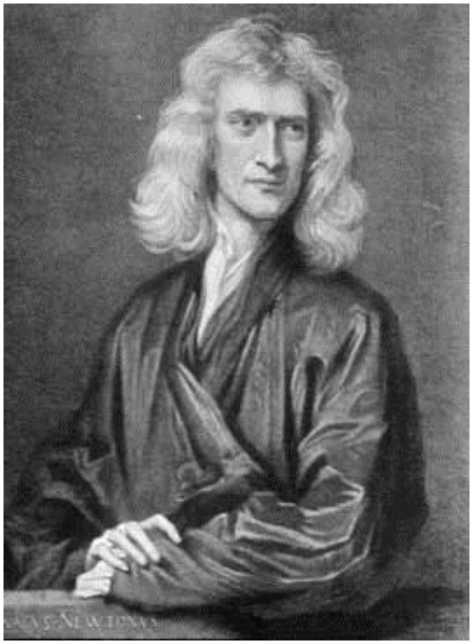

Fig 4. Isaac Newton

It is beyond doubt that Newton did not have an utterly materialistic worldview. Voltaire, who knew him, said:

> "Newton was firmly persuaded of the Existence of a God, and by that word he understood not only a Being infinite, omnipotent, and eternal, who is the creator, but a master who has made a relation between himself and his creatures..." [Quoted in Westfall, 1983, p. 825]

Newton could go as far as to regard *Principia* and his other scientific works as useful because they gave external help to make the laws of The Creator visible. All discovery of scientific law underlined the order and structure that was implemented in creation. Studies in nature were for Newton a question of interpreting the marks of God's hand, and thereby decipher the puzzle of the universe. Such richness, entity and width were above Newton's intense research.

In Principia he also puts up some rules for scientific work, the so called *Regulae Philosophandi*. In his famous *General Scholium* in *Principia*, Newton states this:

> "This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being… This Being governs all things, not as the soul of the world, but as Lord over all; and on account of his dominion he is wont to be called Lord God, or Universal Ruler… And from his true dominion it follows that the true God is a living, intelligent, and powerful Being; and, from his other perfections, that he is supreme, or most perfect. He is eternal and infinite, omnipotent and omniscient; that is, his duration reaches from eternity to eternity; his presence from infinity to infinity; he governs all things, and knows all things that are or can be done. He is not eternity and infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures forever, and is everywhere present; and, by existing always and everywhere, he constitutes duration and space." [*Principia*. A Revision of Motte's Translation by Cajori, 1946, p. 545]

These reflections Newton terminates with the following words: "*So much on God. To think about him on the basis of the phenomenon we can observe in the universe, naturally belongs to science.*" This is a very strong claim. We can also sense a Christian excitement behind it! Newton did not consider faith and science as two separated areas. His religious conviction was so strong that he had to give expression to it, even in his deep scientific treatise. We must add that after Newton's time, 6-7 theories on the origin of the solar system have appeared. But up to this day the problem is an unsolved one.

What was the driving force for Isaac Newton in his intensive activities? In a letter to Dr. Bentley, he gave us at least a part of his answer:

> Sir; When I wrote my treatise about our system, I had an eye upon such principles as might work with considering men, for the belief of a Deity; and nothing can rejoice me more than to find it useful for that purpose. But if I have done the public any service this way,

> it is due to nothing but industry and patient thought.... [Cohen, 1958, p. 280].

Newton's view on the interaction between faith and science made him stress the importance of two matters: *mathematics* and *experiments*. The order and regularity resident in creation made it possible to formulate exact knowledge about it. Mathematics was the language that in the best way could express this exact order. But the mathematically formulated theory always had to build upon an experimental basis. In such a way Newton made the common rendezvous of the two main streams in science: the *empiric experimental* and the *deductive mathematical*. Science was to him the exact mathematical formulation of phenomena in space and time in God's universe. Together with Leibniz, Newton discovered a crucial scientific tool called the *mathematical analysis*, or *Calculus*.

The mathematical analysis

I have elsewhere [1979] discussed the origin of the area of mathematics which we today call Calculus, as also ably discussed by Berlinski [1996]. This is a very important subject, especially for engineers. I have argued that it is possible to find three creative factors that contributed to establish the new subject. A *creative factor* may be understood as an element or aspect that enriched mathematics with fertile ideas, which can lead to further progress.

