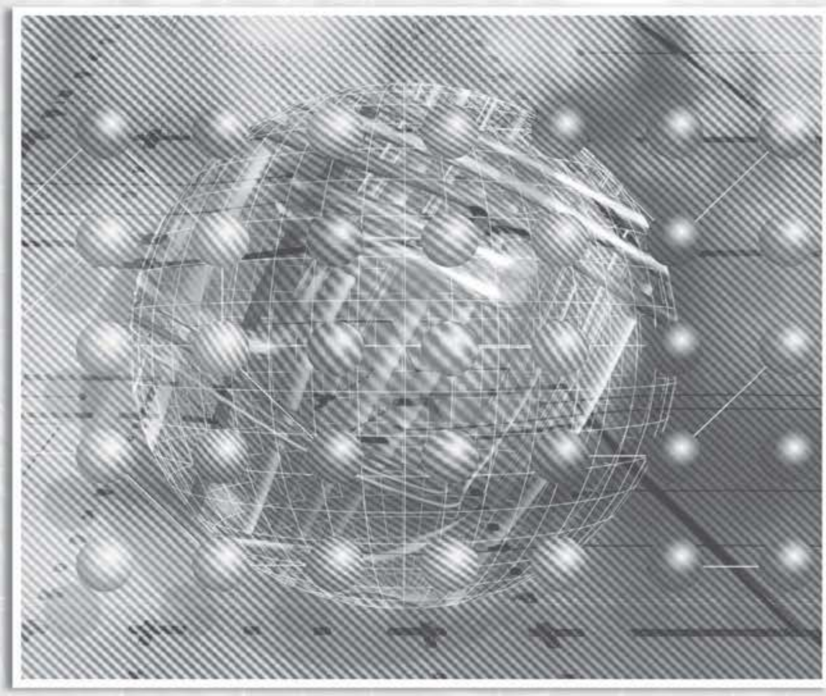
EXPLORING THE WORLD OF PHYSICS



From Simple Machines To Nuclear Energy

JOHN HUDSON TINER

EXPLORING

THE WORLD OF PHYSICS

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Dedication

This book is dedicated to Matthew John Stephens.

How to Use *Exploring The World of Physics*

Students of several different ages and skill levels can use *Exploring the World of Physics*. Children in elementary grades can grasp many of the concepts, especially if given parental help.

Middle school students can enjoy the book independently and quickly test their understanding and comprehension by the challenge of answering the questions at the end of each chapter.

Junior high and high school students can revisit the book as a refresher course. The sections marked "For More Study" are intended to challenge older students. These sidebars can be a springboard for additional study by advanced students.

Thought-provoking questions and problems are found throughout the book. The activities reinforce the essential principles of physics.

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Chapter One

1

Motion

Physics is the science that explores how energy acts on matter. Everything in the universe that we can experience with our senses is made of matter and energy. The Bible recognized this fact in Genesis 1:1–3. After God created earth (matter), He said, "Let there be light [energy]."

Matter has weight and occupies space. Energy can put matter in motion or change it in some way. Physics is sometimes described as the study of matter in motion, but physics is far more than that because physics includes exploring not only motion, but also sound, heat, light, electricity, magnetism, and nuclear energy.

Physics goes far back in time. Aristotle, an ancient Greek scientist, lived more than 2,000 years ago. The Greeks made an effort to gain knowledge through observation and reasoning. However, they seldom did experiments, which are observations that can be repeated under

PROBLEMS

1. How do modern scientists test new ideas?
2. What discovery helped clocks keep better time?
3. How did Galileo slow the motion of falling balls?

Can You Propose Solutions?

controlled conditions. Without experiments, they could not repeat what they observed to test their conclusions.

For instance, suppose they saw a leaf fall from a tree and later saw an apple fall from the same tree. They might speculate as to why the apple appeared to fall more quickly than the leaf, but they would not think to pick up an apple and a leaf and drop them together.

In addition, measurement is essential to good science. Scientists must be able to measure quantities such as weight, distance, time, temperature, electric current, and light intensity. Ancient people had few accurate scientific instruments, so they could not easily measure what they observed. Ancient scientists could only state what they discovered as general conclusions rather than precise scientific principles.

For example, they might see a heavily loaded cart roll down a hill and conclude that it gained speed. From one moment to the next, it rolled faster and faster. However, they had no accurate clocks, so they could not time the cart and measure its actual speed.

