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and from Harper and Young's published data. It is seen that the high-dispersion measures give definitely lower probable errors than those obtained using spectra of moderate dispersion, but that the eye estimates of Harper and Young are almost comparable with the intensity measures for moderate dispersion, which is the same as they employed. The measures suggest that $\epsilon$ Leonis may be somewhat fainter and $\lambda$ Serpentis somewhat brighter than the Johnson-Morgan classification.

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*To be published in detail as *P. Dom. Ap. O.*, **12**, no. 12, 1966.

# WAS GALILEO AN ASTRONOMER OR PYHSICIST?

By Karel Hujer
*University of Chattanooga, Chattanooga, Tennessee*

In 1964 when the quatercentenary of the birth of Galileo was observed throughout the scientific world, culminating in an international symposium in his native Pisa and Florence, Italy, a rich opportunity was offered to reconsider and re-examine immense sources of Galileo's creative heritage. Galileo is popularly associated with the telescope, and with the legend of the dramatic stamping of the ground just outside the inquisitorial hall after the historical trial and the exclamation of his dogged "Oppure si muove", that is, "Nevertheless it does move". The reality was actually very different; it is always revealing to retrace the picture of the struggling beginnings of this leading science of our age.

The passion of Galileo's scientific life was to prove the Copernican heliocentric theory. In achieving this, the greatness of the Tuscanian wizard was evident by his genial mobilization of all the resources of physics which he could foresee and formulate. One of the fundamental problems of the late sixteenth and early seventeenth centuries was to

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decide whether the Copernican theory was true. In the world of the mighty intellectual fortress of Aristotelian peripatetic physics, nourished for a millenium by a galaxy of serious and dedicated scholastic philosophers, Galileo's task was formidable but it was appropriately measured by his genius. The Copernican theory involved the disturbing and provocative suggestion of the motion of that stupendous body, our entire terrestrial globe. Galileo therefore prepared himself for this herculean task.

It is significant that his first work "De Motu",[1] written at the early age of twenty-five, concerned the problem of motion. The peripatetic concept of motion, considered as a process of becoming, required a continuous efficient causation for its maintenance and constituted most important objections to the Copernican theory of the earth's rotation. The arguments that Copernicus himself brought forth in his famous "De Revolutionibus Orbium Coelestium"[2] are entirely of a geometrical and kinematic nature and involve neither dynamical nor gravitational aspects of matter. Today it is therefore difficult for us to imagine how inacceptable was the motion of the earth when the concept of inertia was still unknown. To introduce this new concept in physics into the petrified Aristotelian world view required the highest degree of resourcefulness. A. C. Crombie[3] states significantly:

> It was, in fact, Galileo who was chiefly responsible for carrying the experimental and mathematical methods into the whole field of physics and for bringing about the intellectual revolution by which first dynamics and then all science, were established in the direction from which there was no return.

Indeed, this statement very aptly illustrates the evolution of Galileo's role in physics. Although originally he was inevitably influenced by the peripatetic school of thought yet, at his first post in Pisa, Galileo wrote his treatise on motion where he began to challenge the foundation of Aristotelian physics. He was first to become dissatisfied with the unsupported reference to the philosophical authorities of his time. He introduced careful and systematic observation and experimentation. While this is entirely our scientific method of today, then it was a radical novelty against the conceptual analysis of natural phenomena, a procedure generally practiced by Aristotelians.

One of the fundamental dogma of peripatetic physics was that the time of freely falling bodies was proportional to their weight. While still in Pisa, Galileo showed reasonably well with weights of a ratio as great as 1/200 that this peripatetic view had no experimental verification. However convincing and evidential were his experiments on this point, they could not shatter the authority of the Aristotelians. On the contrary, despite their popularity, his lectures at the University of

Pisa aroused the enmity of the governing authorities. Thus he found conditions in his native town unfavourable for the continuation of his cherished studies.

While experimenting with freely falling bodies, Galileo could not fail to note that they were uniformly accelerated. After all, this was admitted by the peripateticians themselves. Their naive explanation, however, was that all bodies have a tendency to occupy their natural position in the fastest way and for that reason they accelerate. This, of course, could not satisfy Galileo's penetrating mind. He was forced to seek the cause of uniformly accelerated motion and determine its quantitative conditions. Consequently he confronted the difficult problem of delicate time measurement; we must keep in mind that he did not possess a clock or any accurate timekeeper as such instruments did not then exist.

