AN ITALIAN ACADEMICIAN.

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The mission of an academy of science is a function of the age in which it flourishes. The ancient academies accomplished a work now performed by the universities. The Italian academies of the Renaissance, variously estimated at from 500 to 700 in number, represented different purposes almost as numerous as the institutions themselves. But in general they were literary and scientific clans; they belonged to a period when learning was the possession of the few, to a period when one might still take all science for his domain.

The modern academy is, as a rule, closely allied with the sovereign power of some state, whose interests are promoted by it, consciously and unconsciously, in a variety of ways. The service which it renders is sometimes political, sometimes literary, sometimes scientific, sometimes social. But, so far as I can see, they have, in common, these two ends, namely, the encouragement of the individual and service to the community.

The triple purpose of the Illinois State Academy of Science is clearly stated in the second article of its constitution as being "the promotion of scientific research, the diffusion of scientific knowledge and of the scientific spirit, and the unification of the scientific interests of the state"; just how this object can best be secured is the interesting subject of an after-dinner discussion this evening.

I leave this problem, therefore, with the single remark that the importance of cultivating individual initiative and of handing on to the community the best there is in the achievements of science is not likely to be overestimated.

Symonds(1) points out that Athens and Florence owed their wonderful intellectual, artistic and literary success mainly to the fact that they nourished the individuality of their citizens; while Sparta and Venice, comparatively barren of permanent results, illustrate the lack of such encouragement.

I now invite your attention to one of the earliest members of the venerable and thankworthy Academy of the Lyncei, a man who represents in the highest degree the individuality then cultivated in Tuscany, a man whose impress upon his students was so deep that shortly after his death they united to form one of the most productive and justly celebrated of all the Italian academies,(2) a man whose written works fill twenty splendid quarto volumes,(3) a man who in his efforts to put before the people the best science of his times, endured opposition, criticism, disgrace and social ostracism throughout most of his thinking life. I refer to Galileo. But I shall speak only of what he did in physics, because I believe this phase of his work is too little known.

What Galileo saw through telescopes of his own make, though not of his own invention, is so familiar that possibly a majority of intelligent men think of him mainly as an astronomer. The spots on the sun, the mountains on the moon, the satellites of Jupiter, the phases of Venus, the "triple character" of Saturn, the solar rotation period, lunar libration and earth-shine are some of the celestial phenomena associated with the name of Galileo. These and his brilliant defense of the Copernican system are responsible for the impression that his accomplishments are chiefly astronomical.

To another large group of men he stands mainly for liberty, intellectual, social and religious. These men classify him with Giordano Bruno and De Dominis and Campanella who also had some experience with the cardinals of the Inquisition. For them Galileo is the man who dared to differ with Aristotle, the man who brushed aside the mists of philosophy, the man who banished church traditions from his thinking while he calmly pursued his search after unity in the physical universe.(4) It is doubtless his splendid stand for spiritual freedom which leads Goethe(5) in his historical sketch of optics to say

> Even though he never seriously studied the subject of color, I must at least adorn my page with his name.

But there is still a third group of men to whom the great Italian appeals most strongly because he has given them a new method of working and thinking, a new viewpoint, a new *aperçu*. To put this contribution in its proper perspective is not an easy matter; we are too near it and too familiar with it. If, however, one considers the time interval between Archimedes and Kelvin he can not fail to notice a sharp discontinuity in the progress of physics occurring about the beginning of the seventeenth century. Just how commerce and industry led up to, and prepared the way, for this step is the subject of a most interest chapter by a member of this academy, Professor Mann.(6)

Without underestimating the contribution of Pappus or Tartaglia or Benedetti or Stevinus or Leonardo da Vinci, to mechanics; and without denying the important role of statics in architecture and in other structural work one may, I believe, fairly say that the years which intervene between Archimedes and Galileo are practically barren of progress in physics.