The first person to make real progress in understanding physics was Galileo, a scientist who lived in Italy almost 500 years ago. Like the Greeks, he had a brilliant and inquiring mind. In addition to thinking and observing, he was willing to experiment. Experiments are a great way to collect scientific information and test new discoveries.

Galileo entered the University of Pisa in 1581 to study medicine. Europe at that time was coming out of a period known as the Middle Ages. The Middle Ages were sometimes called the Dark Ages in Europe because learning had been in a deep decline. Most people—including leaders of countries—could neither read nor write.

In these dark days, scholars held in high regard the confident writings of Aristotle and other Greeks who lived almost 2,000 years earlier. People of the 1500s turned to ancient books as final authority on scientific matters. They saw no reason to question Aristotle's books or test his statements.

During his first year at the university, Galileo discovered an important principle that ancient Greeks had completely overlooked.

Students at Pisa began their day by going to chapel. One morning Galileo knelt and said his prayers in the dark chapel. He arose to watch a lamplighter light the candles in a lamp which was hanging 30 feet from the high ceiling.

Aristotle taught his students to learn through observation and reasoning.

Lighting the candles caused the lamp to move in a slow back and forth motion. As its motion died down, it seemed to take as long to make a small swing as a large one. Galileo timed the chandelier swing with his pulse.

Galileo returned to his room to try other pendulums. Experiments showed that the time for a complete swing was the same whether the arc was a small one or a large one.

Galileo's discovery is known as the principle of the pendulum. A principle is a law of science. In this case, Galileo had found that two pendulums of the same length would swing at the same rate regardless of how wide or shallow

Aristotle

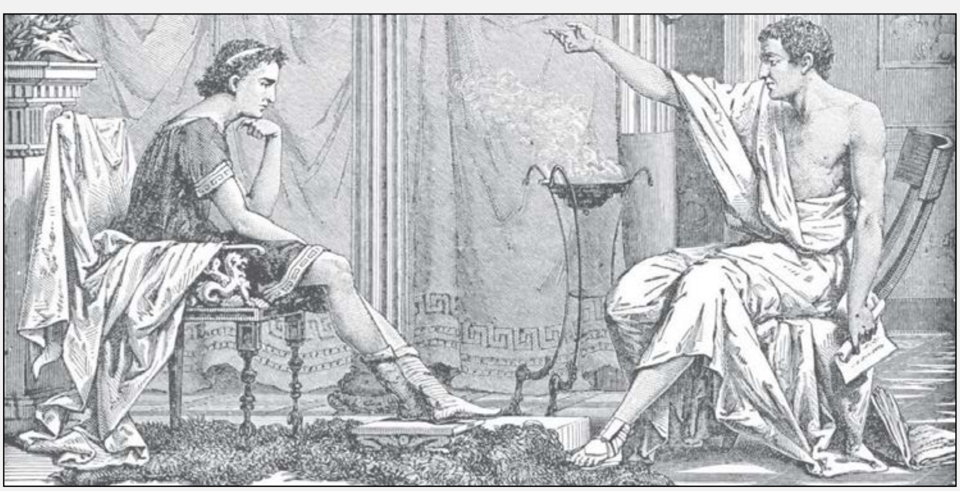
Aristotle (Greek Philosopher, 384 – 322 B.C.) was a great thinker of the ancient world. He attended school at Plato's Academy in Athens, Greece. It was one of the best schools in the world. Aristotle learned to observe carefully, pose insightful questions, and use reason to form conclusions. He did not, however, learn to do experiments to reveal new facts. Doing an experiment required work with the hands, but Greek thinkers thought manual labor was the work of servants.

Aristotle stayed in Athens for 20 years, first as a student and then as a teacher. He returned to his home country of Macedonia and served as the private tutor of the young man who would become Alexander the Great. Alexander the Great grew up to become the greatest military general of the ancient world.

Aristotle and Alexander the Great became good friends. Alexander the Great gave Aristotle money to start his own school in Athens. Aristotle called his school the Lyceum. Aristotle lectured as he walked about in the garden with his students. He encouraged his students to test their observations with common sense and clear thinking.

Aristotle wrote a book about the systems of laws that govern countries. He believed education was essential to the survival of a nation. Aristotle said, "All who have meditated on the art of governing mankind are convinced that the fate of empires depends on the education of youth."

