A SOURCE BOOK
in
PHYSICS

By
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SOURCE BOOKS IN THE HISTORY OF THE SCIENCES

General Editor's Preface

This series of Source Books aims to present the most significant passages from the works of the most important contributors to the major sciences during the last three or four centuries. So much material has accumulated that a demand for selected sources has arisen in several fields. Source books in philosophy have been in use for nearly a quarter of a century, and history, economics, ethics, and sociology utilize carefully selected source material. Recently, too, such works have appeared in the fields of psychology and eugenics. It is the purpose of this series, therefore, to deal in a similar way with the leading physical and biological sciences.

The general plan is for each volume to present a treatment of a particular science with as much finality of scholarship as possible from the Renaissance to the end of the nineteenth century. In all, it is expected that the series will consist of eight or ten volumes, which will appear as rapidly as may be consistent with sound scholarship.

In June, 1924, the General Editor began to organize the following Advisory Board:

Each of the scientists on this board, in addition to acting in a general advisory capacity, is chairman of a committee of four or five men, whose business it is to make a survey of their special field and to determine the number of volumes required and the contents of each volume.

In December, 1925, the General Editor presented the project to the Eastern Division of the American Philosophical Association. After some discussion by the Executive Committee, it was approved and the philosophers of the board, with the General Editor as chairman, were appointed a committee to have charge of it. In November, 1927, the Carnegie Corporation of New York granted $10,000 to the American Philosophical Association as a revolving fund to help finance the series. In December, 1927, the American Association for the Advancement of Science approved the project, and appointed the General Editor and Professors Edwin G. Conklin and Harlow Shapley a committee to represent that Association in cooperation with the Advisory Board. In February, 1928, the History of Science Society officially endorsed the enterprise. Endorsements have also been given by the American Anthropological Association, the Mathematical Association of America, the American Mathematical Society, and the American Astronomical Society within their respective fields.

The General Editor wishes to thank the members of the Advisory Board for their assistance in launching this undertaking; Dr. J. McKeen Cattell for helpful advice in the early days of the project and later; Dr. William S. Learned for many valuable suggestions; the several societies and associations that have given their endorsements; and the Carnegie Corporation for the necessary initial financial assistance.

GREGORY D. WALCOTT.

LONG ISLAND UNIVERSITY,
BROOKLYN, N. Y.
December, 1928.

A SOURCE BOOK IN PHYSICS

Author's Preface

In accordance with the general plan of the series, this Source Book in Physics contains extracts from important contributions made to that science in the three centuries ending with the year 1900 A.D. The period opens with the introduction of the science of dynamics by Galileo. Throughout the succeeding years the ruling concepts are those of dynamics, developed by Newton, and applied by those who followed him to the explanation by dynamical principles of all the principal physical phenomena. This era, in which the concepts employed were purely dynamical or mechanistic, came to an end precisely in the year 1900, when a new era of development began with the introduction by Planck of the quantum theory of the distribution of energy.

The subject is so vast and ramifies into so many branches, each of which strikes root, like the banyan tree, and has an almost independent growth, that it is impossible to present all the important parts of it in a single volume. Some principles of selection must be adopted, if such can be found, to determine what should be put in and what should be left out. With some misgivings I decided to recognize the distinction between mathematical and experimental physics, to omit the mathematical arguments, and to include only the experimental results and such expositions of the theoretical results as were given in words by their discoverers. The choice of the selections to be made from the vast mass of experiment was determined by considering what would be of interest to a student whose knowledge of physics had been acquired from textbooks. These principles have not been applied with perfect consistency, and I fear that many matters have been omitted which specialists would like to see included. I trust, however, that nothing has been given which is not worthy of a place among the classics of physics.

The prefatory accounts of the lives of the physicists whose works are quoted were taken generally from the histories of physics by Poggendorff, Heller, and Rosenberger, when they were given in these books. The accounts of the men whose lives are not included in them were compiled from various sources. The translations were made by myself except when translations were found in the literature, in which cases these were used and are ascribed to their authors. I thought it best to group the extracts under the general headings into which the science is generally divided in the text-books. Within these groups the chronological order is generally followed, although in some cases cognate matters are grouped together without consideration of their dates. Omissions of parts of the originals are usually indicated by rows of leaders.

