Sir Isaac Newton

which may be stated thus: All planets revolve about the sun in elliptical orbits with the sun as one focus. But though these laws of Kepler's were wonderful conclusions to arrive at, yet even they afforded no key to the constitution of the solar system and of the universe. The laws were unrelated to each other. They were unrelated to any dominant principle of astronomical truth by which they might be explained. They were also unrelated to any known fact or principle of nature outside of astronomical phenomena. In short, though they were remarkable and curious, they explained nothing, and were themselves in need of explanation.

Now, what did Newton do? He discovered one simple law, so simple that it can be stated in twenty words, which, when properly understood and applied, explains all the facts that Kepler had established, and every other fact relating to the motions of the heavenly bodies that any other observer had ever established, or that any other observer has succeeded in establishing since Kepler's time. For it must be remembered that Kepler's so-called " laws " were in reality " facts," though they were facts that were based on an infinity of particular observations. But Newton's law is an elementary principle that pervades all nature, and is as applicable to explain the motion of a stone thrown from a boy's hand, or the motion of a ball projected from the mouth of a cannon, as the motion of a planet or a comet that whirls around the sun. His law, somewhat wordily expressed, is this: Every particle of matter in the universe is attracted by every other particle of matter in the universe with a force that is proportional to the mass of the attracting particle and also proportional to the inverse square of the distance between the particles. For example, a certain particle of matter, say a cannon ball, is pulled to the earth with a force that we call its weight. If the earth had twice as much matter in it as it really has, but still remained of the same size, the weight of the ball would be twice what it now is. Also, if the cannon ball could be removed to a distance from the center of the earth twice its present distance, its weight would be only one-fourth of its present weight. And so on. Newton took this law, and he proved that the earth and all the other planets must revolve around the sun, and the moon around Jupiter, in exactly the same way as Kepler had demonstrated from Tycho Brahë's tables that they do revolve—that is, in elliptical orbits, with the sun or other attracting body in one focus, etc., etc.

It must not be supposed, when Newton had discovered his law, and had divined that it was going to be a sufficient explanation of the problem he wished to solve, that his task was an easy one. The inspiration of the idea came to him one day in his twenty-fourth year, when, sitting in his orchard pondering upon the matter, he saw an apple fall. The very force that drew the apple toward the earth might also, he thought, draw the moon toward the earth. And if the moon toward the earth, why not the earth toward the moon? Why not, too, the earth toward the sun? And what was the measure of that force? How did it operate? What effects would it produce? Would the motions of the planets be circular? or elliptical? or of some other figure? What would the shape of the earth be? What effect would the force have upon the waters of the earth? Would it account for the tides? These and many other such were the questions he asked himself. But even when he had thus got on the right track for the

solution of the problem, it took him months and years before he was satisfied that the explanation he had got was the true explanation. And it must not be supposed that Newton was a laborious mechanical calculator like Kepler. Newton invented whole systems of mathematical labor-saving processes to facilitate his calculations. No man that has ever lived could have proved what Newton proved with only the means he had to use when first he began his proof. But Newton's genius in the work he undertook was omnipotent. He not only invented new processes of calculation but he invented new means of observation. The refracting telescope which Galileo had designed he found to be cumbrous, difficult to make, and inefficient. He at once invented the reflecting telescope, the model upon which most astronomical telescopes since his day* have been made. Moreover, he took the problem and he reversed it. He proved not only that the law of gravitation as he stated it is sufficient to account for all the known motions of the heavenly bodies, but also that the motions of the heavenly bodies known can be accounted for only by a law of gravitation identical with that which he assumed.

One difficulty that Newton had in establishing his theory was the incorrectness of the supposed facts that he had to rely upon in working it out. For example, one supposed fact that he had to make use of in his calculations was the size of the earth, or, what is almost the same thing, the length of a geographical degree. At that time it was supposed that the length of a degree on the earth's surface was sixty miles. But, when Newton

* Or at least until comparatively recent years.

used this length as a fact in his calculations, he was unable to reconcile the known motion of the moon around the earth with what his solutions based on his law of gravity showed that the motion should be. He therefore modestly laid his theory aside and was almost persuaded that after all he was wrong in it. Ten years later, however, he discovered that the length of the geographical degree was not sixty miles, but nearly seventy miles. He now resumed the problem, and on working it out had the satisfaction of being able to show that the motion which his theory demanded that the moon should have, exactly corresponded with the motion which the moon actually does have.