About 50 of Aristotle's books were preserved. Errors in his books are minor considering the vast number of subjects he discussed. However, scholars in Europe during the Middle Ages believed his books contained no errors and all knowledge could be found in them. Medieval scholars made few important new discoveries in science. Aristotle would have been appalled if he had known that future people would use his books as the final word on scientific questions.



Aristotle tutoring Alexander the Great who was fourteen years old at the time.

their arcs. Only by making the string longer could he lengthen the time needed to make one back and forth swing.

Ancient Greeks had not mentioned this discovery in any of their books. The 17-year-old Galileo had made a discovery they had completely overlooked. Galileo realized that the ancient Greeks did not have all of the answers.

Galileo's discovery of the principle of the pendulum turned out to have a useful application. In Galileo's time, only length and weight could be measured with any accuracy. Merchants sold cloth, ribbon, and rope by length. They sold grain, potatoes, and coal by weight. They had developed accurate scales and rulers for measuring these quantities, but other tools of science, especially a way to accurately measure time, had not yet been invented.

Short intervals of time were especially difficult to measure. The best clocks of Galileo's day had only hour hands. They could not keep time accurately to the minute or second.

The regular back and forth motion of the pendulum would eventually regulate a clock so time could be measured to the second. However, attaching a pendulum to a clock would not occur until 30 years after Galileo died.

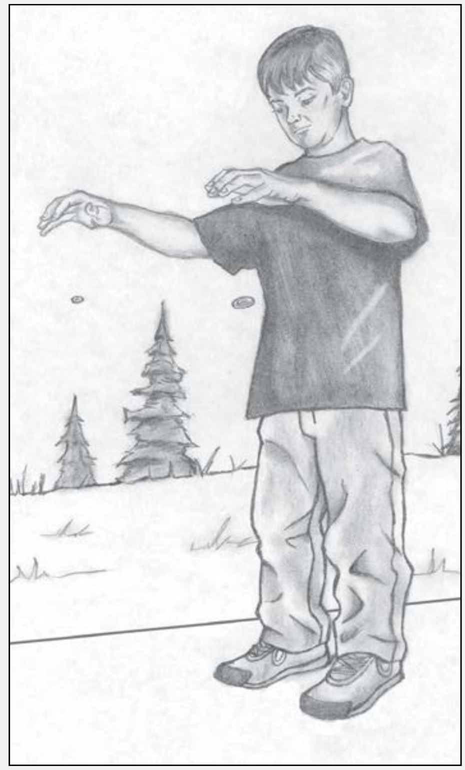
Galileo's experiments with pendulums set him thinking about other forms of motion. Almost everything taught about motion came from the books of Aristotle.

Aristotle claimed that heavy objects fall more rapidly than light ones. A ball ten times as heavy as a lighter one would fall ten times faster. A rumor sprang up that Galileo dropped different size iron balls from the tower of Pisa. It was the Leaning Tower of Pisa even then. Both heavy and light iron balls that Galileo dropped struck the ground at the same time.

He may not have done this experiment, but he did do other ones that convinced him that all objects would fall at the same speed.

Everyone knew that a feather would fall more slowly than a lump of lead. Galileo had to explain this everyday observation. He believed that air resistance caused differences

Falling Objects

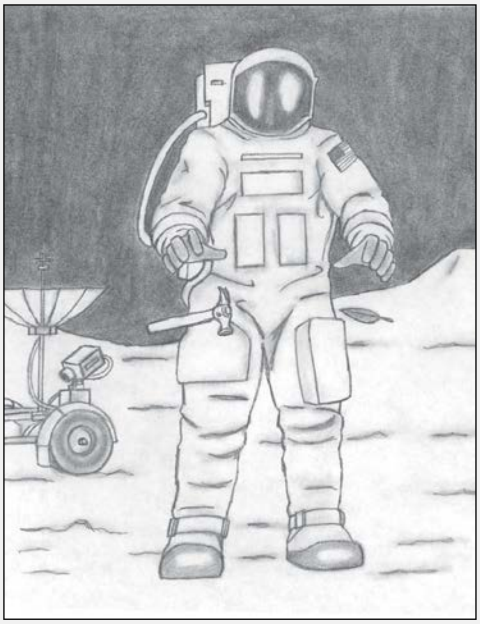


Try this experiment testing the speed of falling objects.