Professor Henry Crew, of Northwestern University, and President Joseph S. Ames, of Johns Hopkins University, were kind enough to examine my preliminary list of titles and to aid me by their advice. The limitations of space forced me to omit many subjects which appeared in this first list, and for such omissions I alone am responsible. I often consulted Professor E. P. Adams of Princeton University and received from him many valuable suggestions.

WILLIAM FRANCIS MAGIE.

PRINCETON UNIVERSITY,
March, 1935.

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A SOURCE BOOK IN PHYSICS

MECHANICS

GALILEO

Galileo Galilei was born in Pisa on February 18, 1564. His parents were of noble families. His father was a student of music, especially of the mathematical theory. He was without means and felt compelled to train his son for profitable business. The boy's extraordinary talents showed themselves while he was at school and his father finally determined to educate him as a physician. He studied at the University of Pisa, where his interest was excited in the study of mathematics, for which he neglected his medical studies. He left the university without taking a degree. His scientific reputation, however, led to his appointment as a teacher of mathematics in the university in 1589, where he remained three years. It was in this period that he made the fundamental discovery of the laws of falling bodies. These laws he discussed in lectures and collected in a memoir which was not published until two hundred years later. In the later years of his life he wrote the treatise entitled, *Dialoghi della Nuove Scienze*, from which the following extracts are taken. In it he returns to his early studies and presents the connection between the motion of bodies and the forces acting on them in a way which has served as a model for all those who came after him. This treatise may be considered as marking the beginning of the science of dynamics.

In December, 1592, he was appointed as mathematician in the University of Padua for a term of six years. This appointment was renewed and at the end of the second term he was appointed professor for life. He attracted to his lectures students from all over Europe. He invented or improved the telescope and applied it to astronomical observations. His discoveries of Jupiter's moons, of the irregularities of the moon's surface, of sun spots, and of the phases of Mercury and Venus all served to support the Copernican hypothesis and to disprove the Ptolemaic system. On this account a strong feeling against him was raised in the minds of some of the leaders of the church. By his removal in 1610 to Pisa as First Mathematician of the university he became subject to the temporal control of the church. After years of uncertainty he was at length brought before the Inquisition, and was ordered not to publish anything in support of the Copernican system. Nevertheless the relations in which he stood with many of the great dignitaries of the church seemed to him so favorable that he finally ventured to publish a book in his favorite form of a dialogue on the two great systems of the universe. In this book both the Ptolemaic and the Copernican systems were presented, but it was generally admitted that the more convincing argument supported the Copernican system. He was again brought before the Inquisition and finally was so weakened in his old age by fear of what might happen to him that he publicly abjured his belief in the Copernican system. From that time on until his death he was technically a prisoner of the Inquisition, though he was permitted to live in the care of his friends and patrons. It was in this period that he wrote his dialogue on motion. He died on January 8, 1642, the year before that in which Newton was born.

The extracts selected from Galileo's work present his fundamental study of falling bodies and two short passages, one dealing with the pendulum and the other with the composition of motions caused by forces. They are given as they appear in *Two New Sciences*, a translation of Galileo's work published in 1914 by Henry Crew and Alfonso de Salvio.

Acceleration and Laws of Falling Bodies

The following pages contain the essential parts of Galileo's study of accelerated motion and some of the most important propositions deduced from the general laws discussed. The interlocutors are Salviati, who is reading from a manuscript of a certain Academician (Galileo), Sagredo, also a scholar skilled in mechanics, and Simplicio.

Salv. The present does not seem to be the proper time to investigate the cause of the acceleration of natural motion concerning which various opinions have been expressed by various philosophers, some explaining it by attraction to the center, others to repulsion between the very small parts of the body, while still others attribute it to a certain stress in the surrounding medium which closes in behind the falling body and drives it from one of its positions to another. Now, all these fantasies, and others too, ought to be examined; but it is not really worth while. At present it is the purpose of our Author merely to investigate and to demonstrate some of the properties of accelerated motion (whatever the cause of this acceleration may be)—meaning thereby a motion, such that the momentum of its velocity goes on increasing after departure from rest, in simple proportionality to the time, which is the same as saying that in equal time-intervals the body receives equal increments of velocity; and if we find the properties (of accelerated motion) which will be demonstrated later are realized in freely falling and accelerated bodies, we may conclude that the assumed definition includes such a motion of falling bodies and that their speed goes on increasing as the time and the duration of the motion.

