GALILEO AND NEWTON: THEIR TIMES AND OURS.*

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In order to appreciate the magnitude and the significance of the contribution made by a great leader of the past in any field of human endeavour, we must study his achievement in relation to the times in which he lived, we must see to what extent he depended on past work, what were the state of knowledge and the attitude of his contemporaries, and what influence he had on them and their successors. In speaking of the two men to whom we pay tribute tonight, I am keeping this in mind and shall concern myself more with their relations to the times in which they lived and worked, and with the bearing of their experiences on scientific practice and thought today than with the detailed tale of their achievements, which in any case could not be given adequately in the time available.

Galileo, who was born in Florence on 15th February, 1564, came into a world that was ready for his genius, his persistent search for truth and his valiant efforts for its establishment. Although, long before his time, there had been occasional protests against the unquestioning belief in the teachings of the past and pleas for the test of experiment from men such as Roger Bacon, in the 13th century, and Nicolas de Cusa in the 15th, these were unheeded and the real starting point of modern science came in 1453, when Copernicus completed his book on *The Revolutions of the Heavenly Bodies.*

When Galileo's scientific career began the theory of Copernicus had received some attention and support and there were a few active workers in experimental science such as William Gilbert in England (1540–1603) whose systematic studies and experiments in magnetism are in keeping with the best traditions of the modern experimental method, and Simon Stevin in Holland (1548–1620). the founder of statics, to whom we owe the theorem of the parallelogram of forces and important work on the equilibrium and stability of floating bodies. Mention should also be made of Tycho Brahe (1546–1601) the astronomer who at Prague for many years made painstaking observations of the positions of the planets, supplying the material that Kepler (1571–1630) was later to use in the great generalisations, the laws of planetary motion known by his name. A few years senior to Galileo was Francis Bacon (1561–1626) who in his writings advocated the experimental method and laid down at length rules for scientific investigation. As a matter of fact, although he is better known than the others, he had little influence on scientific progress; Newton, for example, hardly mentions him while Bacon himself did not realise the value of the work of Gilbert and Galileo. In general it will be found, I think, that the philosopher who was not actually engaged in experimental science has made little contribution by his discussions in that field. The philosopher on experimental science might be compared with the old maid on the bringing up of children: each passes just criticism and gives excellent advice, but it is other people who do the things that really count.

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* This address was delivered before the Society on October 7 in commemoration of the tercentenary of the death of Galileo (1564–1642) and the birth of Newton (1642–1727).

However, when we come to metaphysics, where the test of experiment cannot be applied, the strictures of the philosopher may be necessary because here the scientist often allows himself freedom from the self-discipline that he imposes in the performance and interpretation of his experiments. He is justified in his speculative mental excursions because the field that today is not susceptible to the test of experiment may be tomorrow—but it must be recognised that generally no special weight can be given to his opinions simply because he is a scientist. May I quote from a recent article by Stephen Leacock, entitled *Commonsense and the Universe.*

"When the scientist steps out from recording phenomena and offers a general statement of the nature of what is called 'reality', the ultimate nature of space, of time, of the beginning of things, of life, of a universe, then he stands exactly where you and I do, and the three of us stand where Plato did—and long before him, Rodin's primitive thinker."

With this I cordially agree except for the suggestion at the beginning that the scientist should limit himself to recording phenomena. This is too like the views of Bacon. The scientist must use his observations ; they must be classified and he must seek an interpretation ; he must not stop at the stage of Tycho Brahe. Leacock and Bacon have no place for the inspired imagination, what Sullivan calls the 'physical insight', that is the biggest factor in the greatness of a Newton, a Faraday, a Rutherford.

In spite of the work of Gilbert and Stevin and others of less note the traditions of the past centuries prevailed when Galileo's studies commenced. The science taught was that of the philosophers of ancient Greece, or rather the interpretation given it by the scholastic philosophers of the middle ages. All education being in the hands of churchmen—without them there had been none—it is not surprising that this science was given authority equal to that of the Scriptures. The Greeks were thinkers and reasoners never excelled ; some of them were observers of remarkable skill and thoroughness, but in general they were indifferent to experiment—they did not attempt to increase their knowledge by imposing conditions modifying observations. It seems natural that they would find greatest interest in profound speculations and discussions on the really big things, on the nature of the universe, on the ultimate structure of matter, on the infinities of space and time, while the laws of falling bodies and the commonplaces of mechanics would be treated as incidentals ; such minor topics are of absorbing interest only to those engaged in experiments relating thereto. This may be the reason why in the mechanics of the 16th century we find accepted statements that common experience must have shown to be incorrect, such as the assertion that bodies of unequal weight let fall from a height reach the ground in times inversely proportional to their weights. Aristotle's writings were interpreted to convey this, and it had to be accepted as the truth. On the other hand the Ptolemaic theory of a stationary earth was a working theory ; it enabled correct predictions of planetary phenomena to be made and on the face of it appeared more reasonable than the Copernican theory according to which the earth rotated daily about its axis. Surely speeds approaching 1,000 miles an hour should be noticeable ; an arrow fired vertically into the air should fall to the ground miles to the west if the surface had such velocity ; even if one jumped into the air, remaining off the ground for but a second or so, one should alight hundreds of yards to the west. These and like objections generally were taken to rule out the Copernican view.