Test whether light and heavy objects fall at same or different speeds. Place a dime and a quarter in the palm of your hand. Stand where the floor is hardwood, tile, or another solid surface that is not covered with carpet or a rug. Quickly lower and pull away your hand so the two coins start falling to the floor at the same instant. Listen for their impact.

A quarter is about 2½ times as heavy as a dime. If Aristotle were correct, it would strike the floor well before the dime. However, sounds of the coins show that they strike the floor at nearly the same instant.

Astronaut and Feather



Galileo would have been eager to witness David Scott's experiment.

In 1971, David Scott, one of the *Apollo 15* astronauts who landed on the moon, showed television viewers back on earth an unusual experiment. Scott told them, "Galileo, a long time ago, made an important discovery about falling objects in gravity fields."

He held a falcon feather in his left hand. In his right hand, he held a hammer. Scott let go of the hammer and feather at the same moment.

On earth, the feather would have floated down because of air resistance. On the moon with no atmosphere to slow the feather, it fell at the same speed as the hammer. They fell side by side and hit the surface of the moon at the same time.

in speed. To test his idea, he beat a ball of lead into a thin sheet. When he dropped the sheet, it fluttered down more slowly than a lead ball of the same weight.

Galileo suggested that in a vacuum where air was not present, the feather and lump of lead would fall side by side. Critics of Galileo thought his idea could never be tested. Aristotle had said a vacuum was impossible: "Nature abhors [dislikes] a vacuum." However, about 50 years later, an English scientist named Robert Boyle built an air pump. He put a lump of lead and a feather inside a glass tube. He pumped out the air and turned the tube over. The feather and lead fell at the same speed.

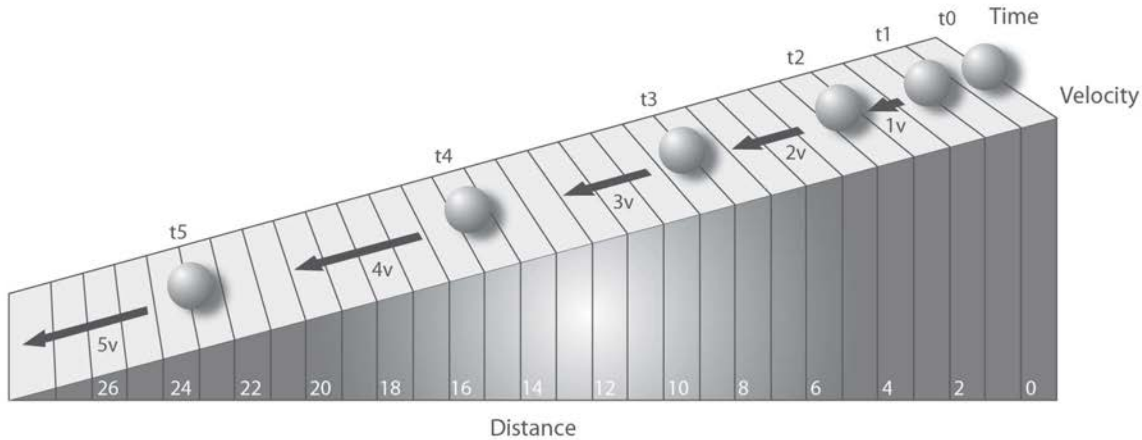
Galileo continued to experiment with how quickly objects fell to earth. To do this he needed to measure speed. Speed is distance per time interval—meters per second, feet per second, or miles per hour. Meters, feet, and miles are measures of distance. Seconds and hours are measures of time.

The speed of an object is found by dividing the distance it travels by the time it takes to go that distance: speed = distance/time. The slash mark, /, is read "divided by."

To calculate speed, divide distance by time. For instance, an automobile that travels 200 miles in four hours, travels at an average speed of 50 miles per hour: speed = distance/time = 200 miles/4 hours = 50 mi/hr. In the expression 50 mi/hr, the slash mark is read as "per." The car could have a speed of 35 mi/hr during part of the trip, and 65 mi/hr during some other part of the trip. The speed of 50 mi/hr is the average speed for the entire four hours.

