A Brief History of Science
Part 11: Philosophy transcends mechanical materialism and metaphysics

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The major developments in science in mid-19th century

In the last issue we focused on the most important advance in science in the mid-19th century: Darwin's theory of biological evolution. While the development of the theory of evolution has far-reaching consequences on our understanding of the material world, there were many other outstanding advances in other fields that occurred around the same time.

We have earlier seen that the first person to observe the cell was Robert Hooke. But at that time the importance of the cell in organizing organic life was not understood. In 1838-1839, M. J. Schleiden (1804-1881), T. Schwann (1810-1882), and R. Virchow (1821-1902) showed that the cell is the basic building block of all living organisms. They proposed the three postulates of cell theory:

1. All living organisms are composed of one or more cells;
2. The cell is the most basic unit of life;
3. All cells arise only from pre-existing cells.

Thus they established a common feature of the animal and the plant kingdoms in terms of structure of these bodies. It was found that the cells in an organism's body are born, go through their lives, and die—as a continuous process running through the course of the organism's life.

Man's understanding about electricity and magnetism also advanced in leaps and bounds during this period. In 1820, Hans Christian Oersted (1757-1851) discovered that electric current could deflect a compass needle. Following the lead, Joseph Henry (1799-1878), Andre-Marie Ampere (1775-1836), Carl Friedrich Gauss (1777-1855), and Georg Simon Ohm (1787-1854) investigated the mutual interaction between electric current and magnetic field. This line of development was crowned by the outstanding experimentalist Michael Faraday's discovery of magnetic induction. He showed that the interaction between electric charge and magnetism was dynamic and not static: only a moving electric charge can induce magnetism and only a moving magnet can induce movement of charge. This established the equivalence between electricity and magnetism. Then the great theorist James Clerk Maxwell (1831-1879) used these results of experimental investigation to establish the theory of electromagnetism as a set of four equations relating electrical and magnetic quantities.

It was the period of the Industrial Revolution, and there was great demand for

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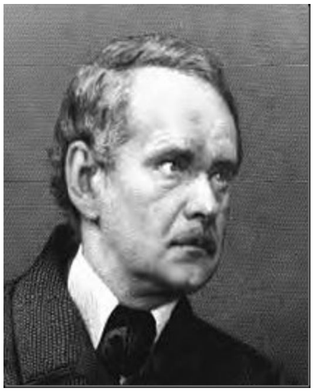
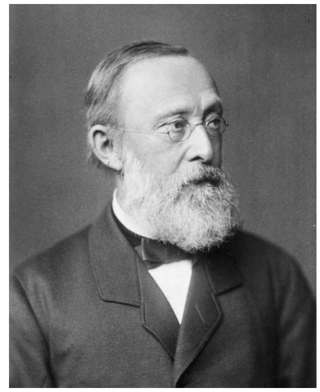
  

The originators of cell theory (L-R): Matthias Jacob Schleiden, Theodor Schwann, and Rudolf Ludwig Carl Virchow