Galileo from his student days was critical of the old teachings and convinced that they were wrong. He displayed from his youth keenness for experiment, and skill and ingenuity in the construction and use of apparatus. Securing favourable notice through several interesting inventions and for his mathematical knowledge, in 1589 he was appointed to a lectureship in the University of Pisa ; three years later he went to Padua, where he held a professorship until 1610. During this period he displayed extraordinary activity in most branches of physics then studied. He made notable contributions in mechanics, including a detailed study of accelerated motion and quantitative examination of projectiles and falling bodies, proving the parabolic path, and he established the facts that we now know as Newton's first and second laws of motion. He carried out investigations on pendulums, pulley systems, specific gravities, pumps, was responsible for the beginning of thermometry, and, in magnetism, repeated and extended some of the experiments of Gilbert. He did important mathematical work, including a discussion on the geometry of the cycloid, and was keenly interested in practical problems, his military and geometric compass, an aid to calculations of diverse character, being an instance of this.

He was a remarkably able teacher and lecturer, and an interesting and entertaining talker, who made many friends, including a number of leaders in church and state. He took advantage of every opportunity of emphasising his opposition to the old doctrines and of urging the claims of the new beliefs. Thus after the appearance in 1604 of a striking new star he gave three public lectures that aroused wide interest ; in these he described the Copernican system and pointed to the *nova* as evidence against the unchanging character of the heavens, an essential feature of the old theory.

Many of our text-books and histories of physics tell us that, early in this period, in 1590 or thereabouts, Galileo carried out an epoch making experiment in which he dropped two unequal weights from the top of the leaning tower of Pisa. Their simultaneous fall to the ground, we read, rang the knell of the old beliefs, disproving Aristotle's assertion that the heavier one would reach the ground first, in one-tenth the time taken by the lighter if the weights were in the proportion of 10 to 1. This experiment was supposed to have been performed in front of a large university concourse but it is almost certain that if performed it was not as described in our histories. Professor Lane Cooper, who occupies a chair of English in Cornell University, provoked perhaps by the belittling of Aristotle, whom he rightly regards as one of the outstanding thinkers of all time, has made a careful examination of the story.* He points out that no mention of this " epoch-making " test was made until about 1654, when Viviani (1622–1703), the last and youngest of Galileo's pupils, related it in a biography of his master. Galileo in his own writings says what would happen in such an experiment but nowhere states definitely that it was performed by him. Lane Cooper reveals important discrepancies in the historical accounts ; the weights sometimes are ten pounds and one, in others one hundred and one ; the time is stated as the morning, though Viviani gives no information on this ; according to some the audience was the whole University, while others tell us that it consisted of the elderly conservative seniors, and we are told of their angry bewilderment at the result, but the outstanding point is that no publication occurred until more than 60 years later. I dwell on this at some length because it shows that we physicists who pride ourselves on the honesty of our work, on our meticulous attention to detail in experiment and record, do not carry this over into our histories. Apparently we feel that while truth may be stranger than fiction, a dash of fiction makes the story more worthwhile.

Lane Cooper goes further. He points out that it is difficult to establish the claim that Aristotle ever made such a statement as that credited to him. Words used by him may be given a meaning different from that intended and it must be remembered that in his day, and for that matter in Galileo's, words had not been invented to convey the ideas of impulse, momentum and the like. Further for the most part Latin translations of Aristotle were used, an extra

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* Aristotle, Galileo, and the Tower of Pisa, Lane Cooper.

chance of uncertainty being thus introduced. However, there is little doubt that whatever Aristotle intended he was interpreted by the scholastics of the middle ages to have made the statement under discussion, and, as a matter of fact, Stevin did actually perform the experiment of letting two weights, one ten times as heavy as the other, fall from a height of about 30 feet. He records their simultaneous arrival on the ground as evidence against Aristotle.

