The Origins and Growth of Physical Science II

ed. D.L.Hurd & J.J.Kipling

July 14 - 21, 2020

This concluding volume brings the story up to Modern times i.e. the turn of the century, i.e. early 20th century with the Atomic theory firmly established and the door opened to quantum theory which would constitute the greatest breakthrough ever in physics.

As we all know speculations about an atomic theory, i.e. the existence of fundamental units of matter, go back to Antiquity. At that time there was no real scientific basis for it, that would take time to develop. The natural idea when it comes to matter is that it is continuous, that it is a quantity indefinitely divisible and invariant under all scales. That this is not the case is a fundamental physical insight and can be observed on macro levels, such as surface tension of water which behaves very differently under scaling. Water drops cannot be enlarged[1]. Thus one can in principle count matter, which were taken *ad notam* by Avogadro who postulated that gases at fixed volumes, temperatures and pressure contain the same quantity of 'units' (which in normal circumstances meant molecules not atoms, which was a source of some confusion), thus in particular the weights of such gases are proportional to the weights of their minimal units. This very simple and strong principle of Avogadro is very fruitful and provides the key to the atomic nature of matter, but it was not immediately noticed an appreciated at the time, but cruder principles were in use which showed up in the remarkable fact that chemical reactions involved small fractions, i.e. integral commensurates of the chemicals involved which enabled Dalton to establish the first facts of atomic theory at the beginning of the 19th century. The actual determination of Avogadro's number was something else and of much less importance, the crucial fact was that it existed and made sense. It could be applied in the researches of Gay-Lussac when combination of gases made the considerations particularly simple and clear cut. One should not forget though that the atomic theory was controversial throughout the 19th century, the great physicist and philosopher Mach though of atoms as useful fictions but not as anything real [2].

Once matter becomes countable, whole new areas are opened up. For one thing atomic

[1] If you make a scale model of the Solar system, it will look the same, the orbital periods due to gravitation will not change. The easiest way to see this is to look at circular motion. We will get that v^2/r is proportional to $r^3/r^2 = r$ hence v is proportional to r and we are done. However, if we enlarge the Earth as to make us in comparison small as ants, we would not have their agility. Strength of muscles and bones depends on the structure of matter not invariant under scaling, there are canonical measures. On a trivial plane, if you let toy cars collide at relatively high velocity, they will not crumble as real cars (which intrigued me as a child). A scale model of the Earth, a ball of iron with radius 64 cm, say being hit by a speck of iron 1 mm across traveling with a velocity of say 3 cm/s will hardly make a dent, but scale it by a factor of ten millions, and the effect will be catastrophic. The scenario of a small asteroid hitting the Earth will scale by a power of five.

[2] something Einstein sought to counter by his explanation of Brownian motion

weights appeared commensurable[3]. This made it possible for Mendelev to make a list of the basic elements, spot gaps, and also more significantly discover a periodic behavior which made it possible to predict properties of hitherto unknown elements; and more significantly give the key to the structure of atoms in terms of shells of electrons, which would have to wait until quantum theory.

Another theme was the emergence of organic chemistry, the overriding philosophical significance of which was that there was no difference between the organic world and the physical, which was a big step for materialism. It also meant that for the first time science would have quotidian applications of great value, not the least when talking about commercial such. Celestial mechanics, which was an intellectual breakthrough of first order, it had no effect on daily lives, basically as little as Medieval Scholastic speculation. In the 19th century a symbiosis between chemistry and industry would come to the fore, especially in Germany, where the most important organic chemists worked. The reason for that was the synthesis of new materials and chemicals of great use in agriculture, but not confined to that. As a trivial, yet commercially important, examples were new dyes, which played a big rôle in the textile industry. An example being the discoverer, or inventor, of the dye mauveine namely Perkin. From a scientific view the great advance as that compounds should not just be thought in quantitative terms, the structure of how they fitted together was of paramount importance, and once again, suggestions for such structures were entirely cerebrally based, direct X-ray investigation was of a later date. Classical is the way of how Keukele figured out how benzene had to be structured; it all came to him in a dream, or at least during a deep slumber.

If organic chemistry affected the lives of people, electricity would do it even more fundamentally, but that would take some time. The origins of the study goes back to Antiquity when of course magnets were not unknown, but similar phenomena could be made by rubbing amber and attracting chaff. The first systematic investigator of magnetism was Gilbert at the turn of the 17th century, but his efforts were mainly descriptive. A real synthesis of the phenomena would have to wait until the 19th century. It would all be part of electrodynamical theory, the intellectual triumph of that century. It started out with the nature of light and here we are confronted with the two giants of 17th century physics, namely Newton and Huygens. Newton proposed the corpuscular theory of light, namely that it consisted of particles traveling very quickly in straight lines; while Huygens advocated a wave theory of light, which would in the early 19th century be taken up by Young and replacing Newton's. However, Newton would have a least a partial vindication, in modern physics light is both particle and wave, and not only light, but also small entities such as the electron. This is of course puzzling but in the world of the atom, ordinary everyday conceptions have no purchase, we have come a long way from thinking of matter made up of small hard and solid balls. The wave theory of light was essential for the creation of the electrodynamical theory, and I guess Newton's corpuscular theory would only have added confusion and prevented an eventual synthesis.