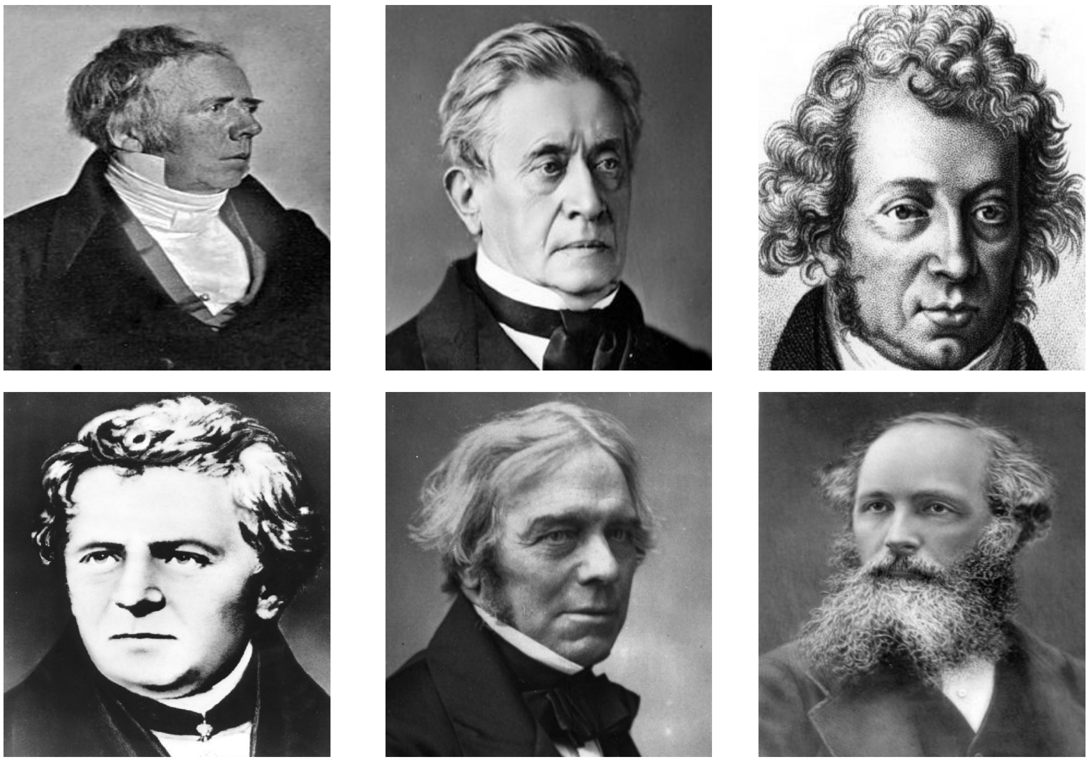
finding ways of powering industry. Many people tried, in various ways, to invent a "perpetual motion machine" with no success. Between 1842 and 1847, scientists like J. R. Mayer, J. P. Joule, H. Helmholtz, etc., established that the different forms of energy could be transformed from one to the other and that the quantity of energy is always conserved in such transformations. Thus, energy cannot be produced out of nothing. Earlier in 1824, Nicolas Leonard Sadi Carnot studied the nature of heat engines carefully and had showed that when heat energy is converted into mechanical energy of the rotation of a shaft, some heat is always lost to the environment, and thus such engines can never be 100% efficient—even in theory. These developments lay the ground for an integrated knowledge about energy—the first and the second laws of thermodynamics.

Shortcomings of mechanical materialism comes to light

These developments in science made it apparent that the prevailing philosophical currents were inadequate to guide further advancement in science. As we have seen earlier, the prevailing philosophical currents could be divided broadly into two categories: the idealistic and the materialistic. While materialism held that matter and the material world exist independent of our consciousness, idealism maintained that matter is not primary; it is spirit that creates matter and the material world. While various shades of idealism were doing their rounds in religious circles, scientists proceeded in their pursuit from the standpoint of materialism.

But scientists of that era saw the world from the point of view of mechanical materialism. Metaphysical way of thinking was still prevalent among a section of scientists. And in logical reasoning, their tool was Aristotelian formal logic. In order to understand why the advancement of science in the early 19th century made these three aspects inadequate, let us first recapitulate what their specific features were.

Formal logic had provided the guiding principles of understanding and analysing things as they are: viewing things as static, stable, and unchanging. But the developments in different branches of science showed that there is nothing really static and unchanging. So it became necessary to study the material world in the process of



Those who developed the understanding of electricity and magnetism, top row (L-R): Hans Christian Oersted, Joseph Henry, Andre-Marie Ampere, Bottom row (L-R): Georg Simon Ohm, Michael Faraday, and James Clerk Maxwell.

change and development. This demanded a system of logic that transcends formal logic and can account for change and development.

Now, it is not true that the ancient philosophers did not see change. Night changes into day and day into night. Each animal is born, goes through growth and maturity, and finally dies. These changes in day-to-day life were of course seen. But the idealist way of thinking linked all changes to some idea or intention. For the idealist, all changes were, in the last analysis, brought about by something outside matter—an idea which is unchanging. For the idealist, all change happens with a purpose. Mechanical materialism, on the other hand, sought the cause for change in the material processes or phenomena. They saw the world being composed of hard impenetrable particles and sought the reason for all change in the motion of these particles and their interaction. In general they tried to understand any change in terms of interaction among the component parts of the entity undergoing change.