This story illustrates two important points emphasised by the philosopher, Professor Collingwood, in his *Autobiography*: one, that in criticising and discussing work of the past we must read the original statements and not content ourselves with the versions of other writers; the second is that in interpreting writings of the past we must view them from the standpoint of the period, we must recall the state of knowledge and thought at the time, and remember that even the meanings of words and phrases might be different from those of today.

The physicist can find illustrations of the second point if he reads papers on heat written early in the 19th century when certain writers undoubtedly felt the truth of the first law of thermodynamics though it was not definitely stated until many years later. Similarly writings on atomic physics at the beginning of this century are rather puzzling if read from the standpoint of today.

There are probably other instances of " crucial " experiments described but never really performed. It is likely that many of the experiments on hydrostatics attributed to Pascal are simply propositions enunciated by him, consequences of the laws of hydrostatic pressure, instead of the statement of the laws being consequences of the experiments. Sir Humphrey Davy's experiment on the melting of ice when two blocks are rubbed together in ice-cold water is probably a statement of what would occur based on his correct interpretation of Rumford's classical observation.

To return to Galileo, in this first period he had established himself as the leader in science of his time and had provided a firm foundation for mechanics, that, without any other contribution, would have earned him a place among the great in science. The next stage commences with his observations with the telescope, the invention of which was reported to him in 1609. He soon worked out the theory of such an instrument and succeeded in constructing one, later making a number of ever-increasing power, one of which gave a magnification of 30 diameters. Early in 1610 he applied the telescope to the examination of the heavens and a few months later published the first account of his observations, recording a vast increase in the number of the stars, resolution of the milky way, detail in the moon indicating that it was of like nature to the earth, certainly that it had mountains and plains, the disc-like appearance of the planets, and, most important of all, tiny bodies close to Jupiter, that continued observation showed to be satellites circling round the planet.

A little later two other important discoveries were made. Saturn was found to be a complex body. What we recognise with our good instruments as the rings appeared to him as two bodies or excrescences on either side of the planet. He did not announce this discovery outright, because of earlier experience when others claimed credit for his findings, but gave it in the form of an anagram, 37 letters in a meaningless sequence, that later he revealed as " *Altissimum planetam tergeminum observavi* ", that is, " I have discovered the most distant planet to be triple ".

The second discovery was also put in the form of an anagram, " *Haec immatura a me jam frustra leguntur* (*o.y.*) ", or " these immature things are read by me now in vain ". Later he gave the solution " *Cynthiae figuras aemulatur mater amorum* " or " the mother of loves (Venus) rivals the figures of Cynthia (the moon) ", or, in other words, Venus has phases like the moon. This discovery he regarded as evidence favouring the Copernican system, while the discovery of the satellites of Jupiter revealed heavenly bodies that rotated round a body other than the earth and so formed an argument against the Ptolemaic theory.

At first this work brought Galileo great credit, and the Grank Duke of Tuscany appointed him to positions of honour in his household and in the University of Pisa that resulted in his leaving Padua for Florence. However, trouble soon commenced as the result of his enthusiastic advocacy of the Copernican theory the truth of which he thought must now be patent to all.

The opposition came mainly from churchmen, though among these there were varied views. Some were opposed by conviction—not only were the arguments mentioned earlier given, but more important still numerous scriptural texts were quoted indicating clearly that the earth was the stationary centre of the Universe. Others Galileo had antagonised by his ruthless method of debate and discussion, opponents of his views being subjected to cutting sarcasm and made to appear both incorrect and foolish, a most effective way of provoking enmity. Probably most of the leaders of the church, who included many friends and admirers of Galileo, would gladly have avoided the conflict that was being forced on them. Some appear to have believed that the new theory did not necessarily conflict with the teaching and authority of the church and others seem actually to have accepted it. However, opposition that is earnest, and even fanatical, must carry greater weight than lukewarm advocacy or indifference, and towards the end of 1615 he was denounced to the Inquisitor in Florence. Early in 1616 the matter was submitted to the Holy Office in Rome and a report was issued affirming the theory of the central sun to be foolish and absurd in philosophy and to be in contradiction to the Holy Scripture, while the theory of the moving earth with its diurnal motion was likewise condemned.

Galileo was admonished that he should renounce the condemned opinions, that he should no longer hold or defend them.