Sagr. So far as I see at present, the definition might have been put a little more clearly perhaps without changing the fundamental idea, namely, uniformly accelerated motion is such that its speed increases in proportion to the space traversed; so that, for example, the speed acquired by a body in falling four cubits would be double that acquired in falling two cubits and this latter speed would be double that acquired in the first cubit. Because there is no doubt but that a heavy body falling from the height of six cubits has, and strikes with, a momentum double that it had at the end of three cubits, triple that which it had at the end of one.

SALV. It is very comforting to me to have had such a companion in error; and moreover let me tell you that your proposition seems so highly probable that our Author himself admitted, when I advanced this opinion to him, that he had for some time shared the same fallacy. But what most surprised me was to see two propositions so inherently probable that they commanded the assent of everyone to whom they were presented, proven in a few simple words to be not only false, but impossible.

SIMP. I am one of those who accept the proposition, and believe that a falling body acquires force in its descent, its velocity increasing in proportion to the space, and that the momentum of the falling body is doubled when it falls from a doubled height; these propositions, it appears to me, ought to be conceded without hesitation or controversy.

SALV. And yet they are as false and impossible as that motion should be completed instantaneously; and here is a very clear demonstration of it. If the velocities are in proportion to the spaces traversed, or to be traversed, then these spaces are traversed in equal intervals of time; if, therefore, the velocity with which the falling body traverses a space of eight feet were double that with which it covered the first four feet (just as the one distance is double the other) then the time-intervals required for these passages would be equal. But for one and the same body to fall eight feet and four feet in the same time is possible only in the case of instantaneous (discontinuous) motion; but observation shows us that the motion of a falling body occupies time, and less of it in covering a distance of four feet than of eight feet; therefore it is not true that its velocity increases in proportion to the space.

The falsity of the other proposition may be shown with equal clearness. For if we consider a single striking body the difference of momentum in its blows can depend only upon difference of velocity; for if the striking body falling from a double height were to deliver a blow of double momentum, it would be necessary for this body to strike with a double velocity; but with this doubled speed it would traverse a doubled space in the same time-interval;

observation however shows that the time required for fall from the greater height is longer.

SAGR. You present these recondite matters with too much evidence and ease; this great facility makes them less appreciated than they would be had they been presented in a more abstruse manner. For, in my opinion, people esteem more lightly that knowledge which they acquire with so little labor than that acquired through long and obscure discussion.

SALV. If those who demonstrate with brevity and clearness the fallacy of many popular beliefs were treated with contempt instead of gratitude the injury would be quite bearable; but on the other hand it is very unpleasant and annoying to see men, who claim to be peers of anyone in a certain field of study, take for granted certain conclusions which later are quickly and easily shown by another to be false. I do not describe such a feeling as one of envy, which usually degenerates into hatred and anger against those who discover such fallacies; I would call it a strong desire to maintain old errors, rather than accept newly discovered truths. This desire at times induces them to unite against these truths, although at heart believing in them, merely for the purpose of lowering the esteem in which certain others are held by the unthinking crowd. Indeed, I have heard from our Academician many such fallacies held as true but easily refutable; some of these I have in mind.

SAGR. You must not withhold them from us, but, at the proper time, tell us about them even though an extra session be necessary. But now, continuing the thread of our talk, it would seem that up to the present we have established the definition of uniformly accelerated motion which is expressed as follows:

> A motion is said to be equally or uniformly accelerated when, starting from rest, its momentum receives equal increments in equal times.

SALV. This definition established, the Author makes a single assumption, namely,

The speeds acquired by one and the same body moving down planes of different inclinations are equal when the heights of these planes are equal.

By the height of an inclined plane we mean the perpendicular let fall from the upper end of the plane upon the horizontal line drawn through the lower end of the same plane. Thus, to illustrate, let the line *AB* (Fig. 1) be horizontal, and let the planes *CA* and *CD* be inclined to it; then the Author calls the perpendicular *CB* the "height" of the planes *CA* and *CD*; he supposes that the speeds acquired by one and the same body, descending along the planes *CA* and *CD* to the terminal points *A* and *D* are equal since the heights of these planes are the same, *CB*; and also it must be understood that this speed is that which would be acquired by the same body falling from *C* to *B*.