Speed is always measured as distance divided by time. A high school runner would be pleased with finishing the 100-meter dash in 10.6 seconds. The runner's speed is 100 meters divided by 10.6 seconds or 9.35 m/sec.

The "miles per hour" or "meters per second" are units of speed. Scientists know that units are an important part of the overall quantity and always state them. Without units, the number part is meaningless. To say that a car was doing 90 could be fast (90 miles per hour) or slower



Galileo rolled steel balls down a gently sloping incline. He measured the distances moved in equal intervals of time using a water clock. Velocity increased uniformly with time as the ball moved down the incline under the force of gravity.

(90 feet per second, about 61 miles per hour). In a European country, it could be 90 kilometers per hour, which is about 56 miles per hour.

Galileo became interested in measuring how quickly objects fell to earth. For an object to fall for five seconds, he would need a tower 400 feet high. The Leaning Tower of Pisa was only 180 feet high. Even with a high tower, objects would fall too rapidly for him to measure their speed accurately.

Galileo found an inventive solution. Rather than dropping a ball, he rolled one down a ramp. A ramp with a gentle slope would lessen the force of gravity. When dropped from a height, a ball fell 16 feet in the first second, but on a gently sloping ramp that is 16 feet long and two feet high, a ball took eight seconds to roll 16 feet. Its motion could be studied in detail at slower speed.

Measuring time was still a problem because Galileo had no accurate clock. He again found a creative solution. While the ball rolled down the ramp, he allowed water to escape from a hole in the bottom of a container. Then he weighed the water—accurate scales did exist. He measured time by weight of the water.

The last problem was to limit friction. Galileo made smooth bronze balls and highly polished wooden tracks. Friction became so minor as to be ignored.

After Galileo collected his data, he set about seeing what he could learn. He analyzed the data, and he noticed that the ball rolling down the ramp did not get up to speed instantly. Instead, it started slowly and continued to gain speed all the way down the ramp. Falling objects followed the same rule. They began falling slowly and then continued to gain speed as they fell.

After he understood the effect of gravity on balls rolling down a ramp, he calculated distance, speed, and acceleration of a freely falling body for each second of travel. (See Table: Motion of Falling Objects.)

In the first column, Galileo recorded total time in seconds. The second column shows the distance the ball fell at the end of each second. Next, Galileo calculated average speed by dividing distance by time. For instance, in the last row, time is five seconds and distance is 400 feet, so the average speed is 80 feet per second: speed = distance / time = 400 ft/5 sec = 80 ft/sec.

The third column has the final speed at the end of each second. The final speed is greater than the average speed because the falling ball is constantly gaining speed.

The average of two numbers is found by dividing their sum by two. If the first number is zero, then the average is merely one-half of the second number. In Galileo's experiment, the balls started at rest, so their beginning speed was zero. Their average speed was one half of the final speed, which is another way of saying final speed was twice as great as

Table: Motion of Falling Objects

Time seconds	Distance feet	Average speed ft/sec	Final Speed ft/sec	Acceleration of Gravity ft/sec^2
1	16	16	32	32
2	64	32	64	32
3	144	48	96	32
4	256	64	128	32
5	400	80	160	32

average speed. For five seconds, the falling object has an average speed of 80 ft/sec. The final speed was twice 80 ft/sec, or 160 ft/sec.

Notice final speeds at the end of each second: 32 ft/sec, 64 ft/sec, 96 ft/sec, 138 ft/sec, and 160 ft/sec. Galileo discovered something very interesting. Each speed differed from the previous one by 32: 64 − 32 = 32; 96 − 64 = 32, 128 − 96 = 32, and 160 − 128 = 32.

The last column shows acceleration due to gravity, which is one of Galileo's important discoveries. Acceleration due to gravity on earth is written as 32 ft/sec^2. This quantity can be read as 32 feet per second per second or 32 feet per second squared. In the metric system, the acceleration due to gravity is 9.81 m/sec^2.

Acceleration is the change in speed compared to the time taken for the speed to change. Acceleration is found by dividing the change in speed by the change in time: acceleration = (change in speed)/(change in time). Acceleration compares how speed changes with time, and speed compares how distance changes with time.

People find acceleration confusing, and with good reason. Acceleration is the rate at which another rate (speed) changes, but acceleration is not speed, nor is it even a change in speed. Instead, it is the change in speed compared to the change in time. Time is squared because it appears twice in the calculation of acceleration.