From this point we have less of experiment and observation by Galileo. There had not been systematic publication of the great volume of experimental work already performed by him and his main contributions henceforth consisted in the examination and discussion of his results, in preparing them for publication and above all in presenting convincingly the case for the new science. Nevertheless important new work does appear in the later part of his career, for example, but a few years before his death he made a discovery of major importance, the libration of the moon, and later still occupied himself with practical problems such as the determination of longitude at sea by means of lunar observations, and the application of the pendulum, the subject of his earliest research, to time-keepers. Further, there were new topics of discussion such as the tides and comets concerning which, however, views strenuously maintained by him have turned out to be quite incorrect.

The *Dialogues Concerning the Two Principal Systems of the World* occupied him from about 1623 to 1629 though already in 1610 he mentions the work as being in preparation ; a further period of several years then passed before he received permission to have it published. Urban VIII, who had been elected Pope in 1623, had long been a friend of Galileo and had not agreed with the verdict of 1616. He had said that belief in the Copernican theory was not heretical but rash and that it might even cease to be rash. Galileo, who never could understand the refusal of intelligent people to be convinced by the overwhelming evidence he could present, naturally felt that he might depart at least in the spirit if not in the letter from the injunction of 1616, and in the book presented indirectly a convincing case for the new system. It takes the form of a discussion on four successive days between three characters. Two of these, Salviati and Sagredo, named after deceased personal friends of Galileo, take the standpoint on the questions examined that Galileo himself would, while the third, Simplicio, named after Simplicius, a 6th century commentator on Aristotle, advocates the old science and the Ptolemaic system. Galileo gives free rein to his sarcastic wit, and in the debates on the various topics discussed Simplicio always comes out badly and is made to appear ridiculous.

What Galileo considered one of the most important points in the book is a discussion on tides. Actually it is the weakest part because he was rather badly informed concerning the subject and developed a theory that is incorrect. He did not accept the view that had been advanced that the tides depended on the moon but found an explanation in terms of the diurnal rotation of the earth and its revolution about the sun ; he considered this to be an incontrovertible proof of the rotation of the earth and of the truth of the Copernican system. So important did this seem to him that he wanted to call the book " The Flux and Reflux of the Tides ".

To Galileo's disappointment he met considerable difficulty and delay in publication. The licensing authority demanded repeated revisions ; the Pope insisted on a change of title, omitting reference to tides, and directed that an argument should be included to the effect that even though the phenomena of the tides were consistent with the idea of the double movement of the earth that was not a proof that such movement existed—that God the Almighty in his omnipotence could ordain the tides on the stationary earth. This opinion is reasonable ; the fact that we are able to explain a phenomenon only on one hypothesis does not prove that such hypothesis is correct, it may rather reveal limitations of our knowledge or imagination. Unfortunately this statement, dictated by the Pope, Galileo puts into the mouth of Simplicio at the end of the book, affording a powerful weapon to his enemies, the suggestion that the fool of the piece is represented by the Pope.

The book, printed at last in 1632, immediately raised a storm. It is true that Galileo did not state that the new system was correct—it was advanced simply as an hypothesis—but the form given to the discussion was such as invariably to show that the old view was untenable and that its advocate made himself rather foolish. Another point was raised : Galileo thought that he had been forbidden only to hold or to defend the new system ; he had a letter from Cardinal Bellarmini to that effect, but a minute, unsigned, was produced by his opponents in which he was forbidden to hold, defend or *teach* the forbidden doctrine. The minute had been written in 1616 but the question was had it been communicated to Galileo. If so it would prohibit the discussion of the Copernican system even as an hypothesis, not necessarily claimed to be true. Evidently Urban VIII was persuaded that Galileo had been guilty of transgressing this minute and he appointed a commission to consider the book. It reported that Galileo had transgressed orders by asserting the mobility of the earth and the fixity of the sun, had incorrectly deduced an explanation of the tides from the non-existent double motion of the earth, and had been fraudulently silent concerning the command of the Holy Office in 1616 that he should not hold, teach or defend the hypothesis of the fixed sun and moving earth.

Galileo was next summoned before the Inquisition and in spite of the efforts of his friends was compelled to stand his trial and, as we know, then nearly 70 years old, stricken with illness, bewildered by the attitude of intelligent men and, as always, unable to realise how this work could make him anything but the orthodox Catholic that he felt he was, was persuaded to recant, to acknowledge the error of his views and his transgression of the order of 1616.