It is true, indeed, that during this interval a large number of isolated physical facts had been discovered; indeed there is scarcely a chapter in physics in which some advance of this type can not be mentioned; but, during all this while, nothing in the way of development is seen; individual discoveries remain isolated; they do not bear fruit; speculation and guessing were still employed where we use observation and measurement and computation. Leonardo da Vinci likens a scientific conquest to a military victory in which theory is the field marshal; experimental facts, the soldiers. The philosophers who preceded Galileo had, in the main, been trying to fight battles without soldiers. The only possible exceptions to this statement are Roger Bacon, Leonardo da Vinci, Stevinus and Gilbert. They had measured some mechanical quantities—a few of them—masses and stresses—such as could be obtained by means of a steel-yard and a measuring stick; but they were still in the domain of statics. Now from a geometrical, esthetic or even utilitarian standpoint, it is difficult to imagine any finer subject than graphical statics; and yet when we regard the progress of physics, statics is to dynamics somewhat as osteology is to physiology, a veritable valley of dry bones. The live part of mechanics is kinetics, the study of masses which are in motion, the consideration of bodies which are changing their velocities, currents of water, oscillating magnets, vibrating strings, rotating wheels, electric motors, heat engines, electromagnetic waves, and X-rays. These are the problems over which men lose sleep; these are the questions which compel the interest of the physicist; these are the subjects whose mastery confers power upon the engineer. The one confessed aim of physical science is, indeed, to describe the motion of bodies in the simplest possible manner. Indeed it is only by the aid of this modern science of the energy of motion that any of the ancient mechanical doctrines—such as the atomic theory of Democritus—have acquired validity; it is this same science which has rendered the heliocentric theory of Copernicus not merely "a plausible view" but the one possible view.

We pass now to a more definite question, namely, what contribution did "our Academician" make to the solution of problems of this type, to the science which now goes by the name of physics? To answer briefly and baldly, he instituted the method and set into motion the machinery by which practically all these problems have been solved, in so far as they have been solved at all. But lest I give the false impression that Galileo was the ancester of all the physical sciences, I hasten to a more detailed answer to the query, What did Galileo?

1. First, no greater mistake could be made than to suppose that Galileo was the first man to differ with Aristotle; the academy of Cosena, having opposition to the peripatetic philosophy as its avowed purpose, was established at Naples about the time when Galileo was born; but he was the first man to offer experimental evidence against the conclusions of Aristotle; and in so doing he established what we now call the experimental method. He was not handing on an opinion which some "dusty minded professor" had inherited from an ancestor of the same type.

Only two methods of investigation were known to the ancients, the philosophical and the mathematical; to these Galileo added a third, the experimental. The philosophical method consisted in assuming certain general principals and trying to find in them an a priori explanation of the universe. Briefly described, the attempt was to stare nature out of countenance. Failure was inevitable, not for want of intellectual acumen, but because, as every one in this assembly knows, it sometimes requires a lifetime of effort to explain a single detail. Witness almost any chapter in Darwin's "Origin of Species." Details must be mastered before one can pass to general principles.

The mathematical method consisted only in applying geometry to certain well known areas, volumes and angles, especially to those angles observed in the sky, but always with the idea of describing the known rather than discovering the unknown: the mathematicians do not appear to have put any deliberate questions to nature; or as Rowland said:

> A mathematical investigation always obeys the law of the conservation of knowledge: we never get out more from it than we put in. The knowledge may be changed in form, it may be clearer and more exactly stated; but the total amount of the knowledge of nature given out by the investigation is the same as we started with.

The experimental method, established mainly by Galileo, not only combines the observations of the philosophers with the measurements of the mathematicians, but adds deliberate experiment with a distinct purpose to interrogate nature concerning some detail of her behavior. Generalizations based upon these details the experimenter reserves for a later date. The high regard in which Galileo held experimental facts is reflected in the following from a letter (7) to the Grand Duchess Christina, dated 1615. He says:

> I would entreat these wise and prudent fathers to consired diligently the difference between opinionative and demonstrative doctrines, to the end that

> they may assure themselves that it is not in the power of professors of demonstrative sciences to change their opinions at pleasure.

Or witness the following paragraph from the "Saggiatore"(9) as illustrating the great weight which Galileo attached to experimental evidence. He says

> We examine witnesses in things which are doubtful, past, and not permanent, but not in things which are done in our presence.
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> If discussing a difficult problem were like carrying a weight, then since several horses will carry more sacks of corn than one alone, I would agree that many reasoners avail more than one; but discoursing is like coursing, and not like carrying; and one barb by himself will run faster than a thousand Friesland horses.