Units of time for acceleration are usually the same, such as sec^2, but different units of time can be used. For instance, a high-speed drag racer goes from zero miles per hour to 300 miles per hour in about five seconds. The dragster increases its speed by about 60 miles per hour every second. Acceleration = (change in speed)/(change in time) = (300 mi/hr)/(5 sec) = 60 mi/hr per sec, or 60 mi/hr × sec. After the first second, the dragster is going 60 miles per hour.

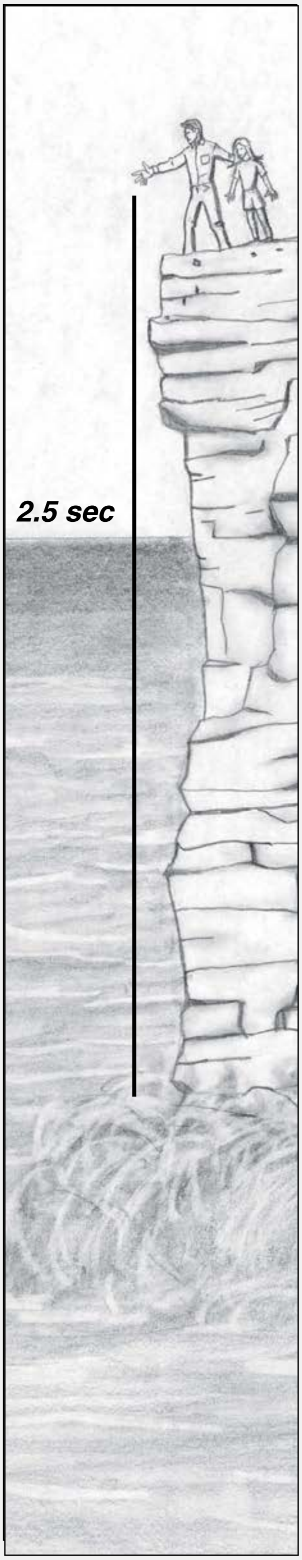
Units of time for acceleration of the dragster are not the same. One is in hours and the other is in seconds. The units for this acceleration are mi/hr × sec because both the hours and seconds are in the denominators of the fractions. They are multiplied together.

Galileo's discoveries about motions of objects on earth had a strong impact on scientists of his day. He replaced centuries of argument and speculation with a few simple equations that led to a much better understanding of motion.

Galileo studied the motion of cannonballs blasted from a cannon. Projectile motion had been poorly understood until he proved that a cannonball followed a curving path known as a parabola. It was part of a series of geometric curves known as conic sections that had been studied in detail for centuries. Because the parabola was so well understood, the paths of projectiles became easy to calculate.

Galileo's discovery about cannonballs applied to any object that was fired or thrown.

For More Study — Final and Average Velocity



Suppose you toss a pebble from a cliff into the ocean and notice that the pebble falls for 2.5 seconds before it strikes the surface of the water. How high is the cliff?

One way to solve this problem is to first calculate the final velocity using the equation $v_f = g \times t$, where vf is the final velocity, g is the acceleration of gravity, and t is the time.

$v_f = g \times t$
$v_f = (32 \text{ ft/sec}^2) \times (2.5 \text{ sec})$
$v_f = 80 \text{ ft/sec}$

Next, calculate the average speed from the equation $v_{ave} = ½ \times v_f$, with v_{ave} standing for average velocity:

$v_{ave} = ½\, v_f$
$v_{ave} = ½\; 80 \text{ ft/sec}$
$v_{ave} = 40 \text{ ft/sec}$

Finally, calculate the total distance with the equation $d = v_{ave} \times t$, with d the distance, v_{ave} the average velocity, and t the time.

$d = v_{ave} \times t$
$d = 40 \text{ ft/sec} \times 2.5 \text{ sec}$
$d = 100 \text{ ft}$

The answer of 100 feet is correct, although it took three steps to find the answer. Distance an object falls in 2.5 seconds can be found by a single equation. The three equations shown above can be combined into a single equation to give distance:

$d = v_{ave} \times t$	
$d = (½\, v_f) \times t$	replace v_{ave} with $½v_f$
$d = ½\,(g \times t) \times t$	replace v_f with $g \times t$
$d = ½\, g \times t^2$	replace g with 32 ft/sec^2

The equation $d = ½\, g \times t^2$ can now be used to find distance:

$d = ½\,(32 \text{ ft/sec}^2) \times (2.5 \text{ sec})^2$
$d = 16 \text{ ft/sec} \times 6.25 \text{ sec}^2$
$d = 100 \text{ ft}$

By the way, many processes in physics are reversible. Instead of dropping a pebble, suppose you threw it straight up in the air. If it takes 2.5 seconds before its upward motion stops, then it left your hand at 80 ft/sec, and it will go 100 feet into the air.