It is unnecessary to discuss this recantation or to speculate on the result of alternative action. The actual punishment imposed was relatively slight ; he had to recite the seven penitential psalms once a week for three years and was sentenced to virtual imprisonment, in effect simply a restriction on his place of residence and on his visitors, that was gradually relaxed, though he was never allowed to return to Florence. Possibly the greatest punishment was the memory of the fact that he had yielded to the persuasion to abjure doctrines that he knew to be true.

It should be noted that opposition to the new doctrines was not restricted to the catholic church ; the protestant clergy was at least as emphatic. We are told, for instance, that at a protestant conference in Tübingen, Kepler was condemned for his support of the Copernican theory and had to take refuge with the Jesuits.

After the ordeal of his trial Galileo was yet to publish what some consider his finest work, the *Dialogues Concerning Two New Sciences*, completed in 1636 and published in Holland. It takes the form of the earlier dialogues ; the same three characters appear and the discussion is divided into four days, later a fifth and sixth being prepared. The topics in general relate to mechanics, and of special interest is the matter of accelerated motion and of the parabolic path of projectiles ; others are cohesion, friction, strength of beams, production of vacua, vibrations of sounding bodies, and in particular he discusses the fall of bodies of unequal weight dropped from a height. Most of the experimental work on which these discourses are based was performed in the first stage of his scientific career, that is before 1609. The tone is more friendly than in the earlier dialogues ; Aristotle's views are shown to be wrong but Simplicio is not made to appear as stupid as in the past.

Galileo's health was bad in these last years, and early in 1638 he became totally blind. Restrictions against visitors were then relaxed and he had visits from many notable people while his pupils, Viviani and Torricelli, were allowed to share his home. After a partial recovery, accompanied by a renewal of scientific activity, he became seriously ill towards the end of 1641 and died on 8th January, 1642.

Galileo had established experimental physics ; through his efforts and through his sufferings the new method of science became widely known and generally accepted in spite of the attempts to discourage the study of his writings. During the 17th century we find a steadily increasing number of workers, in his own country and abroad, some his pupils and all inspired or at least influenced by him. Torricelli and Viviani have been mentioned ; other well known names are Mersenne, Grimaldi, von Guericke, Pascal, Boyle, Huygens, Wren and Hooke, and, one who for a long time dominated scientific method and thought in France and elsewhere, Descartes. However, Descartes' theory of vortices, while plausible enough, was always inadequate, for example, it could not be reconciled with the laws of planetary motion. A new hypothesis should at least be consistent with known phenomena ; it is of value when it leads to wider knowledge of the facts of nature.

Soon after the middle of that century there was considerable interest in Science ; the new methods were adopted in the main and we find organised effort in the form of scientific institutions in various countries, such as the Royal Society of London. The way was prepared for Newton just as it had been for Galileo in an earlier generation.

Newton was a scientific genius. Superlatives on him are inadequate. A quotation of one line conveys the best idea :

> " God said, ' Let Newton be ' and there was light."

He ranks as one of the greatest mathematicians the world has known, he is placed in the first order of experimenters and he possessed to a remarkable degree that indefinite quality that might be called inspired imagination that enabled him with uncanny skill to pick on the right explanation of his observations, to discriminate among the several possible, a rare gift of the highest importance in scientific progress.

Newton's work on gravitation, on mechanics, on light, the mathematical methods discovered and developed by him, are outstanding achievements any one of which would have earned him a place in the highest rank. He made important contributions in other fields of physics, heat and electricity for example. Yet only a relatively small portion of his life was devoted to this work ; Sullivan estimates that about one-third of his effective working time was spent on physics and mathematics, much of the rest being devoted to theological studies, historical research, chemistry and alchemy, fields that for considerable periods appeared more important to him.

He possessed exceptional powers of concentration that combined with his extraordinary ability enabled him to achieve results in remarkably short times. We read that one of the Bernoullis had propounded two problems concerning falling bodies, challenging mathematicians to give a solution in six months ; Leibnitz solved one but asked for a year for the second. Newton gave the solutions within 24 hours ; yet, apart from him, in mathematics there were giants in those days. However, accompanying this power of concentration there was a readiness to change the subject of his study. Early in his career when he had made great progress in his work on gravitation he left it, without any announcement or publication of what he had achieved, for work on light and colour, that in turn was dropped for the development of methods of grinding surfaces of lenses and mirrors.

Compared with Galileo we find many points of difference. Newton had the quality of the " lone hand " ; he was not concerned with the appreciation or understanding of his work by others ; left to himself much would not have been published and in general he made no attempt to write his papers in a form readily to be understood, in fact, sometimes he seems deliberately to have made them difficult. His lectures were few and poorly attended ; apparently he had little interest in this work. His investigations were made because they were of interest to himself, and he was indifferent to the praise of his admirers, though, like Galileo, he was irritated by what appeared stupid objections and misinterpretations.

