THE ELEMENTS OF PHYSICS

THE ELEMENTS
OF
PHYSICS

FORMERLY PUBLISHED UNDER THE TITLE OF
THE ELEMENTS OF APPLIED PHYSICS

BY
ALPHEUS W. SMITH, PH. D.
Professor of Physics, Ohio State University

SECOND EDITION
FOURTH IMPRESSION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST.; E. C. 4
1927

THE ELEMENTS OF PHYSICS

INTRODUCTION

1. Subject Matter of Physics.—Physics is a broad science having a wide application to most aspects of modern life. It is, therefore, a study about familiar things and an attempt to find satisfactory explanations for them. The object of physics is to determine exact relations between physical phenomena. It tries to give as simple explanations as possible for the causes and effects which are observed in the physical universe. For such explanations exact measurements are very necessary. In order then to proceed with the study of physics, it is necessary to have an agreement with respect to the units in which such measurements are to be made. The two systems of measurement commonly employed are the decimal metric system, devised by the French, and the more familiar English system.

2. Units of Length.—The unit of length in the metric system is taken as the centimeter, which is $\frac{1}{100}$ part of the standard meter. The standard meter is defined as the distance at the temperature of melting ice between two marks on a certain platinum-iridium bar which is kept at the International Bureau of Weights and Measures, near Paris. Two copies of this meter are kept at the Bureau of Standards at Washington. It is a familiar fact that a bar of metal changes in length when heated or cooled. In order then to have this unit of length accurate, it is necessary to keep the bar at a fixed temperature.

The unit of length employed by the English-speaking people for ordinary purposes is the yard. By an act of Congress the yard is defined as 3,600/3,937 m. Hence,

$$1 \text{ m.} = 39.37 \text{ in.}$$
$$1 \text{ in.} = 2.54 \text{ cm.}$$

3. Units of Mass.—The unit of mass in the metric system is called the gram. It is the 1/1,000 part of a kilogram, which is the mass of a metal cylinder kept at the International Bureau of

Weights and Measures, near Paris. Two copies of this standard are kept at the Bureau of Standards at Washington.

It was the original intention of those who chose this standard that 1 g. should be the mass of 1 c. c. of water at 4°C. More exact determinations have shown that this relation is not strictly true. The error is so small that it may be neglected for all practical purposes.

Among the English-speaking peoples the pound is ordinarily used as the unit of mass. The pound is defined as the mass of a certain piece of platinum in the possession of the British government. By Act of Congress, the kilogram was declared to be equivalent to 2.2 lb. Hence, the relation between these units of mass is as follows:

1 kg. = 2.2 lb.
1 lb. = 453.6 g.

4. Units of Time.—For most scientific purposes the second is chosen as the unit of time. It is defined as the 1/86,400 part of the mean solar day. The mean solar day, as used here, means the average interval throughout the year between successive passages of the sun across the meridian. The minute, which is equivalent to 60 sec., and the hour, which is equal to 60 min., are also used as units of time.

5. Matter.—A large part of physics is devoted to the study of the properties of matter under different conditions. Matter occurs in three different states; **solid, liquid, and gaseous.** Numberless facts show that matter is never perfectly continuous but that it contains numerous vacant spaces or pores. It is in fact made up of an immense number of very fine particles which are very close together but have vacant spaces between them. These particles are called molecules.

A solid substance is one that can offer large resistance to forces which tend to change its shape. Such substances as wood, chalk, or steel are solids. They suffer change of shape or volume only under large forces.

A liquid is a substance in which the molecules are held together with forces which are sufficient to cause the substance to maintain a definite volume, bounded by a definite free surface. A liquid assumes the shape of the containing vessel in which it is placed. It is only slightly compressible but more so than solids.

Gases expand to fill the entire volume of the vessel in which they are enclosed. The molecules of which they are composed move with much greater freedom than those of liquids, and the attractive forces between these molecules are much less than they are in either solids or liquids. Gases are easily compressed.

6. Conservation of Matter.—Many careful experiments have shown that the quantity of matter existing at the end of an experiment is exactly the same as the quantity of matter at the beginning of the experiment. Matter may be changed from one state to another or it may combine with other forms of matter, but in the end the total amount of matter is unchanged. Such experiments have led to one of the very important laws in physics—**the law of conservation of matter. The principle of the conservation of matter states that matter may be altered in form but it can never be created or destroyed.** The amount of matter in the universe remains completely unchanged.

7. Density.—The mass per unit volume is called the density of a body. In the English system of units, densities are usually expressed in pounds per cubic foot. In the metric system, densities are measured in grams per cubic centimeter.

Let V = the volume of a body.
M = the mass of the body.
d = the density.
Then

$$d = \frac{M}{V}.$$

Example.—A volume of mercury weighs 136.5 g. It has a volume of 10 c. c. What is its density?