In all his thinking nothing is exempt from experiment. Astronomy even, in his hands, ceases to be a purely observational science; for when he wishes to discover whether the bright portions of the moon's surface are rough or smooth, he sets up two surfaces, one rough and one smooth; then illuminates them with Italian sunlight. Desiring to learn at what rate falling bodies gain speed, he devises a time measuring machine, invents a method of "diluting gravity" and actually measures the rate at which speed is gained. His discussions begin and end with experiment—a method so familiar to us that we forget how recent and powerful it is.

His two great dialogues—one dealing with astronomy, the other with mechanics—abound in experiments—most of them apt and clever. Leonardo da Vinci advocates experiment: Galileo uses experiment.

2. The second great achievement of Galileo was his seizure upon momentum as the fundamental quantity in the science of mechanics, and his demonstration that velocity is a factor in momentum. Galileo was by no means the first to study and discuss kinematical problems.

Benedetti (1530-1590), one of the many distinguished alumni of the University of Padua, had not only expressed dissatisfaction with the artificial distinction between "violent" and "natural" motions, but had gone farther and had paved the way for mechanics and the differential calculus by recognizing the fact of continuous variation in motion: Benedetti (10) had in particular studied oscillatory motion and had shown that such a motion is continuous even when the vibrating particle is at rest at the end of its path. He had in fact introduced the modern idea of continuous variation. But none of the predecessors of Galileo had, so far as I have been able to discover, pushed their study of moving bodies beyond the mere consideration of change of position. None of them had recognized the inertia of the moving body as a fundamental—perhaps the fundamental-fact of mechanics. Princes and paupers, for ages, had stumped their toes against bricks and stones: they were doubtless quite as familiar as we with the mere fact of inertia. But to Galileo it was a cardinal fact, because he was the first to see that the future history of a body depends upon its possession of inertia. To him the importance of a motion is, in general, measured by the inertia involved, or as was then said—the weight involved. Hence he assigned to the product of the weight and velocity of a body the name "momentum," which is merely the Latin word for importance; as a synonym he sometimes uses the word impetus, thus emphasizing the impetuosity of motion.

But Galileo never got beyond the point where he measured inertia by weight, as, indeed, engineers still do—all, at least, except electrical engineers. The invention of the idea of mass was reserved for Newton. Even Huygens,(10) who first mastered the idea of centrifugal force, never got beyond the point where he measured centrifugal forces in terms of weight, thus avoiding the conception of mass in all his work.

Those who wish to see just how clearly Galileo conceived that the future behavior of a body is connected with its inertia should read those propositions in his "Mechanics"(11) in which he calculates the path of a projectile by assuming that the horizontal speed of a shot, after it has left the muzzle of a gun, continues to be uniform. His repeated use of this principle makes it perfectly clear that he discovered what we now call—and perhaps properly call—Newton's first law of motion. Galileo failed to generalize it by extending it to all bodies whether subject to the earth's gravitation or not. This Newton did because he had acquired the new concept of mass—that constant property which never deserts a body in any position or condition.

3. The next great step which Galileo made was the discovery of the constant factor in the motion of falling bodies. One of his earliest experiments, performed while still a young man at the University of Pisa, was to allow a bronz ball to roll down a perfectly prepared inclined plane, an experiment from which he cleverly inferred that while the position and speed of the ball were changing, the time-rate at which it gained momentum remained constant. It was with reference to these particular experiments that Goethe remarked "dem Genie, ein Fall fur tausend gelte." The experiment is completed by showing how one can compute the momentum (or

speed) of a body after it has been falling for any given time or through any given distance. In all these computations, the unit of momentum employed is that which a body acquires in falling freely through an arbitrarily selected unit of distance.

As illustrating how tenacioully he clings to the idea of momentum, witness the following clear, exact and thoroughly modern definition dating from the year 1604: (12)

> I call a motion uniformly accelerated when starting from rest its momentum, or degree of speed, increases directly as the time, measured from the beginning of the motion.