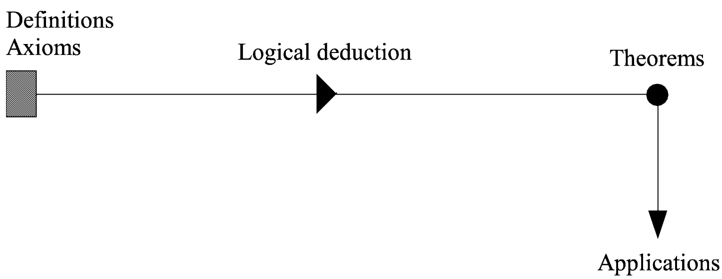

Fig. 5. Context of justification

When we today present a subject of mathematics at the universities, we follow a quite strict deductive form, presenting axioms, definitions, theorems with proofs, and at the end applications. This can be called a *context of justification* (cf. Suppe 1974, p. 125). But the *context of discovery* may be completely different. New areas of mathematics often start on an intuitive basis. After this intuitive phase, however, there must follow a critical reshaping of the subject, where the whole presentation is made exact and deductive. This formalization removes all vague notions, and conserves only concepts and symbols that represent the abstract mathematical relations. Such a formalization-process gives up the link between the concepts and the original relations they where conceived from. One forgets that the axiomatic structure was constructed upon for example an empirical basis.

Regardless of this, logical thinking is a necessary substance in any mathematical project. The first creative factor is therefore logic. This is something we have inherited from the Greeks. They were engaged in deducing truth, and especially the Platonic school stressed that truth only could be reached upon mathematical abstraction and reasoning. Leibniz and his *characteristica generalis* may specially be seen in connection with the Greek way of thinking. But all mathematicians that contributed in making the new mathematical analysis made use of the Greek way of thinking as an important part of their 'mental tools.'

The Greeks, however, had been so consistent in their demand for exactitude, that all imprecise ideas were rejected from mathematics. They could easily end up in paradoxes of the type known from Zeno's paradoxes. A consequence of this was that infinitely small quantities were discarded. Infinitesimal considerations could not be used. Around the year 1600 mathematicians, however, were looking for new methods that could make it possible to deal with tangent, area and volume problems more directly. These problems often had a physical and astronomical origin. The work with these problems gave suggestions and direction to mathematical methods, and complicated mathematics was created to solve them. Mathematics got ignition towards a new dynamic way of thinking.

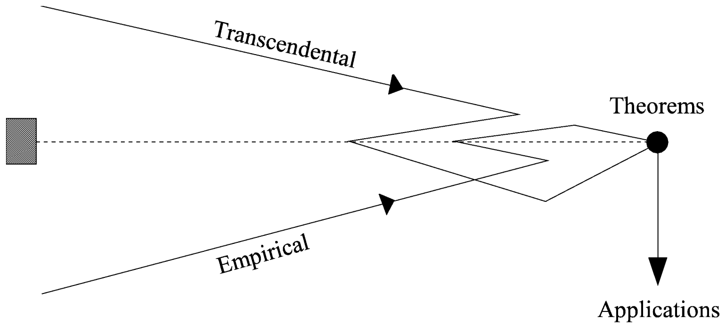

Fig. 6. Context of discovery.

Most mathematicians at this time believed, for religious reasons, that there existed a close isomorphism (structural equality) between the outer world and mathematics. They realized that there where obscurities in the mathematical methods they used. But they were risking venturing far on uncertain mathematical ground because the methods gave correct physical results. Mathematics and physics were so closely linked that the strength of physics supported the weakness of mathematics. This creative factor may be suitably labeled the *empirical* factor. A well-known example here is Newton's theory of limits ("primary and ultimate ratio") that are retrieved from physical empiricism. Hundred and fifty years later the mathematical formalization of this method was firmly based on the concept of *limits*.

