A Brief History of Science: Part 6: The Newtonian Synthesis

Soumitro Banerjee*

AS WE HAVE SEEN in the last installment of this article, the second half of the seventeenth century saw a rapid development in science. After centuries of slumber during the middle ages, people started taking a fresh look at nature with eyes unhindered by religious dogma. The mood of the time was probably best expressed by Hooke who insisted on the use of "a sincere hand, and a faithful eye, to examine and to record, the things themselves as they appear." "The truth is," wrote Hooke, "the science of nature has already been too long made only a work of brain and fancy: It is now high time that it should return to the plainness and soundness of observations on material and obvious things." The Royal Societies were formed in England and France, which acted as rallying points for the new breed of scientists. Excitement was in the air, and Boyle, Hooke, Wren, Halley, and many others made seminal discoveries which were presented and discussed in the Royal Society.

The contribution of Isaac Newton towers over everybody else of that period. His book "*Philosophiae Naturalis Principia Mathematica*" (Mathematical Principles of Natural Philosophy) had enormous influence on human thinking; it shaped the face of science for centuries to come. That is why it is necessary to understand the source of his inspiration — what determined the content and the direction of his scientific work. But the problem is confounded by the myths that have been built up around the personality of Newton: that he was an unsocial isolated eccentric genius; that the fall of an apple on his head caused the discovery of the theory of gravitation, etc. We need to unearth the reality by removing the veils of such common misconceptions.

The history of science is a part of world history. And there are two points of view in looking at world history. One point of view sees history as a chronological account of the kings' ascent to power, conflicts between kings and kingdoms, the rise and fall of empires, and the gallantry and heroics of kings and their generals. This is how history is taught in our schools and colleges. This is not a scientific viewpoint of history, because, while the focus is on the events of the past, the underlying social processes that determine the course of events are obscured from view. A scientific view of history, on the other hand, focuses on the peoples' life and livelihood, and the development of the productive forces in the different epochs, as reflected in the peoples' livelihood. The social factors underlying the major developments in history are then understood in terms of the conflict between the productive forces and the production relation prevailing in each phase in history. This is how we understand the transition from a hunting-gathering society to slavery,

*Dr. Banerjee is a Professor of Physics, Indian Institute of Science Education & Research, Kolkata, and a member of the Editorial Board of *Breakthrough*.

from slavery to feudalism, and from feudalism to capitalism. The kings and emperors who ruled in these periods are important, but are not central to the understanding of the course of history.

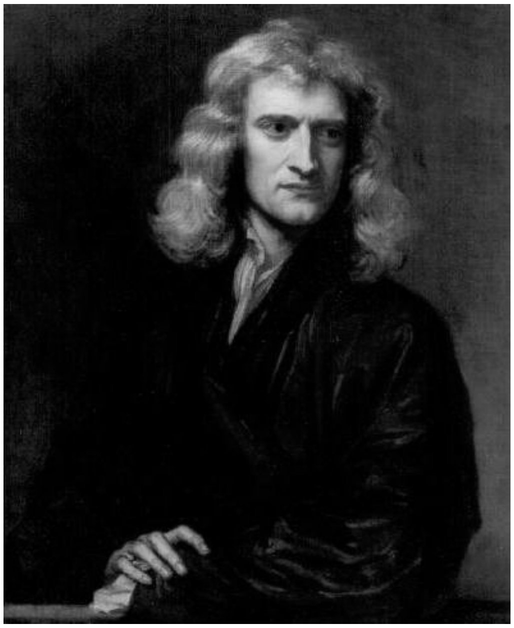
That is why, in order to understand the motivation behind Newton's scientific work, we have to look at the development of the productive forces in that period of time, and the scientific problems posed by it.

The development of the productive forces

What was the social condition in the period preceding Newton's time? In the earlier installments of this article we have seen that it was a time marked by the transition from the feudal middle ages to a new capitalist form of production. The merchant class that developed within the womb of the feudal society was becoming financially powerful, and was starting mass-production of goods in "manufactories". Initially these were simply sheds where a number of artisans together produced goods using the raw material and implements supplied by the merchant. But slowly, through the 16th and 17th centuries these manufactories became bigger, produced larger quantities of goods, and consequently the financial and political power of the producers increased.