SAGR. Your assumption appears to me so reasonable that it ought to be conceded without question, provided of course there are no chance or outside resistances, and that the planes are hard and smooth, and that the figure of the moving body is perfectly round, so that neither plane nor moving body is rough. All resistance and opposition having been removed, my reason tells me at once that a heavy and perfectly round ball descending along the lines *CA*, *CD*, *CB* would reach the terminal points *A*, *D*, *B*, with equal momenta.

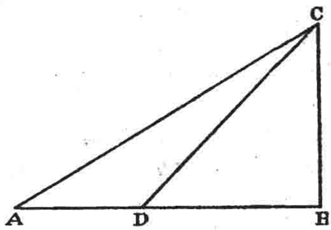

FIG. 1.

SALV. Your words are very plausible; but I hope by experiment to increase the probability to an extent which shall be little short of a rigid demonstration.

Imagine this page to represent a vertical wall, with a nail driven into it; and from the nail let there be suspended a lead bullet of

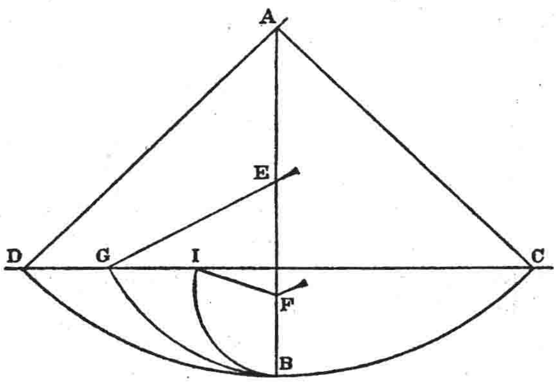

FIG. 2.

one or two ounces by means of a fine vertical thread, *AB*, (Fig. 2) say from four to six feet long, on this wall draw a horizontal line *DC*, at right angles to the vertical thread *AB*, which hangs about two finger-breadths in front of the wall. Now bring the thread *AB* with the attached ball into the position *AC* and set it free; first it will be observed to descend along the arc *CBD*, to pass the point *B*, and to travel along the arc *BD*, till it almost reaches the horizontal *CD*, a slight shortage being caused by the resistance of the air and the string; from this we may rightly infer that the ball in its descent through the arc *CB* acquired a momentum on reaching *B*, which was just sufficient to carry it through a similar arc *BD* to the same height. Having repeated this experiment many times, let us now drive a nail into the wall close to the perpendicular *AB*, say at *E* or *F*, so that it projects out some five or six finger-breadths in order that the thread, again carrying the bullet through the arc *CB*, may strike upon the nail *E* when the bullet reaches *B*, and thus compel it to traverse the arc *BG*, described about *E* as center. From this we can see what can be done by the same momentum which previously starting at the same point *B* carried the same body through the arc *BD* to the horizontal *CD*. Now, gentlemen, you will observe with pleasure that the ball swings to the point *G* in the horizontal, and you would see the same thing happen if the obstacle were placed at some lower point, say at *F*, about which the ball would describe the arc *BI*, the rise of the ball always terminating exactly on the line *CD*. But when the nail is placed so low that the remainder of the thread below it will not reach to the height *CD* (which would happen if the nail were placed nearer *B* than to the intersection of *AB* with the horizontal *CD*) then the thread leaps over the nail and twists itself about it.

This experiment leaves no room for doubt as to the truth of our supposition; for since the two arcs *CB* and *DB* are equal and similarly placed, the momentum acquired by the fall through the arc *CB* is the same as that gained by fall through the arc *DB*; but the momentum acquired at *B*, owing to fall through *CB*, is able to lift the same body through the arc *BD*; therefore, the momentum acquired in the fall *BD* is equal to that which lifts the same body through the same arc from *B* to *D*; so, in general, every momentum acquired by fall through an arc is equal to that which can lift the same body through the same arc. But all these momenta which cause a rise through the arcs *BD*, *BG*, and *BI* are equal, since they are produced by the same momentum, gained by fall through *CB*, as experiment shows. Therefore all the momenta gained by fall through the arcs *DB*, *GB*, *IB* are equal.