Self-contained though he was, he formed a number of real friendships that he valued very highly, and intercourse with him had a great influence on contemporaries like Wren and Halley, while, as everyone recognises, his work has been the guide and inspiration of all physicists in the centuries that followed.

In his boyhood and youth Newton showed himself to be a good scholar with a wide range of interests. He had unusual mechanical skill and took great pleasure in making working models of various kinds. At Cambridge he got his first introduction to the study of mathematics and the opportunity of reading some of the work of science of that day, in particular Kepler's *Optics.* His early life at the University seems to have been much the same as that of others and it is even recorded that at this time he fell mildly in love, the only instance of anything approaching sex interest in his life.

The years 1665 and 1666, the two plague years, he spent in his mother's home in Lincolnshire (his father had died shortly before his birth) and in this period, working alone, his genius blossomed with extraordinary suddenness. In these two years he discovered the differential and integral calculus, worked out the essentials of his theory of gravitation, and carried out most of his investigations on colour and the composition of white light ; for the experimental work in this last subject he had to make his own prisms and lenses and, for that, his own grinding and polishing machines. In all these fields a considerable amount of work was done later, but the essentials were completed in this short period, an extraordinary performance even had he been a mature investigator with life-long experience.

Soon after returning to Cambridge he communicated a mathematical paper on Analysis to Isaac Barrow, the Lucasian professor, who described it as a work of unparalleled genius, and on Barrow's retirement in 1669 his recommendation that Newton should be his successor was adopted. Newton was elected a Fellow of the Royal Society in 1672 and shortly after communicated a paper on the Composition of White Light.

Up to this time ideas concerning colour were vague; many held the Aristotlean view that colour was the result of a mixture of light and darkness, the actual colour depending on the proportions; Descartes had advanced another hypothesis in terms of pressure in the matter that, according to him, filled all space, but this, and other views propounded at the time, were indefinite and unsatisfying.

Newton, using prisms and lenses made by himself, performed numerous experiments on colour. Viewing red and blue papers through a prism, he saw that blue was refracted more; forming real images of strongly illuminated black threads on the coloured papers he found that the two could not be focussed on a screen for the one position of a lens. He sent a narrow beam of sunlight through a prism and projected a spectrum on a screen; the light from portion of this, passing through a small hole in the screen on to a second prism, was not dispersed but deviated, the deviation being greater for blue than red. By an inverted prism he combined the dispersed spectral beams again to form white light; by screening each half of the spectrum in turn he obtained complementary colours in this synthesis. He found the conditions necessary for a pure spectrum and rightly ranks as the pioneer of spectroscopy. The number, variety and significance of the experiments he performed on colour, on the nature of white light, on its analysis and on its synthesis remind us of the searching methods of Faraday, 150 years later.

Naturally he arrived at the facts of chromatic aberration and concluded that the refracting telescope could never be highly satisfactory. At the time there was not the variety of glasses made later and we can understand his belief that dispersion must always be proportional to deviation so that an achromatic combination did not suggest itself. As a result he developed the reflecting telescope.

He made systematic study of the colours of thin transparent films, a subject receiving attention from a number of workers at the time; we recall the well-known exhibit entitled Newton's rings.

At that period there was considerable interest in light and the theory of light; besides the new facts derived by Newton we must mention Grimaldi's diffraction experiments, the discovery of double refraction by Bartholinus, important work by Hooke on interference, and by Huygens on the explanation of reflexion and refraction by a wave theory.

Newton never succeeded in postulating a theory of light that satisfied himself; his, like others of the time, was necessarily indefinite, an inevitable result when so many new facts were being discovered and studied. He held that light was corpuscular in nature, but interference phenomena made him realise that there must be associated with it a periodicity of some kind. Like others at the time he believed in an ether, a subtle medium to which light and other phenomena were to be related but it was an ether different from that postulated in the 19th century.

Newton's experiments and views on light were published in his *Opticks* in 1704 but much was given in the paper presented to the Royal Society in 1672. In this, his first paper to the society, his matter was carefully prepared and clearly presented, but to his surprise it met objections and criticisms. His attitude of conveying the facts of nature simply as he observed them without reference to preconceived ideas, without asserting that he confirmed or disproved classical hypotheses was not understood ; the traditions of the past still prevailed to some extent. Further, there were accusations of carelessness and of misstatement, following which he was involved in a difficult and distressing correspondence, that in the end exhausted his patience so that after 1776 he made no further communication on light to the society and, in fact, shortly after seems to have given up his interest in physics and mathematics for several years during which he devoted himself chiefly to chemistry and the other subjects mentioned earlier.