The increase in production posed a few scientific problems. The goods had to be sent to distant lands for trade and commerce. But in those times, land transport was very rudimentary. The ox-drawn carts could not carry much load, and were very slow. In comparison, waterborne transport in barges, ferries and ships could carry far more goods, and was much faster. That is why the focus of that time was in improving waterborne transport. This demanded improved design of the ships, and for that one had to know the laws governing the motion of floating bodies. The tonnage capacity of the ships could be calculated only if one knew the quantity of water it displaces at different depths of submergence. While maritime transport was the preferred mode for reaching one country from another, river-based transport was the preferred mode for goods transport within a country. In addition, to increase the reach of inland transport, an elaborate system of canals was developed. The design of efficient canals and lock-gates demanded knowledge of the rules governing the flow of liquids through channels and cavities of different cross sections. Thus, waterborne transport posed various problems in hydrostatics and hydrodynamics.

An important problem in maritime transport was the problem of determining a ship's position in open sea. The position is specified by the latitude and longitude. Determining latitude was relatively easy: it could be found from the altitude of the sun at noon (i.e., at its highest point), if one has a pre-calculated table giving the sun's declinationfor the day at different latitudes. But the determination of longitude posed a tough scientific challenge. Until the solution of the problem was found, the ships had to move close to the shore, and thus had to travel much longer distances to reach the destination. People realized that the problem of determination of longitude is essentially the same as that of determination of the time at a given location, relative to the time at a "standard" location. A way of finding the time was through the observation of the bodies in the sky — the moon, planets, and stars. Thus, preparation of the catalog of the positions of these heavenly bodies became a matter of practical importance, and in most of the seafaring nations observatories were established with the express objective of preparing the charts of the positions of these heavenly bodies. Some of these bodies, like the moon and the planets move, and hence it became



Isaac Newton (1642-1727) at a young age.

necessary to know the laws governing their motion. Scientific attention was thus directed to the objects in the sky, and their motion.

In this period the struggle between the old kings, nobles and aristocrats, and the emerging bourgeois class took the form of armed fight for supremacy. As a result, warfare increased in number as well as in intensity. The demands of warfare also posed important problems before science. Firearms and cannons were already in use since the thirteenth century. For effective use of the firearms it became necessary to know the process that takes place when gunpowder is ignited. Why does a gun recoil, and by how much? At what angle should the cannon be inclined so that the cannonball can hit the target at a given distance? What is the trajectory of a bullet after it is fired? What is the effect of air resistance on the trajectory? Solution of these problems demanded the development of mechanics.

The necessities of larger volume of production needed ever larger quantities of metals — especially iron and copper. Increased warfare only increased the demand of metals. Thus mining came out of the old "craftsmen" character and became a major industry. Deeper and deeper mines had to be explored in order to reach the right kind of ores. This again posed important scientific problems. Water had to be continuously pumped out of the mine chambers. The mines had to be ventilated by pumping in air. The ore had to be transported out of the mine. The metallic iron and copper had to be extracted from the ore. These are problems of mechanics and chemistry. The excavation of the mine chambers and the connecting tunnels also needed a good idea of solid geometry.

In those days the main medium of exchange in trade was gold. The increase in the volume of trade needed ever larger quantities of gold. The gold mines of Europe were soon exhausted, resulting in a "gold famine". This was one of the reasons behind the royal patronage of the expeditions to distant lands. The gold famine also resulted in a great interest in alchemy — the forerunner of chemistry — because at that time it was believed that it was possible to turn other metals into gold using chemical processes.

Thus we see that the rapid development of productive forces in the period following the renaissance posed important scientific problems — in mechanics, hydrostatics, hydrodynamics, mathematics, and chemistry. But, out of all these, the most profound questions concerned mechanics, which absorbed the attention of scientists of that time. The further development of the productive forces crucially depended on the solution to these scientific problems.

Age of reason — personified: the life of Isaac Newton

It is a common belief that the making of a genius requires a complacent childhood, favourable hereditary tracts, and guidance and financial resource of parents. In this yardstick nobody would expect Newton to be what he was. His life confirms that every man is a product of his own struggle, and the people whom we call genius are more so.