Newton was the most self-effacing philosopher known in the history of science. If it had not been for the persistent watchfulness of those who knew his genius, it is probable that many of his discoveries and solutions would never have become known to the world except by accident. Some of his greatest discoveries became known only because his friends took it upon themselves to make them known. His "*Principia*," the work that embodies his theory of gravitation, and his solutions of the motions of the heavenly bodies, was not published till 1687, although it had been practically ready for publication for some years before that date. Even then it was published only through the kindness and painstaking interest of Halley, afterwards Astronomer Royal. As it was, Halley had great difficulty (because of the controversy Newton feared it would provoke) in persuading him to publish the very part the world would be most interested in, the part that explained the motions of the solar system. But a more remarkable instance of Newton's modesty even than this is recorded. In the working out of the problem relating to the motions of the moon, Newton had obtained a result which did not agree with a fact established by astronomical observation. This discrepancy remained for many years the only thing known to science that the law of gravitation did not account for. And yet, so scrupulous is science, because of this small discrepancy, the universality of the law was to some extent doubted. Even new statements of it were proposed. But in the beginning of the present century, a distinguished French mathematician discovered that by working out the problem with greater completeness in some details that had previously been neglected, theory and fact might be reconciled. The point of importance is this: A few years ago, among some unpublished papers of Newton's, there was found, worked out by Newton himself, the problem in its full completeness. Newton had thus caused the discrepancy to disappear, and yet had not said a word about it to anyone.

Newton's character was as noble and lovable as his genius and career were distinguished. The details of his life, too, are very interesting, but few of them can be recounted here. He was born at Woolsthorpe, in Lincolnshire, and was the only son of a father who died before his birth. As an infant he was weak and puny, and his life was many times despaired of, but he grew up to have a fair measure of health and strength, and he lived to a good old age. In his childhood he was remarkable principally for his devotion to all sorts of ingenious boyish contrivances, such as windmills, water clocks, sundials, aerial lanterns, and the like. As a youth he became studious and deeply absorbed in physical problems some-

III. SIR ISAAC NEWTON

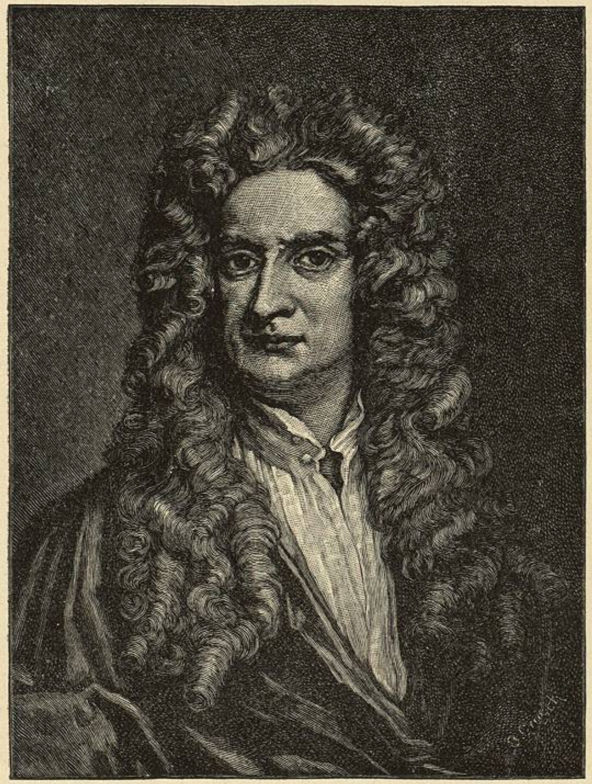
1642-1727

BIOGRAPHICAL STUDY

BY JOHN EBENEZER BRYANT, M. A.

Galileo's was the greatest genius that in the realm of physical science up to his era the world had ever known. But on the very day that Galileo died—December 25, 1642—a greater genius even than Galileo's was given to the world—a genius that in the realm of mathematics, and of mathematics applied to science, was the greatest ever possessed by man. And even this is an insufficient statement. for it implies comparison. But Newton's genius in the field he especially cultivated was incomparable. Neither an equal nor an approximating second can be named with it. In the power of abstract mathematical investigation, and especially in the power of investigating the mathematical laws which dominate the physical world, Newton is not simply peerless. His reputation is like a sun. When it is seen no other luminary is visible.

To understand something of what Newton did for the world of science it will be best to take up his greatest achievement—namely, his discovery of the law of gravitation, and his application of it to the explanation of the motions of the solar system. To do this it will first be necessary to glance at what previous investigators had discovered or achieved. Copernicus (1473-1545) had controverted the old theory of the constitution of the universe (namely, that the earth is the center of the universe, and that sun, moon, and stars all revolve about the earth) and had stated the true theory, now called in his honor the "Copernican theory" (namely, that the earth is a planet; that the planets revolve about the sun; that the moon is a secondary planet and revolves about the earth; that the sun, with its planets primary and secondary, constitute one system called the "solar system;" and that this system is only a very small portion of the universe). Galileo (1564-1642) had by means of his invention of the telescope, and his fine powers of physical demonstration, established innumerable proofs of the truth of this theory. Tycho Brahë (1546-1601), a Danish noble, one of the most painstaking and accurate astronomical observers that the world has ever known, had accumulated an enormous mass of recorded observations that embodied exact particulars as to the revolutions of the planets—their paths, their periods, their positions at certain times in their periods, their distances from the sun, etc.—but these particulars he was unable either to systematize or to show to be affected by fixed general laws. Finally Kepler (1571-1630), an assistant of Tycho Brahë's, a most indefatigable calculator and investigator, had taken the observations of his master, and, by wonderful ingenuity continued through many years of laborious industry, had discovered that the motions of the planets seemed to obey three laws (now known as the "three laws of Kepler"), the first of



SIR ISAAC NEWTON.