Newton's contribution to the anthology is very readable and reveals him not only

[3] Complicated by the existence of isotopes, the atomic weight of chlorine being a classical example. From a strictly logical point of view that should have killed the theory of integral commensurability, but in science one is wary of premature falsification and tend to leave the door open.

as a theoretical genius but also a very practical man[4], in fact an excellent experimental physicist. Huygens was one of his few contemporaries who could start to approach to match him. He reports interestingly on his ways of arguing in physics admitting that there is no way one can obtain the same certitude as in Geometry; the reason being that in geometrical reasoning one can rely on fixed and incontestable principles, while in physics principles prove their worth by their consequences. In physics one can only prove things up to some probability, but when the conclusions one draws are in accordance with experiments, especially a great number of them and furthermore further consequences are derived, likewise in no conflict with experiments, one can be pretty certain that things are correct.

It is interesting that at the time of Newton and Huygens one had a very good sense of the speed of light. This determination was due to the Danish astronomer Rømer who looked at the oculations of the Jovian satellites. The explanation of the measurements given by the editors of the anthology is not that clear, but the point being that the paths of at least some of those satellites are almost circular, hence one can rather easily predict when they were to happen, but Rømer found that some slight irregularity occured, the length of the periods increased only to decrease and so on. What he was observing was a Doppler phenomenon, as the Earth approached Jupiter the periods shortened and conversely when the Earth was getting more distant, the periods increased. Now at the time one had a pretty good estimate of the astronomical unit (the average distance of the Earth to the sun) one obtained a fairly accurate estimation of the velocity of light which turned out to be very large but finite.

The beginning of the electro-magnetic theory is also due to a Dane - Ørsted who noticed that a current going through a wire will make a magnetic needle move, thus creating a magnetic field. But before that one needed to control electricity in more elaborate ways than just rubbing amber. Benjamin Franklin was able by means of a kite to catch and deflect the electricity of a thunderstorm. At the end of the century Galvani discovered that electricity can get the amputated legs of frogs to move. He thought that the electricity was biologically generated but his compatriot Volta opposed him and created the first battery, a pile of metal plates interspersed with with damp card-board. The first battery was created and systematic experiments with electricity could be started. The French physicists Coulomb and Ampere clarified the situation further, the first being a skilled experimental physicist established the inverse square law of attraction/repulsion of charges, his contribution showing the subtlety of such measurements. Ampere clarified the significance of Ørsteds discovery, predicting that two wires conducting currents would either attract and repel each other. By lying a firm quantitative foundation for the subject he would prepare the way for Faraday who introduced the notion of a field in order to describe electromagnetic attraction and repulsion, a fundamental concept in modern physics. The final synthesis would be effected by Maxwell in the form of a set of elegant partial equations. Those equations turned out to have intriguing symmetries in which the velocity of light entered and would presage relativity theory. The practical consequences of the equations, namely to construct electro-magnetic waves, was achieved by the prematurely deceased Hertz. And the rest is history. A scientific theory whose applications would turn out to

[4] As a child he was quite adapt at constructing mechanical gadgets.

have the most far reaching impacts on human life, but would not be generally available until the 20th century.

Physical chemistry would likewise come to the fore in the 19th century, with fundamental work once again done by Faraday. Roult investigated how the concentration of salt in solutions effected the freezing point, Gouldberg and Wage, two Norwegians, investigated speeds of chemical reactions, meaning how concentrations of different compounds affected their interaction, summarized in the laws of mass action. Arrhenius clarified the ionic theory and Ostwald looked into catalysts and their speeding up effect on chemical processes.

Finally the modern age of physics broke at the end of the 19th century, just after lord Kelvin famously announced that physics was complete and nothing new stood to be discovered[5]. There was Roentgen and his X-rays, the discovery and experimentation with which is nicely presented by him. There was Becquerel and the discovery of spontaneous radiation, and of course Pierre and Marie Curie working laboriously to concentrate new radioactive elements out of the pitchblende ore (a few tons of which had been donated to them by a plant). Thompson, whose influence on future physicists was truly impressive, discovered the electron measuring the ratio between mass and charge later to be developed by Mullikan[6]. Early atomic theory would not be complete without the inclusion of Rutherford the discovery of the atomic nucleus being something which was easy to explain to young students, although the editors have not chosen that discovery as their sample. And then there is Max Planck whose idea of the quantum would truly revolutionize modern theoretical physics and make a more abrupt rupture with what had passed before (without of course repudiate it) than had ever happened before or after.

`July 23-24, 2020` **Ulf Persson:** *Prof.em, Chalmers U.of Tech., Göteborg Sweden* ulfp@chalmers.se

[5] Kelvin gave an upper bound for the age of the Sun, based on known sources of energies. That bound was too low to really allow biological evolution, as well as not corresponding to the age of Earth suggested by geological processes. Darwin was almost ready to abandon his theory due to the authority wielded by Kelvin.

[6] My father let us do those experiments at school in the late sixties, having ordered the appropriate equipment.