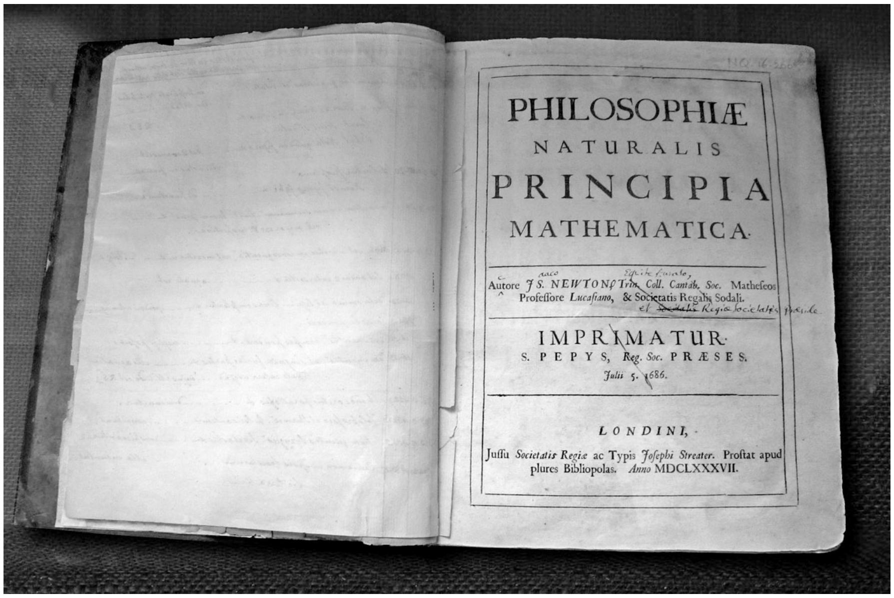
Isaac Newton was born on December 25, 1642 (the year Galileo died) in the village of Woolsthorpe, England. His father, who died before Newton's birth, was a farmer of moderate means. Newton descended from common men on both sides; there is no record of any notable ancestor.

Newton's mother remarried and left her three year old son with his grandmother. At the age of twelve Newton was sent to school at Grantham. Here, during his leisure hours, he constructed a number of innovative mechanical toys including a water clock, a mill (powered by a mouse), and many sun-dials (one of which still survives). In 1656 Newton's mother was widowed again and Newton was called home to help with the farm at Woolsthorpe because of the family's financial crisis. He proved to be useless in taking care of sheep, and was sent back to school, and in 1661, at the recommendation from his uncle, he proceeded to the University of Cambridge for further studies.

In those days the custom was that the students from poor families had to work as servant (called a subsizer) to students from richer families. Newton had to work as a subsizer at the university to make both ends meet. His academic record in his undergraduate years seems to be outwardly undistinguished. However, these were the years of formation of his scientific being and he waged a serious struggle to inherit the contemporary philosophical cross-currents and scientific ideas. From the critical notes in his notebooks, researchers have concluded that in these years he thoroughly studied Aristotle's "Organon" and "Ethics", Euclid's "Elements", Galileo's "Dialogo", Descartes' "Geometrie" and "Principia Philosophiae", and other important books on philosophy and science. From these studies he developed his own personal viewpoint in the matter of scientific investigation, and it seems the mathematical approach of Descartes has profound effect on his thought process.

In 1665, an outbreak of plague caused the universities to close and Newton returned to his home in the country, where he remained till 1667. There, in the two years of rustic solitude — age 22 to 24 — his creative genius burst forth in a flood of discoveries unsurpassed in the history of human thought: the binomial series of negative and fractional exponents, the differential and integral calculus, universal gravity as a key to the mechanism of the solar system, the splitting of sunlight into the visual spectrum by means of a prism — with its implication of understanding the nature of light, etc. He was a very cautious man in the matter of scientific work, and did not want to make his discoveries public until he obtained definitive experimental evidence confirming his analytical work. Yet, his mathematical abilities were so evident that his teacher Prof. Isaac Barrow resigned his Lucasian Professorship in 1669 and Newton was offered the post at the age of 27.

He initially conveyed his discoveries on the nature of light and colours to the Royal Society. But soon he retreated into his shell because some criticisms were raised when his communications were read at the Royal Society meetings. He kept working, performing experiments, checking his conclusions. Then in 1684 a meeting with Hal-



A surviving copy of the Principia Mathematica.

ley changed all that. By then Halley had come to the conclusion that there must be a central force acting on the planets, but at that time nobody had been able to work out the orbit of the planets starting from that premise. He asked Newton what would the trajectory of a planet be, if it is acted on by a central force of the inverse square type. Newton answered, simply, that it would be an ellipse. "How do you know?" "I have calculated it."

Halley was flabbergasted. This man knows the answer to a question everybody is looking for, and yet he has not published it? He urged Newton to let the world know about his calculations. This prompted Newton to embark on a grand plan to write down everything that he has obtained in the area of mechanics into a single book. This took an almost inhuman effort, working day and night for two years. Finally when it was published in 1687, the Principia Mathematica went on to become one of the books that changed human history.