What was the nature of the interactions? The mechanical materialists saw each component part of an entity (or particles at a fundamental level) as having separate and distinct existence. To them, the totality of the interactions gave the totality of what can happen to that entity. In the big picture, the totality of the interactions among particles in the universe, in their view, constituted the totality of everything that happens in the universe (recall Laplace's assertion that he can compute everything that will happen in the future, if he is provided with the information about the initial state of each particle in the universe, and enough computing power to solve the equations governing their motion). Crucially, they saw these interactions to be strictly of mechanical type, in the sense that they consist only of the external influence of one particle on another. This is like viewing the whole world as a complex piece of machinery. They sought answers to all questions about the material world in the working of this machinery, in its mechanism.

All mechanisms have a few characteristic features. First, they have component parts that fit together; second, they require a motive force to set them going; and third, the parts interact following laws that can be exactly stated. How would you find out the mechanism of typical machinery like a watch? You would break it up into parts, would find how the parts fit together and what laws the parts obey when interacting with each other, and how these interactions give rise to the working of the watch as a whole. This is how the scientists of the time tried to understand nature: they would divide nature into small pieces, and would study a piece at a time. To study each such piece, they would find out what the component parts were, how they fitted together, and what were their laws of working. This approach worked fine in many cases, but proved inadequate in dealing with the challenges faced by science in the mid-19th century.

Any piece of machinery keeps on working in the same way over the course of its life, eternally repeating the same cycle of mechanical processes. So the mechanical materialists looked for something that does not change, something that is permanent, within the observed processes. They took it that the material world is basically unchanging, all changes that we see are governed by mechanistic laws. Mechanical materialists saw changes everywhere, but viewed these as mere repetitive cycles of the same process. This viewpoint failed to analyse nature in its course of development, in the emergence of new qualities—like the appearance of a new species or a seed sprouting into a sapling.

Yet, by the mid-19th century it was clear that there were small quantitative changes as well as great qualitative changes in nature. The development in chemistry showed that all chemical reactions led to qualitative changes in the constituents; the development in thermodynamics showed that any form of energy can be qualitatively transformed into another; and exploration of the process of biological evolution showed that the course included speciation events—qualitative transformations that led to the emergence of new species. Discovery of these processes threw new challenges that the mechanical materialist viewpoint was philosophically unable to cope with. It was increasingly being revealed that the processes of nature did not merely involve infinite repetitions of the same cycles of mechanical interactions. In reality natural processes involved continual development and evolution, producing new forms of existence.

Finally, a problem with the approach of mechanical materialists was that they could not remain materialistic consistently. As any piece of machinery requires a motive force to set it going, when they faced the question about the motive force driving the machinery of the universe, they sought recourse in the idea of an extra-material 'prime mover'. This opened the door to idealism, what they intended to oppose.

Those who established the science of transformation of energy. Top row (L-R): Julius Robert Mayer (1814-1878), James Prescott Joule (1818-1889), Herman von Helmholtz (1821-1894). Bottom row (L-R): Nicolas Leonard Sadi Carnot (1796-1832), Rudolf Julius Emanuel Clausius (1822-1888), William Thomson (Lord Kelvin) (1824-1907)

The problems with metaphysical way of thinking

The metaphysical way of thinking, developed in ancient times, persisted in course of the scientific development of the 17th and 18th centuries. This style of thinking implies thinking in abstraction, divorced from reality. Scientific developments clearly established that each material entity exists in specific conditions of existence and its character depends on that. Now, if one talks about some inherent quality of a material substance without reference to its conditions of existence (for example, iron being hard without reference to its temperature), treating that quality abstractly as if it is independent of its condition of existence, then that reflects a metaphysical way of thinking.

Secondly, the metaphysical way of thinking would study things assuming its characters as given, fixed, and stable, without any change and development. For example in the study of psychology, a metaphysical way of thinking would consider a person as essentially good or bad, intelligent or dull—without reference to the conditions of his/her life that gave rise to these characteristics, and without considering the fact that these characters change as the person evolves in his/her life. The whole idea of measuring a child's IQ reflects a metaphysical way of thinking as it considers intelligence as something fixed, intrinsic to an individual, independent of the person's life-struggle.