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{136.5}{10} = 13.65 \text{ g. per cubic centimeter.}$$

8. Scalar Quantity.—A scalar quantity has magnitude only. It is subject to the ordinary arithmetical laws of addition and subtraction. A block of wood weighs 8 lb. A piece weighing 3 lb. is sawed off. The remainder then weighs 5 lb. Mass is a scalar quantity. Time, volume, area, etc. are scalar quantities. They have magnitude only.

9. Vector Quantity.—A vector quantity possesses a directional quality in addition to its magnitude. In order to describe a vector quantity completely, it is necessary to give its direction as well as its magnitude. *Displacement is a vector quantity.* If an object is moved 10 m. from its original position, it may be anywhere on a circle with a radius of 10 m. whose center is at the original position of the object. When the object is moved 10 m. *east*, its new position is clearly specified.

If it is stated that an automobile is running 30 miles per hour, the information is not sufficient to enable one to locate the machine. In addition to stating the speed of the machine, it is necessary to give the direction in which it is moving in addition to the point from which it starts. **Directed speed, called velocity, is therefore a vector quantity. Any quantity which possesses both magnitude and direction is a vector quantity.** Forces are vector quantities.

10. Addition of Vectors.—A single vector which, acting alone, produces the same result as two or more vectors which are acting together is known as the **resultant of these vectors.** When two or more vectors are combined to give the single vector to which they are equivalent, the process is called the **addition of vectors or the composition of vectors.** Similarly, a single vector may be replaced by two or more vectors to which it is equivalent. This process of finding the vectors to which a single vector is equivalent is known as the **resolution of vectors.**

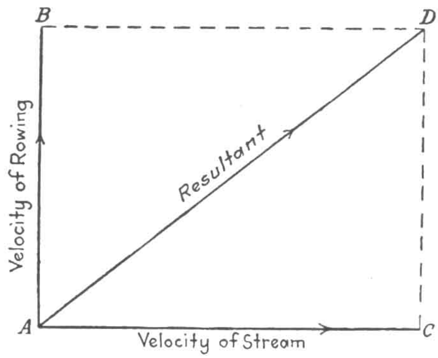

FIG. 1.—Addition of vectors.

The graphical method is the simplest way of combining or resolving vectors. Consider a man rowing a boat across a stream in which the current is 5 miles per hour. If the man rows directly across the stream with a speed of 4 miles per hour, the boat has two velocities, one due to the stream and the other due to the man's rowing. The effect of these combined velocities is that the boat is carried across the stream and at the same time is carried down the stream. The speed with which the boat actually moves and the direction of its motion are found by constructing a rectangle (Fig. 1) so that one side represents the speed and direction of motion of the boat due to the rowing and the other side represents the speed and direction of motion of the boat due to the stream alone. The actual direction of motion and speed of the boat is given by the diagonal of this rectangle.

The diagonal of the rectangle represents the resultant of these two vectors.

11. Trigonometrical Formulae.—In a right triangle ABC (Fig. 2) it is convenient to define the relations between the sides in the following way. It is to be remembered that this is purely a matter of definition suggested by convenience and that by making these definitions much time is saved in finding the sides of such a triangle. Consider the angle at A. Divide the side BC, opposite A, by the hypotenuse AB and call the ratio, for brevity, **sine A.** Now divide the side AC, adjacent to A, by the hypotenuse AB and call this ratio **cosine A.** Then divide the side BC, opposite A, by the side AC, adjacent to A, and call this ratio **tangent A.**

$$\sin A = \frac{\text{side opposite}}{\text{hypotenuse}} = \frac{BC}{AB}.$$

$$\cos A = \frac{\text{side adjacent}}{\text{hypotenuse}} = \frac{AC}{AB}.$$

$$\tan A = \frac{\text{side opposite}}{\text{side adjacent}} = \frac{BC}{AC}.$$

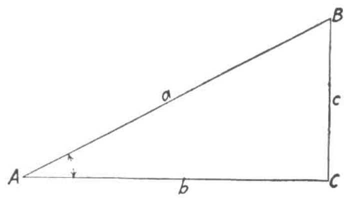

FIG. 2.—The definition of sine, cosine and tangent.

Let a = the hypotenuse, b = the adjacent side, and c = the opposite side.

$$\sin A = \frac{c}{a}. \qquad c = a \sin A.$$

$$\cos A = \frac{b}{a}. \qquad b = a \cos A.$$

$$\tan A = \frac{c}{b}. \qquad c = b \tan A.$$

Tables are prepared giving the values of sin A, cos A, and tan A for all values of A. With such a table at hand it is easy to find any side of a right triangle when an acute angle and one of the sides are given.