The Principia Mathematica

The Principia Mathematica was written in an abstract mathematical language. This could not be otherwise, because Newton's intention was to tell the world how the problems of the day could be solved by assuming a few "laws" of nature, using the techniques of mathematics. Still he took care to be intelligible to the learned people. Even though he had arrived at most of the results using the technique of calculus which he invented, he never used calculus in his expositions. Instead, he took pains to derive the same results using the methods of geometry which the learned people of that time were familiar with.

The Principia Mathematica is written in three volumes. In the first volume Newton clearly defines the terms to be used in the exposition[1], and then states the laws of motion. Thus, he lays the groundwork

[1]Here he adheres strictly to the demands of formal logic.

on the basis of which the theoretical framework will be built.

The second volume is devoted to the application of these laws to achieve the solution of mechanical problems related to the movement of bodies. He treats motion of bodies in resistive medium (this solves the problem of ballistics, and has direct implication in warfare), the motion of floating bodies and hydrostatics (this formed the theoretical basis for the design of ships), the compression of gases and liquids under pressure (recall the problems posed by mining), movement of liquids in channels and tubes (theoretical foundation for the design of canals, locks, and water pumping equipment), and the movement of pendulums against frictional resistance (this had implication for the construction of pendulum clocks), etc.

The third volume of Principia is fully devoted to what he calls "System of the World". Based on the laws of motion and the theory of universal gravitation, he explained the observed motion of the planets, proved Kepler's laws, explained why tides occur, and showed how one can predict the position of the moon and the planets at any time in the future. This not only had immense importance in navigation, as we shall soon see, it completely changed the way scientists perceived nature.

Thus we see that the problems posed by the contemporary society and the development of the productive forces supplied the subject matter of Newton's line of thinking. The picture of Newton's character as an isolated genius, unconcerned about the society, discoveries sparked by falling apples — these are simply myths propagated by people who have failed to understand the content of Newton's work because of the abstractness of his exposition and the absence of direct reference to the above practical problems.

It is always found in the history of science that, whenever the society is ready for certain development of ideas, usually a number of people would be working on each idea at the same time. We have seen that at that time the society posed certain scientific questions, and the further development of the productive forces crucially depended on the solution of these problems. In that situation it is natural to expect that many people would be contemplating the solution of each problem at the same time. That is exactly what had happened. The Royal Society records show that many people at that time were working on the problems of hydrostatics, hydrodynamics, and mechanics. In fact, both Hooke and Halley had realized that the motion of the planets must be under the action of a central force, and guessed that the force would follow an inverse square law. But, they could not prove that a force that goes as the inverse square of the distance between two objects would mathematically imply the Kepler's laws of planetary motion. Hooke and Newton were working on optics, the theory of colours, and the nature of light at the same time, and had reached different conclusions. While Hooke saw light as a wave, Newton favoured a corpuscular theory of light. Newton and Leibniz developed the methods of calculus at the same time.

In such a situation it is not unnatural to see debates between scientists on the content of the discoveries, and controversies concerning who discovered something first. Today, the primacy of a discovery is decided on the basis of who communicated a discovery to a scientific journal first. At that time there were no scientific journals or system of recording the date when a paper is communicated, and so it was difficult to settle the claims. Mostly the scientists made the discoveries while working away from each other, and so it was impossible to ascertain who made a discovery first. The disputes between Newton and Hooke on the nature

Robert Hooke (1635-1703). Artist's impression, drawn at a later time.

of light, and that between Newton and Leibniz on the primacy of the discovery of calculus should be seen from this angle. It may be true that each piece of idea may have been worked out by different people at almost the same time, but there is no denying that it was Newton who achieved the grand synthesis — to create a system of knowledge which was to form the basis of scientific thinking for centuries to come.

There is another aspect worth keeping in mind when evaluating the contribution of Newton. We have seen that Newton's time immediately followed the renaissance in Europe. We have seen in the last installment that, through the period of the renaissance, people like Galileo, Bacon, and Descartes charted out a new path of doing science. The change happened with incredible swiftness: Copernicus' book was published in 1543, Galileo died in 1642, and Newton was born in the same year. Thus, after a millennium of unquestioning submission to religious dogma, the "age of reason" took root in a section of the people within a short span of only a hundred years. But the majority of the population was still under the spell of the Church — Catholic as well as Protestant. Religious obscurantism, bigotry, and blind beliefs were still ruling the minds of the common people. Only among a section of the learned people the seed of doubt had been sown about the correctness of beliefs propagated by the Church. The central belief that everything in the world is created and controlled by God was till intact. The universities were still centres of dry scholasticism.