Observe that we have here, without any mention of the word, precisely the dynamical idea which we today use under the name of a "constant force." There is, indeed, no necessity for the name; for Galileo attempts nothing more than to discover how the momentum of a body changes owing to the presence of another body such as the earth in the neighborhood (action at a distance) or owing to contact with an elastic body such as the hot gases of exploding gunpowder in the barrel of a gun (action through a medium). Later generations had not yet beclouded the idea of force with "tendencies to motion"; they had not yet identified it with that vastly more complex "muscular sensation"; they had not yet made it over in the form of a "man"; they had not yet named it an "agent"; they had not yet identified it with a state of stress or strain which one elastic body exhibits when held permanently at rest by another elastic body; still less had there been any attempt to convince people—principally high school lads and college students—that all these various things are one and the same, since, forsooth, at various times we call them by one name, "force." Some of Galileo's most worthy successors, such as Clifford,(13) Poincare(14) and Hertz, have pointed out our inconsistent definitions of force, and have advocated in the most outspoken manner, a return to the simple methods of this Italian academician.

The best known of all his experiments is, of course, that is which he proves that the time of fall is independent of weight, an experiment which completes to a first approximation the laws of falling bodies practically as we have them today. He accomplishes a second approximation by eliminating the bouyant force of the medium. He is prevented from making ing a third approximation only because he meets the barrier of viscosity, a barrier which still renders impossible the solution of any but a few simple cases in fluid motion.

The one remaining fundamental phenomenon of falling bodies, is that the acceleration of gravity is independent of the substance of which the falling body is composed. This Galileo(15) proved by swinging, side by side, two pendulums, having bobs of lead and cork, respectively. When the suspension fibers had equal lengths and the pendulums swung through equal amplitudes, they had equal velocities at each point of their path. It is difficult to find in Newton's hollow pendulum experiment much more than a second approximation in which he eliminates the air resistance from this experiment of Galileo.

4. The fourth advance which we owe to Galileo is the observation that the momentum communicated to a body in one direction does not alter its momentum in a direction at right angles. This independence of components of momenta, now known as Newton's second law of motion, was in the hands of Galileo no mere philosophical theorem, no vague guess, but a practical rule of action to be empolyed in mechanical operations. It is by compounding a uniform horizontal velocity with an accelerated vertical velocity that he proves, for the first time, that the path of a projectile is a parabola. It was by means of this principle that he prepared a range-table for gunners. The fact is then that Galileo discovered and employed the first two of Newton's laws essentially as we use them today.

It requires more than sheer strength to climb a difficult mountain peak; one must start in on the right trail. More than mere intellectual ability is needed to make an important discovery in physical science; one must start in with the correct viewpoint. This viewpoint is precisely what Aristotle lacked and exactly what Galileo possessed. It is Gomperz,(16) the distinguished historian of Greek thought, who says:

> The physical doctrines of Aristotle are a disappointing chapter in the history of science. They display to us an eminent mind wrestling with problems to which it is in no wise equal.

5. As a minor achievement of Galileo allow me to mention some discoveries to which he blazed a part of the road.

In a letter to a friend he says he had spent more years in the study of philosophy than weeks in mathematics. It is therefore, extraordinarily surprising to find set forth in his "Dialogues on Motion"(17) all the detailed facts and ideas which are involved in the modern definition of an infinite quantity developed by Boltzano, Cantor, and Dedekind, viz., an assemblage containing a part which may be put into one-to-one correspondence with the whole.

Again he paves the way, in a very distinct manner, for the differential calculus, in pointing out that the definitions(18) of constant velocity and constant acceleration hold only when the times considered are "all whatsoever." If, therefore, one wishes to employ these definitions in the discussion of variable motion he must take his time intervals indefinitely small.

The invention of the well-known thermoscope which Galileo employed in his lectures at Padua also belongs here; for while it is not a true thermometer it doubtless led immediately to those exquisite sealed instruments shortly afterwards constructed by the Accademia del Cimento and still preserved in the Tribuna di Galileo at Florence. The theory of "dimensions," first stated by Fourier, was led up to in the First Day of the Dialogues on Motion.

The principle employed in his measurement of the density of air(19) is one which is not only faultless in principle but one which makes it plainly evident that Galileo had properly conceived that idea of atmospheric pressure which, in the hands of two of his students, led to the invention of the barometer, and, in the hands of von Guericke, to the air pump. Torricelli knew well the Dialogues on Motion.