Galileo and his telescope

Galileo established that a projectile would travel its greatest distance if fired at an angle of 45 degrees — halfway from the horizontal to directly overhead. Today, athletes practice throwing the shot put, discus, and javelin at this angle for the greatest range. You can experiment with a stream of water squirted from a garden hose to see that this rule is true.

Scientists are pleased when they find a way to replace what appear to be many different observations with a single, simple principle. Galileo's simple and concise equations applied to many different types of motion. Nature, rather than being a head-scratching puzzlement, proved to follow a few simple principles. Galileo showed that nature had been given a design that human beings could understand.

Galileo is best known for his discoveries with a telescope, although his experiments measuring the speed of balls rolling down ramps are just as important. He did not invent the telescope, but he was the first to use it to study the heavens. He made a small telescope and turned it to the night sky. He saw mountains and valleys on the moon, four large satellites orbiting the planet Jupiter, and many stars too dim to see with eyes alone.

Scientists and teachers refused to look through his telescope. They argued, "Aristotle tells nothing of them. They must be the fault of Galileo's glass." Galileo said, "I have offered a thousand times to show the leading philosophers my studies. They will not consent to look at the planets or moon through the telescope. They close their eyes to the light of truth!"

Jealous professors tried to discredit him. They implied that he was trying to prove that the Bible was wrong.

Their charge was groundless. His argument was with those scientists who blindly followed Aristotle. Galileo charged that Aristotle had made mistakes, not prophets of God.

Galileo spent the last part of his life under house arrest. He used his time to meet with friends and to train students. Galileo wrote a book about his discoveries called *The Starry Messenger*. Professors banded together and forced Galileo to stop publishing his books for many years.

Galileo planted seeds of doubt about Aristotle and other Greek philosophers whose ideas had brought scientific progress to a halt. Galileo's stubborn insistence upon experiments and careful observations blossomed into a new spirit of discovery known as the Scientific Revolution.

Galileo was deeply religious. He believed that none of his theories dishonored any of the facts in the Bible. His faith in God grew stronger, not weaker, because his telescope showed such a marvelous universe.

SOLUTIONS

1. They do experiments to test new ideas.
2. The principle of the pendulum measures seconds.
3. Ramps slowed the motion.

Galileo's equations described many different types of motion.

Questions

A B C D 1. Physics is the science that explores how energy acts on (A. heat B. light C. matter D. sound).

T F 2. The ancient Greeks were noted for their careful experiments.

T F 3. The regular back and forth motion of a pendulum was used to regulate the first accurate clocks.

T F 4. In Galileo's time, only length and time could be measured with any accuracy.

A B C D 5. A feather and lump of lead will fall at the same speed in (A. a high speed wind tunnel B. the atmosphere C. a vacuum D. water).

6. To calculate speed, divide distance by ______________.

A B C D 7. To study the motion of falling objects, Galileo (A. beat them into cubes B. dropped them from a high tower C. pushed them from a cliff D. rolled them down a ramp).

A B C D 8. Acceleration is found by dividing the (A. average velocity B. distance C. gravity D. change in speed) by the change in time.

A B 9. On earth, the acceleration due to gravity is (A. 32 ft/sec^2 B. 60 miles/hour).

For More Study

10. Suppose a canoeist takes 70 days to paddle the entire length of the Mississippi River, a distance of 3,710 miles. The canoeist's average speed in miles per day is ______________.

11. An ordinary passenger car can accelerate to 60 miles per hour in about eight seconds. What is the car's acceleration?

12. On the moon, the acceleration due to gravity is 5.3 ft/sec^2 rather than 32 ft/sec^2. If an object fell six seconds before hitting the ground, it strikes the ground with a speed of ______________ ft/sec. (Hint: use the final velocity equation.)