Thus, in those tumultuous times, old religious values were still very strong; the new outlook based on reason had taken birth, and was in struggle with the old. Every man's thought process is built by absorbing the cross-currents of thought existing in the contemporary society. So was Newton's. Many commentators have not even tried to understand this aspect, and have made Newton's religious belief a focal point in their evaluation. We have to understand that this contradiction in Newton's personality was only normal. The philosophical ground for the emergence of a secular mind completely devoid of religious influence had not yet been created in Europe's intellectual atmosphere. The evaluation of any great man has to be done on the basis of which philosophy — the old backward-looking line of thought or the newly emerging line of thought — is reflected in a greater measure in his work. Seen from this angle we find that the newly emerging age of reason had its best personified expression in Newton.

Why Newtonian mechanics dealt a blow to idealism

What is the essential content of Newtonian mechanics? Since time immemorial people had seen motion of bodies — the motions of the sun, moon and the planets, the motion of an arrow released from a bow, etc. But in the ancient time people did not know the reason behind the motion of material bodies. So they assumed a supernatural

Gottfried Wilhelm von Leibniz (1646-1716).

hand behind every motion. They thought that God makes the sun, the moon, and the planets move. They even saw a divine hand deciding the path of an arrow released from a bow. This is because, following Aristotle's theory, people thought force produces motion. Thus, wherever they saw motion, they assumed the existence of some entity continuously applying force.

Galileo showed that force does not produce motion; force in fact produces a *change in motion* — what we know today as acceleration. Newton made it his first law — "unless acted upon by an external force, a body will continue in uniform rectilinear motion in a straight line." This told people not to look for something applying a force whenever they saw motion; and to look for it only if they saw change in motion. Thus the role of God in causing all sorts of motion became truncated.

But we do see many instances of change of motion in the bodies around us. The motion of the moon around the Earth is an instance where change of motion is taking place at every instant. Who is applying the force in this case? Newton showed that gravitation — a universal property of matter — is responsible for it, and that it follows a definite mathematical rule. Thus the application of this force does not depend on the will of God. The role of God became further restricted.

Then Newton showed that if a force is applied, the change in motion of any body also follows a definite mathematical rule: force = mass $\times$ acceleration. Using this rule one can obtain a differential equation for the motion of any body. Now, if we know the initial condition of motion of the body (like the initial position and velocity), then one can solve the differential equation to obtain the condition of motion at any time in the future. He showed that the motion of the planets, comets, arrows, and cannonballs can be predicted by application of this method.

This implies that there is no role of the God in the motions of the planets and other "heavenly" bodies. Man can calculate their future positions using the method proposed by Newton. The motion of cannonballs and arrows would simply be parabolas — these may only deviate a bit from the parabolic paths due to air friction. Newton also showed by how much they would deviate. Thus there remained no role for God in any type of motion.

After being eclipsed by idealism for millennia, materialism made a forceful comeback in the sphere of philosophy. This is what set the agenda for science for centuries following Newton. And this is the historical importance of Newton and his Principia Mathematica.

The emergence of mechanical materialism

Due to the influence of religious philosophy, many people could not digest the role of God becoming so insignificant in their picture of the world. They agreed that if something is in motion it will always remain in motion unless acted upon by an external force. But they asked, who created motion for the first time? Who gave the first impulse? They pictured this as the role of God: giving the first push and setting the universe in motion. Thus came the concept of a “Prime Mover”. Due to his own religious belief, Newton himself sided with this position. This was the limitation of the time: the stage was not yet set for the emergence of a truly secular world-view. That situation emerged only in the nineteenth century when the idea emerged that there can be nothing in absolute rest, without any motion. Matter exists means it exists in motion. Therefore it is unscientific to think that initially all matter was at rest, and at some point of time somebody injected motion into it. It is now understood that motion is a mode of existence of matter.

Newtonian mechanics created a new picture of the universe, where everything is in motion following the fixed laws. The stars and planets are moving in specific orbits obeying the laws of motion, like the hands of a clock. In this mental picture the whole universe looks like a gigantic machine. The motion of each specific body is like that of a part of the machine — each part moving in its own course, following fixed rules. This line of thinking gave birth to a philosophy which is in nature materialistic, and in that sense it worked towards freeing people from many obscurantist ideas and misconceptions, but its form was mechanical. The historical importance of this philosophical trend, known as mechanical materialism, was that it again brought materialism to the centre of current thought. □