But mathematicians also introduced concepts of no definite physical meaning. This we may call the *transcendental* factor, which therefore consists of concepts outside the area of experience. An example here is the concept of *indivisibles* also called *infinitesimals*, i.e. things so small that there is no way to measure them [Lai 1979]. It pops up several times in history, for example by a Jewish philosopher, with several of the scholastics in the Middle Ages, with Leonardo da Vinci, Kepler and so on. Leibniz' concept 'infinitesimal' also has its background in a transcendental idealism. A mathematical formalization of these ideas did not appear until 1960 with Abraham Robinson's non-standard calculus [Robinson 1967]. The concept *infinite* was also widely used, and to think in infinite processes was allowed. It has been proposed that the Greeks' rejection of the 'actual infinite,' especially such as expressed by Aristotle, was one of the principal reasons why they did not manage to unite arithmetic and geometry. This was about introducing a concept that the mathematicians saw with their 'spiritual eye.' The boldness in creating new concepts has much of its explanation in philosophy and religion, and has implied that large parts of mathematics in our time have been described as "*The Science of the Infinite,*" as Hermann Weyl has expressed it. [Weyl 1950]

Even if the old understanding of mathematics as the truth about nature has faded in our days, mathematics still proves to be surprisingly useful in the study of nature. Fields such as group theory, non-Euclidean geometry, and statistical theories appear to be of key importance to understanding the physical world round us.

Conclusions

The first part of an answer to our quest for the origin of Western science must be with the Greeks. They gave the Europeans the right kind of rational thinking. The triumph of the Greek philosophy was that it operated with a rational notion of the universe. According to the Greek view, the universe is ordered and based on mathematical principles and ideas. Structure and order were considered to be essential for the understanding of the universe, and mathematics was the key to this abstract harmony. In this way the human intellect could comprehend the universe. This later on also became the 'mental tool' in modern science.

But the Greek culture alone did not give us the scientific breakthrough. They became in a way 'too theoretical.' Science for them was a part of philosophy. They put too much stress on reaching the truth by metaphysical and rational analysis of the universe. The Greek position was that truth came from man's intellect, and not from the outer, physical world. This implied that their great philosophers were the actual authority. Aristotle was considered to be the greatest among the Greek authorities, and science was based on his thinking more than on observation of the outer world.

The Greek thinking was, however, transferred via the Arab culture to Europe in the Middle Ages. Here we also encounter the analogy where the universe was compared with a clockwork. The historian Lynn White Jr. writes that:

> "… regularity, mathematically predictable relationships, facts quantitatively measurable, were looming larger in men's picture of the universe. And the great clock, partly because its inexorability was so playfully masked, its mechanism so humanized by its whimsicalities, furnished the picture. It is in the works of the great ecclesiastic and mathematician Nicholas Oresmus, who died in 1382 as Bishop of Lisieux, that we first find the metaphor of the universe as a vast mechanical clock created and set running by God so that 'all the wheels move as harmoniously as possible.' It was a notion with a future; eventually the metaphor became a metaphysics." [White, jr. 1962, p.125.]

This relation must further on be seen in connection with the spiritual climate that was born in Europe with the Renaissance in the south and the Reformation in the north. In this epoch, religion was an important element in cultural life. What people were thinking about God had a strong influence on their concept of nature, and thereafter had effects on their methods to explore nature. In the 16^{th} and 17^{th} century a new worldview was born.

The mathematician Alfred N. Whitehead was a century ago working together with Bertrand Russell on a large philosophical work supposed to give philosophy the same firm basis as science. They intended to reach this goal by using the mathematical science as model. While Russell through his whole life expressed a negative attitude towards a religious worldview, Whitehead changed his understanding of religion. Whitehead insisted that there were convincing evidence that Christianity instead of having been at hindrance for the development of scientific thinking, rather was one of the necessary prerequisites for the modern technological-scientific investigation of nature. Without the Christian conception of the world, created with order and meaning by a divine rational intelligence, science and its interpretation of existence would not have taken place. Whitehead expresses it like this:

> "When we compare this tone of thought in Europe with the attitude of other civilizations when left to themselves, there seems but one source for its origin. It must come from the medieval insistence on the rationality of God, ..." [Whitehead 1926, p. 15]

In other words, because the first scientists believed that the universe was created by a sensible God, they were not surprised to discover that by the use of reason, it was possible to find some truths of nature and the universe upon observations and experiments. Men like Kepler, Galileo, Cavalieri, Pascal, Barrow and Newton were all deeply religious and saw the universe as a design from God's hand. All these pioneers may only be properly understood on the background of the theology where they had their roots. The Bible was not considered a textbook in physics, but it was understood as forming a basic framework within which science itself could be performed. The esthetical qualities of the equations describing the laws of nature and their optimal initial conditions provided the deepest and ultimate guarantee and explanation of a divine design of the universe as taught in the Bible.