First, Galileo had to define uniformly accelerated motion.[4] He had two choices: either he could define motion in such a way that velocity is proportional to the distance covered by the body, or define uniformly accelerated motion as a movement whose velocity is proportional to time. After some hesitation Galileo chose the second definition. If the definition is properly formulated, we can deduce therefrom results which can be verified by measurement. This procedure presents Galileo as a modern experimental scientist. He was first to conduct systematic experiments. On the basis of preliminary observations he created a working hypothesis. From the working hypothesis he traced such consequences as could be verified by measurement. In his measurements he selected such conditions that would be accessible to his instrumental equipment. The results of his measurement he checked with the outcome of his working hypothesis. Unlike Descartes and others, he followed the course of physical events rather than their cause. Even this indicated his distinction because the search for causes can only follow the accurate quantitative description of natural phenomena. No one before Galileo followed this procedure; it is his uniqueness in the history of physics.

Indeed, Galileo took the hard way in building foundations of Newtonian physics while paving the way for the Copernican world view. The brilliance of his physics is in the scrutinizing study of freely falling bodies in which he applied his strict procedure. His working hypothesis was the admission that the free fall is uniformly accelerated. From his definition of uniformly accelerated motion he derived the relation between time and distance. He did so because the measurement of the dependence of velocity on time is very difficult, much more so than the

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measurement of the dependence of distance on time. It was impossible to observe a freely falling body directly, as its course was too swift for measurement. Therefore he slowed it down; instead of dropping his spheres he let them roll down the inclined plane. In this he was guided by the supposition that the movement along the inclined plane can differ from the free fall only by the rate of its speed, not by the relation between velocity and time. Of course, for these experiments Galileo was in dire need of accurate measurement of time and, as stated before, no instrumental means were available to him; he therefore had to find his own ingenious method.

The manner in which Galileo arrived at his assumption concerning motion on the inclined plane is characteristic of his pioneering procedure in physics. He based it on observation of the moving body from the highest point to the base of the inclined plane wherefrom it is forced to move upward along the plane of the opposite inclination. From observation and reasoning he reached the conclusion that a sphere would rise to the same elevation from which it started to roll down.[5] Furthermore, he concluded that a body would reach the same final velocity at its lowest point as if it were freely falling, without regard to the angle of inclination of the plane, provided it started from the same elevation above the lowest point. This conclusion Galileo verified by the observation of the oscillating pendulum.[6] He represented the swinging pendulum as a succession of motions of a body along a series of short planes of varying angles of inclination. How much this reminds us of the method of indivisibles practiced by Archimedes, whom Galileo liked to call his beloved teacher! The results of these observations not only confirmed Galileo's original assumption but provided further important discoveries. In order to practice such preliminary assumptions and to appropriately process his observations, he had to resort to idealized conditions. He was indeed the pioneering master in such mental processes. They enabled him to arrive at a number of other important revelations such as the trajectory of a projectile as a result of the composition of two vectors. Consequently this finding facilitated the study of complex movements and substantially influenced the further growth of physical science.

It is at this point that we realize the crux of Galileo's genius as a physicist and modern experimentalist: his discovery of the principle of inertia. It was his keen, penetrating observation of moving spheres along an inclined plane. As indicated before, a ball rolls upward along the opposite inclined plane to the same elevation from which it started downward. Now he posed a question to himself: What would happen

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if he continued to lower the opposite inclined plane along which the sphere was impelled to move upward after it reached the lowest position? If the angle decreases, the ball would have to move farther in order to attain the same elevation. And what happens if the opposite inclined plane, along which the ball moved upward, were lowered to a horizontal position? Except for friction, the sphere evidently would roll along this horizontal plane indefinitely, moving with the velocity it had on reaching the base of the inclined plane. It is in this way that Galileo arrived at the discovery of the principle of inertia. While slowly changing conditions that influence the phenomenon without affecting the very foundation of the process itself, Galileo was in a postion to reach a conclusion valid for circumstances that were different from those at the beginning of the experiment and thus to arrive at a generalization of the observed phenomena. In this he paved the way in a most effective manner for the eventual establishment of the Copernican world view that was only possible by the foundation of Newtonian physics. Later on, in his principal work "Dialogue on Two Chief World Systems"[7] published in 1632, it is Galileo as an eloquent physicist who becomes the defender of the Copernican system. His magnificent description of the physical scenes and phenomena inside a quietly moving ship, representing the moving earth through cosmic space, may be described as a superb exposition of the principle of inertia or the accomplished, masterful and first introduction into the principle of relativity.

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