Newton was unfortunate enough for considerable portions of his life to find himself involved in like bitter controversy with some of his fellow scientists, generally on questions of priority of discovery. Already at this time a dispute concerning the claims of Leibnitz to the discovery of the calculus had commenced ; this was destined to disturb him to the end of his days. To some extent Newton was to blame because of his indifference to publication ; he could not be similarly indifferent to unjust accusation of plagiarism and dishonesty, so that his rejoinders were often of a provocative nature tending to prolong the quarrels and to accentuate his own distress, with the result that on several occasions, as in 1676, he abandoned the work in hand for other interests.

However, more than anyone Robert Hooke is to be blamed for Newton's difficulties. Hooke, who was a few years older than Newton, was a physicist of outstanding ability who made notable contributions in many branches of the subject that should entitle him to an honoured place in the history of science. He was however a very vain man, jealous of the success of any of his contemporaries, and he gained an unenviable reputation as a carping critic and a persistent claimant for priority at the announcement of every new discovery. Hooke was indeed unlucky to have Newton among his contemporaries, a younger man who overshadowed him both in experimental and theoretical investigation, who solved, apparently with ease, problems that had puzzled him for years. He criticised Newton's optical work, questioned the correctness of his observations, asserted that he himself was the discoverer of the law of gravitation and that Newton had got the idea from him. Being skilled enough to discover one or two errors made by Newton in their correspondence concerning falling bodies in the earth's gravitational field, he took pains to dilate on this publicly in his consistent and resentful efforts to belittle his great rival. In the end the only remedy open to the sensitive Newton was to vacate the field.

The story of Hooke suggests that in assessing a man's value we should take into account the negative as well as the positive. Remarkable as are his achievements, are they not more than compensated by the loss of Newton to science for many years, because the other activities to which he turned, important as they seemed to Newton himself, were productive of little benefit to mankind ?

Time does not allow a detailed account of Newton's great work on gravitation. It was started during the plague years and dropped at about the same time as the optical work, though trying correspondence and discussion with Hooke continued for some time later. His interest was revived in 1684 by Halley to whom he announced, in reply to a question, that he had proved years before that the inverse square law of attraction would account for the elliptical orbits of the planets, a proof that had been sought by Wren, Hooke, Halley and others. He again obtained the solution that he had lost in the interval, and, stimulated by Halley, recovered his former enthusiasm with the result that after less than two years' intensive work he produced the monumental treatise, the *Principia*, that established him as the founder of theoretical or mathematical physics. In this comprehensive collection of propositions in mechanics and gravitational theory we find thoroughness and completeness corresponding with those of the experimental work on light and colour, and not the least remarkable feature is the fact that most of these were worked out in about 17 months. The actual publication is due mainly to Halley ; he induced Newton to do the work and made himself responsible for the cost, an attitude in marked contrast to that of Hooke, who still insisted that Newton stole his ideas. As a matter of fact Hooke and many others had suggested that the inverse square law held but were unable to prove it.

The *Principia* was eagerly read but it was not until the second half of the 18th century that it bore full fruit when the great French mathematical physicists, having at last dropped the Cartesian theory, accepted and developed the Newtonian method. Of course all the progress of the 19th century, in light, electricity, heat, sound, in every branch of physics, is really an extension of Newton's work.

After the publication of the *Principia*, Newton again gave up his scientific work and in fact little more was done by him apart from the publication of his *Opticks* in 1704, after Hooke's death, and the preparation of later editions of the *Principia*.

This withdrawal from active participation in science was probably due to a series of irritating quarrels with Flamsteed, the Astronomer Royal, that went on intermittently, and on various subjects, from 1691 for more than twenty years, and to a revival and intensification of the controversy with Leibnitz and his supporters, mentioned earlier.

For a time Newton represented the University of Cambridge in the English parliament, and later occupied the position of Warden and then Master of the Mint, where he did good work in instituting greatly needed reforms. There was an unhappy period in about 1693 when he was mentally unbalanced, a state revealed by amazing letters containing painful reproaches and accusations sent to Locke and other good friends.

In 1703 he was elected President of the Royal Society and was re-elected each year until his death, though he took no active part in the control of the society.