According to Whitehead, Jewish-Christian theology should be conceived as the "*the mother of science*" who gave us "*the faith in the possibility of science*" [Whitehead 1926, p. 16]. An understanding of the laws in the material world should also contribute to bettering mankind's daily life. Of course, religion was not the only element that made modern science. We have mentioned inheritance from the Greeks, and social, economical and political factors also played a significant role. But Christianity has been one of the creative and sustaining components. Albert Einstein also underlined the important religious element related to science when stating:

> "Science without religion is lame, religion without science is blind." [Einstein 1950, p.27]

The classic Greek thinking was, as we have seen, subjected to the rational record. But the new worldview that was born in Europe made all scientific activity subjected to the record that could be made from the observations - even if they at first did not seem to be rational at all. Problems were complicated, but solvable because the objective reality existed and was rational and mathematical. In this way two great philosophical trends were united in Europe: Greek philosophy and Jewish-Christian theology. The late R. Hooykaas, who was professor of the History of Science, states:

> "For the building materials of Science (logic, mathematics, the beginning of a rational interpretation of the world) we have to look to the Greeks; but the vitamins indispensable for a healthy growth came from the biblical concept of creation." [Hooykaas 1972, p.85]

Therefore, we must not understand the rise of modern science as a change from faith towards science, or from religion towards criticism, or from an authoritarian view towards a liberation of man's curiosity, or from superstition towards exact measurement. Such presentations are often given both in literature and in lectures. They are, nevertheless, obviously mistaken.

The new science was developed precisely on the basis of what Genesis in the Bible states about reality - namely that the universe is not governed by a lot of fragmented, mythical or magical forces, but instead of a causal relationship. Matter itself is not inhabited by a soul, but it is functioning on the basis of laws that man is capable of comprehending. The world is real, and is discernible in a manner that it is possible for man to grasp intellectually. The unique historic period which we have discussed above, is therefore a good example of a positive interaction and linking between science and religion. Within this period of time there were few or no disputes between religion and science. It was rather like a quiet alliance with mutual connections. In the catholic countries the relations were somewhat more upset, but nothing like a regular strife between religion and science.

Often Christianity has been criticized as being restrictive on scientific thinking. Individual representatives from the church have without doubt done stupid things toward scientists, but this constitutes only a small part of the total picture. With the above analysis I have tried to present the true interaction between Christian faith and science that took place in our culture during the 17th century. Faith obviously had a fertilizing and promoting influence on science. The church as such may not be said to represent some type of front against new discoveries and ideas. Problems primarily arose when new theories were advocated as ultimate and final truths, or when the

Scriptures were (mis)used to legitimate what was discovered. When the researchers had a sober and undogmatic attitude to their ideas, they had little or nothing to fear from the church. Many church leaders also were active in promoting open minds and forwarding scientific thinking.

Science never developed as a proper and satisfactory study of reality in non-Christian cultures. Neither did it develop in the worshipping of Saints of the Middle Ages, where most of the focus was on how man could go to heaven and less on our existence here and now.

Today, of course, a person may be a clever scientist, no matter what his religion is. Science works with nature out there, and not only with nature as it is apparent in my mind. So a Buddhist is during his research exposed to the same objective reality as the Christian is. The question is, however, whether or not a non-Christian worldview could have produced science as we now know it. The evidence from history suggests that the answer is that non-Christian worldviews are unlikely to have been able to give rise to anything like science, even though the scientific method by now is accepted and adopted in most cultures around the world.

The general pattern that we are facing is an intellectual breakthrough, which took place because of the inner dynamics of some very special scientific, religious, cultural and social relations. Every one of these ingredients played its role, and without one of the elements the events might have happened quite differently. The splitting of the mind in faith and science of our day may lead us into a cold and technical world. In my opinion, it is very likely that we'll be unable to manage our inventions rightly and to understand creation properly, until we again can see material reality in its correct relations to the transcendental realities. Science still has much to gain by 'honoring its father and its mother.'

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