Metaphysics presupposes that each thing has its own fixed nature, its own fixed properties, and considers each thing by itself, as isolated from all other things. It views the properties of each thing as a given, separate object of investigation, without considering things in their interconnection and in their change and development. It follows the dictum of Aristotelian formal logic "each thing is what it is and is distinctly different from all other things". It follows an "either-or" logic: an animal is either a reptile (lays eggs) or a mammal (delivers babies and suckles its young). This logic again ran aground when scientists first encountered the platypus—an animal that lays eggs and suckles its babies. This logic ran into trouble when scientists considered evolution—where a species changes into another. It became clear that a better approach was needed when doing science in the 19th century.

However, the classification of things into separate "bins" arose out of necessity. For a biologist, it was not possible to think clearly without classifying the biological world into kingdom, phylum, order, family, genus, and species. For a chemist, it was necessary to classify things into bins like metals, non-metals, acids, alkali, sugars, etc. Yet, it was becoming clearer with each passing year that the distinctions were not as hard-and-fast as they were first thought to be. If you try to put a thing either in category A or in category B, you are in trouble if you find a thing that has some characters of A and some of B. You run into trouble when you find that in some situations it behaves as A and in some other situations it behaves as B. You run into trouble if you find that A can, in some circumstances, change into B. These contradictions were in fact encountered in 19th century science, which called for development of a proper approach that could guide the further advancement of science.

It is important to note that metaphysical way of thinking is not be equated with thinking in abstraction. All human thought contains abstraction in some form or other. The problem with metaphysics is that in the process of abstraction things are considered in separation from one another, ignoring their interconnections; it considers things as fixed and unchanging and ignores the process of development and evolution, and it considers things in isolation, separated from their condition of existence.

Further development of materialism

So, in view of the tumultuous developments in various areas of science over the 18th and 19th centuries, mankind faced the question: What should be the correct scientific approach in looking at and perceiving nature? In what ways should we direct our investigation to further unravel the mysteries of nature?

Faced with these questions, science firmly took the side of materialism as against idealism. Science starts with the premise that the world exists independent of our consciousness. Now that we understood that man also came into being through a process of evolution, a natural corollary was that nature existed even before man emerged on this planet. It will continue to exist even if there is no intelligent being to do the perceiving. As intelligent beings our job is to understand nature, how it works, and the laws governing the existence, motion, and evolution of everything in this material world. While idealism held that matter is a product of idea, science upheld materialism in demonstrating that idea is always formed in a human brain—a material entity, and ideas are generated through interaction of the human brain with the surrounding physical world and society. Thus, matter is primary, idea is secondary.

But what is matter? The materialists' idea is that everything in this material world is matter. But that needs to be defined properly. Apples, bananas and oranges are "things" with specific characteristics, and when you leave out their individual characters and focus on the general property, you come to the idea of "fruit". Similarly, there are millions of different "things" in this material world, and when you leave out their individual characters and abstract out the general property—that of existing independent of our consciousness—then you come to the idea of "matter". It is therefore a philosophical category, and everything existing independent of our consciousness is matter; this concept of matter is reached through the process of generalization and abstraction.

How do you know that each piece of matter really exists? We know that because they leave some impression on our sense organs. I know that the table exists because I can see it. I know that the food is being cooked in the kitchen because I can smell it. Likewise, I can feel by touch, hear the sound and feel the taste of material substances. That is how I know that they really exist. Some things may not be so palpable as to directly influence our senses. For example, we cannot see the distant galaxies or minute molecules, but can still perceive their existence using appropriate instruments which in effect work as extension of our sense organs. Since the ability, sensitivity, and reach of our instruments are increasing with each passing year, things that were not perceptible 50 years back are being perceptible now. And in the infinite universe there will always remain very distant objects whose existence will be revealed only when our instruments develop adequately. The proper understanding of matter should take these aspects into account. Thus the idea developed that matter is that which has the quality of being perceptible to our senses, either directly or with the aid of instruments. This implies that something that is in principle not perceptible is not matter, and therefore science would not be concerned with it. Secondly, matter is not just what has mass (the way most science textbooks define it); light and other forms of electromagnetic radiations are also matter, because they also exist independent of our consciousness and are perceptible to our senses either directly or with the aid of instruments.