6. Finally, Galileo was an inspiring teacher and built up at Padua a great school of physics. Many of his students lodged under his own roof; helped him in his own garden; ate at his own table. He had his own workshop and employed his own mechanicians. Generous with his time, his energy and his money, master of a fine literary style, endowed with a keen sense of humor, familiar with the best that had been said and thought in the world, standing in the front rank of investigators, is it any wonder that young men of talent hastened to Padua from all parts of Europe? Could any higher compliment he paid to a teacher than the devotion exhibited by the youthful Viviani, a lad in his 'teens, for his master already some seventy years old and a "Prisoner in Arcetri?" If deferred payments of the kind that teachers mostly depend upon ever get as far as the next world, surely this courageous spirit, harried throughout his long life by poverty, ill-health and the censorship of the church, must have been gratified by the the work of the Accademia del Cimento which was, with the exception of a single man, composed entirely of his students. Mechanics was the one subject to which he was devoted constantly and persistently throughout his life; it was the subject of his earliest investigation when a young man at Pisa; the subject upon which he lectured when in his prime at Padua; the subject of his latest and most mature reflection at Arcetri. His most important contribution to dynamics was published in the seventy-third year of his age.

If, in conclusion, I were asked to summarize in a single sentence the principal contributions to the science of physics, I should mention the two following facts: (1) That knowledge of physical phenomena which is to receive "impersonal verification" and become useful, must be obtained mainly by experiment adapted to ask of nature some particular question. (2) That momentum considered as a function of time and position is a fundamental dynamical concept; or, in other words, to discover how the change of momentum of any body is connected with the physical circumstances in which the body is placed, is the one great problem of dynamics.

But perhaps, after all, his most important contributions lie outside of physics. Indeed Galileo has not yet shot his last arrow. For his life still teaches us that nothing is so because any man says it is so. His example still shows how experiment can rob a man of all arrogance of opinion, how familiarity with unsolved problems can give a man genuine humility, and how, on the other hand, the possession of clear experimental evidence arms him with sure confidence.

Critics tell us that Florence, during the Renaissance, shown with a borrowed light—a light reflected from Athens. But I venture to think that those who will take the pains to look over the pages of Galileo will find them self-luminous.

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(1) "Renaissance in Italy," Vol. I., p. 234.

(2) Accademia del Cimento, founded in 1657; disbanded in 1667.

(3) Edited by the scholarly care of Professor Favaro, of the University of Padua, and published by the Italian government, 1890-1909. Referred to hereafter as "Nat. Ed."

(4) For a masterly presentation of this phase of Galileo's work, see Dr. Charles J. Little's article in the Methodist Review, Vol. 88, pp. 204-218, 1906.

(5) Gothe, "Farben-lehre Historiche Theil," art. Galileo.

(6) Mann, "Teaching of Physics," pp. 107-110 (Macmillan, 1912).

(7) "Nat. Ed.," Vol. 5, pp. 326. Translated in Fahie's "Galileo," p. 187.

(8) "Nat. Ed.," Vol. 6, p. 340. Translated in Fahie's "Galileo,"

(9) Lasswitz, "Atomistick," Bd.2, pp. 14-23, gives a good description of Benedetti's work.

(10) Huygens, "Horologium Oscillatorium," Part V., Prop. 13; or Hobart, "School Science and Mathematics," Vol. 11, p. 692 (1911), for translation of Huygens' paper.

(11) Galileo, "Dialogues on Motion," Fourth Day, Problem I. et seq.

(12) "Nat. Ed.," Vol. II., p. 166.

(13) Clifford, Nature, Vol. 22, p. 122 (1880).

(14) Poincare, lecture before the Wissenschaftlich Verin in Berlin, p. 116 (Teubner, 1912).

(15) "Nat. Ed.," Vol. 8, pp. 128-130, First Day, translated into German by von Oettinger, Ostwad's Wiss. Klassiker, No. 11, p. 76.

(16) "Greek Thinkers," Vol. 4, p. 108, Berry's translation.

(17) First Day, "Nat. Ed.," Vol. 8, p. 78.

(18) Third Day, "Nat. Ed.," Vol. 8, p. 191.

(19) "Nat. Ed.," Vol. 8, p. 124, First Day.