During his later years he devoted himself largely to religious studies and bible interpretation, in which he revealed strong feeling against the Roman Catholic Church, finding numerous unpleasant references to it in the book of Daniel, and shortly before his death he prepared a great volume on Scriptural Chronology, but on these works we need not dwell as they do not affect our appreciation of his greatness.

It is pleasant to recall that his last recorded activity was associated with Science : on 28th February, 1627, he presided at a meeting of the Royal Society a few days before he was stricken by the illness from which he died on 20th March.

Today how are we to regard the work of Newton and Galileo ? We have to agree that many of their conclusions are not correct. Newton's theory of light is inadequate and widely different from that of our time, his idea of the absolute is discarded, and his mechanics are but a special case of a more general system. Galileo's struggle may appear futile because now we realise that we may take the earth, or the sun, or any other body, as our standard of reference as we find it convenient, and in fact I wonder whether ever any Copernican was so consistent as to refrain from speaking of sunrise and sunset.

What I wish to emphasise is that these men did what the world was ready for at the time ; it took 200 years of scientific progress, based on Newton's work and inspired by his example, before we were prepared for the new concept of Planck and before there was need for the generalization of Einstein. Had Newton advanced such modern views they would have been no more than metaphysical speculation, incapable then of experimental verification and leading nowhere. The great lesson taught by Galileo and Newton is that such speculation is of secondary importance.

Galileo's struggle, at the time, appeared to be for the acceptance of one of two conflicting systems of the universe, but now we know that in fact it was for the establishment of freedom of thought. His defeat was victory, a victory without which progress had not been possible.

Today, as 300 years ago, great problems are still unsolved, the questions of science and religion, faith and reason. Galileo had to fight against the faith that excluded reason ; today it may be necessary to fight against a reason that denies the claims of faith.

Something might be found common among the widely divergent views on these problems, common to the extreme materialist and to him who puts full trust in revealed religion. Actually all have faith of some kind, even if it is faith only in human reason, but, more important, we all *know* that our universe is one of law and order. I remember, years ago, reading of Kepler's first paper in which, supporting the Copernican theory, he maintained the thesis that, besides the earth, there could be but five planets, basing this on the fact that there were but five regular solids, and developing a scheme of spheres, containing the orbits, inscribed in and circumscribing the polyhedra taken in a certain order. At the time I regarded this with scorn and wondered at the friendly reception it received from the wise Galileo and the methodical Tycho. Today I regard it as a manifestation of our desire for order and law, of our search for relationships between the phenomena of nature.

Perhaps the main difference between our extremists is that the one assumes that the Universe, once started, goes on inevitably in accordance with laws, unchanging and definite, while the other assumes the possibility of the laws being suspended, presumably at the will of a divine Guide and Controller. In the principle of indeterminism it might be claimed that modern physics gives an indication in this direction, and in connection with recent developments in atomic and cosmic physics the suggestion has been made that under certain conditions the law of the conservation of energy may not hold.

Another difference is between their methods of describing the start of the Universe. The one says, " In the beginning God created the heaven and the earth " ; G. K. Chesterton would call this commonsense. The other usually assumes either an initial chaos of primitive entities that for some reason commence to group themselves, developing into the complex structures we know, or an initial vast single molecule that divides, eventually to form the bodies that make up the world. These suggestions are as difficult to understand as the first but the word " God " is avoided and they are called rational.

However, debate on these matters is irrelevant. The greatness of Galileo and Newton is not conditioned by their religious beliefs. They were regarded as giants in their own times ; we, at a distance of three centuries, endorse this view ; we see them towering above their fellows, and approached but rarely in the intervening years. I am not alone in maintaining that, measured by their achievement, or by their influence on the progress of civilisation, they rank higher than the greatest of the kings, statesmen, captains, round whom our histories are written.

On this note I end with a quotation from an appreciation of science, *Wintry Delights*, by the late Poet Laureate, Robert Bridges, a quotation fitting the occasion and the times in which we live :

What was Alexander's subduing of Asia, or that
Sheep-worry of Europe, when pigmy Napoleon enter'd
Her sovereign chambers, and her kings with terror eclips'd ?
His footsore soldiers inciting across the ravag'd plains,
Thro' bloody fields of death tramping to an ugly disaster ?
Shows any crown, set above the promise (so rudely accomplisht)
Of their fair godlike young faces, a glory to compare
With the immortal olive that circles bold Galileo's
Brows, the laurel'd halo of Newton's unwithering fame ?