Developments in science till the 19th century made it clear that the world is not a collection of readymade things, with fixed properties. Everything in the material world is going through change and evolution. From this came the realization that the task of science is not to study things as fixed and static, but as things in change and evolution. Not only that, things are continuously coming into being and going out of being. Stars form, go through their lives, and finally meet explosive ends. Cells in the animal bodies are born from other cells, live for a time, and die. Each animal is born, goes through life, and finally dies. Each species, likewise, is born, has a period of existence, and finally goes extinct. In some physical process and chemical reactions, specific things are created and in other physical processes they may be annihilated. Thus the idea emerged that things come into existence and go out of existence. Therefore the task of science should be to study matter in its change and development, it has to understand how things come into being and go out of being. These ideas crystallized in the new materialist philosophy, which demanded the study of objects and phenomena in a state of flux, in a process of development and change. The new philosophy stressed that science should focus not on studying things; rather it should focus on studying processes. We should not view the material world as a complex of things; we should view it as a complex of processes in which things are continuously undergoing changes, continuously coming into being and going out of being. Metaphysics studies "things as they are"; now science should focus on understanding the process of change and development of matter.

The new philosophy insisted that science should not study things in isolation; rather it should study things in their interconnections. It should recognize that things are connected with, dependent on, and determined by each other. Science should not abstract properties of things divorced from their conditions of existence. Rather it should study how the properties of things change as the conditions of existence change.

What about the mechanical materialist programme of understanding all change in terms of interaction of particles constituting each body? Can this approach succeed in understanding change, evolution, development, and things coming into being and going out of being? It was clear that this approach was not successful in addressing the issues confronted by 19th century science. But what exactly was the problem?

It was realized that the main problem was that mechanical materialism treated matter as inert mass, to which motion has to be imparted from outside. The development of thermodynamics showed that the different forms of energy were nothing but different forms of motion of matter. Sound was one form of motion of matter while heat was another form, electricity was yet another. When one form of energy is transformed into another, actually one form of motion is transformed into another. But motion always remains. Following Galileo, it was realized that when a body appears to be at rest, it is actually at rest with respect to the observer; and both are moving with the motion of the Earth, that of the solar system, and so on. Therefore the general concept was proposed: matter cannot exist without motion, and motion is meaningless without reference to matter. Hence the correct understanding is to say that motion is the mode of existence of matter. With this viewpoint, it was no longer plausible to conceive matter as inert mass, to which motion had to be imparted from outside. Motion was now conceived as an inherent attribute of matter.

The other assumptions of mechanical materialism also did not stand ground in the background of the development of science in the 19th century. One tacit assumption was that each thing or particle, whose interaction constituted all change in the material world, had a fixed nature independent of everything else. Each thing was considered as an independent unit, existing in separation from other things. With the further development of materialism it was understood that this assumption was wrong: each body or particle also undergoes change and exists in interaction with other bodies or particles. Unless we take that into account, our study of dynamic nature will invariably be misled.

Another erroneous assumption was that the totality of all change observed in the universe was nothing but sum total of the interactions among the particles—separate units entering into external relation with other things. If this were true, it follows that the whole of a body is nothing but sum total of the parts. Cell theory amply demonstrated the error in this assumption: the cell is composed of millions of molecules, but its character is not a simple sum total of the motion and external interactions between the molecules. The cell as a unit has characteristics distinctly different from those of its parts, and can perform specific tasks. Likewise, a man is also composed of many different molecules, but the character of the man cannot be understood simply as a sum total of the motion of the molecules. At a particular level of aggregation and interaction of the constituent parts, a particular new character emerges. The same is true for each organism, each species, each planet, each star, and each galaxy. The properties and laws of development of the whole cannot be fully understood by simply breaking things apart and studying the properties of its parts.

The gigantic task of assimilating the essence of the discoveries of different fields of science, of pointing out the lacunae of prevalent lines of thought, and of showing the correct direction of thinking—in short, of developing a new world outlook based on science—was done almost singlehandedly by two men: Karl Marx (1818-1883) and Frederick Engels (1820-1895). All the arguments outlined in this section that freed science of the hangovers of mechanical materialism and metaphysics are their contribution.

They especially stressed on the ever-changing nature of matter and the material world, and the need to understand the process behind the change, evolution, and progress observed in nature. Different fields of science had shown that the process of change in each thing was in some ways different from others, but there was always some commonness. If we leave aside the differences, what remains are the common features of all change and evolution observed in nature. The first common feature is that there are opposing tendencies or forces in each thing, and the basic cause of change is the interaction between these opposing tendencies. The exact nature of these opposing tendencies differ from one body to another, but, in any process of change, one can always identify the opposing tendencies, each trying to change the object in opposing directions, one trying to change the object and the other resisting change. The second common feature is that change or evolution does not proceed linearly; there is continuity as well as breaks—while undergoing slow and quantitative process of change a nodal point is reached when one observes a qualitative transformation. When this happens in the process of development—here comes the third general feature—a new thing appears negating the earlier existence, assuming a different identity. This new emergent thing would also be subject to contradictory tendencies whose interaction would lead to small quantitative changes, and when a nodal point is again reached, would undergo a qualitative transformation, negating its earlier existence. Thus, again a newer thing would be born. This is the internal process responsible for change and development observed in nature. Thus, the general principles governing change and development were identified as : 1. The unity of opposites; 2. From quantitative change to qualitative change and vice versa; and 3. Negation of the negation.

If one recognizes these general principles, the directions of studying change and development in nature becomes clearer: In every particular process a scientist would have to identify the opposing tendencies. When stability prevails, one would be able to write equations by equating these opposing tendencies, and when a quantitative change occurs one would be able to write differential equations governing the process by writing the opposing tendencies in quantitative terms. When a nodal point reaches and a qualitative change occurs, it negates the earlier existence and hence the opposing tendencies also change. Now these have to be freshly identified and the process of its change has to be freshly worked out.

In developing this theory, Marx and Engels adopted Hegel's dialectical logic (see the last instalment of this article). In the early part of the 19th century Hegel formulated the basic laws and categories of dialectics which was undoubtedly one of the great achievements of human thought. But Hegel was an idealist who considered that the basis of nature and society was the absolute idea or 'world spirit' that exists eternally, independent of man and nature. But, while Hegel saw these merely as rules of logic that operate in the realm of ideas, Marx and Engels pointed out that they work because these are the general features of all changes and evolution seen in the natural world.

Thus they combined dialectics with a consistent materialist world view to create a truly scientific materialist world outlook. Since the emergent scientific materialism was based on this dialectical logic, the new philosophy is called dialectical materialism.

However, unlike other philosophers, Marx and Engels did not stop at telling people how to interpret nature and society. They went further and said that, if we really understand the laws governing change in nature and society, we should be able to change things for the better. We cannot change the laws of nature, but by understanding the laws we can utilize them to improve human life. Similarly, we cannot change the laws of development of society, but by understanding them we can change society for the better.

That a scientific philosophy could be applied to society so as to change it became an inconvenient truth for those who stood to gain by maintaining the system, and who would spare no effort to maintain it and who would resist tooth and nail any attempt to change the status quo. That is why their views on science were never publicized or propagated. The ideas of dialectical materialism were never taught in the academic system. Those being trained to become scientists of the future were deprived of the opportunity of absorbing a correct scientific worldview to guide their pursuit.

Yet, science has, in the main, adopted the guiding principles they had put forward. Any practising scientist today will agree that these are the principles followed in science today; yet most of them do not know who originated these ideas as a scientific philosophy. Their names may have been blocked out, but science cannot help but adopt their ideas, because these are true. You cannot successfully do science without adopting the correct scientific viewpoint and method. So we see a peculiar dichotomy today: scientists adhere to these guiding principles in their scientific pursuit, and yet, outside the laboratory many scientists believe and conduct their lives following ideas of idealism and metaphysics.

There have also been attacks on this scientific materialist philosophy, which has slowed down the advancement of science in the period following the great advancements mentioned earlier. A strong philosophical current called positivism developed as a challenge to scientific materialism, by which many scientists of the later part of the 19th and early 20th centuries were influenced. We'll talk about that in the next instalment of this essay.