Example.—In a right triangle ABC (Fig. 2) the angle A is 30 deg. and the side BC is 2 ft. Find the hypotenuse.

$$\sin A = \frac{BC}{AB}.$$

$$\sin 30 \text{ deg.} = \frac{1}{2}.$$

$$\frac{1}{2} = \frac{2}{AB}.$$

$$AB = 4 \text{ ft.}$$

PART I.—MECHANICS

CHAPTER I

MOTIONS OF TRANSLATION

12. Types of Motion.—The motions of bodies may be divided into three classes: (1) **translation,** (2) **rotation,** (3) **vibration or oscillation.** A body is said to have a motion of translation when it moves on continuously in the same direction. A ball thrown from the hand of the pitcher and an automobile running on a straight road are illustrations of **motions of translation.** If the body instead of traveling forward turns on a fixed axis, the body has a **motion of rotation.** Thus the flywheel of a stationary engine turns continuously around its axis without ever moving forward. Any point on the wheel returns again and again to its original position. This is a motion of rotation. The drive wheels of a locomotive are moving forward and are at the same time rotating. They will therefore have two motions, one of rotation and the other of translation. Some bodies reverse their motions from time to time and return at regular intervals to their original positions. Such bodies are said to have a motion of vibration or oscillation. The pendulum of an ordinary clock swings back and forth at regular intervals and after a certain time repeats its former motion. It has a motion of vibration. It can be easily seen that vibration may be considered as a special mode of translation.

13. Velocity.—**The velocity of a body is defined to be the rate at which the body is passing through space or the space passed over in unit time in a given direction.** It is determined by dividing the space through which a body has passed by the time required to pass over that space.

$$\text{Velocity} = \text{space per unit time} = \frac{\text{distance}}{\text{time}}.$$

Example.—A train which is moving at a uniform rate passes over 75 miles in 3 hr. What is its velocity?

$$\text{Velocity} = \frac{\text{distance}}{\text{time}} = \frac{75}{3} = 25 \text{ miles per hour.}$$

14. Constant and Variable Velocities.—The velocity of a body is constant or uniform when the body passes over equal distances in equal intervals of time. The magnitude of such a velocity is measured by the space passed over in unit time. A body has a variable velocity when it passes over unequal distances in equal intervals of time. Where the velocity of a body changes from time to time, it is convenient to consider what is known as the **average velocity.** The average velocity is that constant velocity which would cause the body to move from one point to the other in the same time which is required when the velocity is variable. Thus the average velocity of a train which runs 600 miles in 20 hr. is $600 \div 20 = 30$ miles per hour. This means that the train would travel this same distance in 20 hr. if it had a constant velocity of 30 miles per hour instead of the variable velocity with which it actually travels. In case the velocity changes uniformly, the average velocity over any interval of time can be found by taking the velocity at the beginning and at the end of the time, adding them together and dividing the sum by two. This gives the velocity with which the body on the average has been moving. Part of the time it has moved with a velocity greater than the average velocity and the remainder of the time it has moved with a velocity less than the average velocity. The distance covered is the same as if the body had always moved with a velocity as great as the average velocity.

Example.—At the beginning of a certain time the velocity of a body is 30 ft. per second. The velocity changes uniformly for 5 min. and is then 80 ft. per second. What is the average velocity over this time?

$$\text{Average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

$$= \frac{30 + 80}{2} = 55 \text{ ft. per second.}$$

15. Acceleration.—The rate at which the velocity of a body changes is called the acceleration. It is found by dividing the change in velocity by the time in which the change takes place. It is, therefore, the change in velocity per unit of time.

Example.—A ball which at one time has a velocity of 30 ft. per second moves for 5 sec. and at the end of that time is found to have a velocity of 70 ft. per second. Find the acceleration.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}.$$

$$\text{Change in velocity} = 70 - 30 = 40 \text{ ft. per second.}$$

$$\text{Acceleration} = \frac{70 - 30}{5} = \frac{40}{5} = 8 \text{ ft. per second per second.}$$

Hence, the velocity of the ball is increasing 8 ft. per second for each second during which it moves. It is important to observe that two units of time must be stated in order to express an acceleration. One of these units expresses the unit of time in which the original velocity is measured. The other of these units expresses the unit of time used to measure the interval of time over which the velocity is allowed to change.

An acceleration may be either **uniform** or **variable.** A uniform or constant acceleration is one in which equal changes of velocity take place in equal intervals of time. To calculate a constant acceleration, it is only necessary to divide the total change in velocity by the time in which it took place. Where the acceleration is variable, the total change in velocity divided by the time gives the average acceleration.

16. Illustrations of Uniform Acceleration.—When a train is stopping at a station, it is losing velocity. When it is leaving the station, it is gaining velocity. In the former case the acceleration is negative, in the latter it is positive. If it gains velocity at the same rate, for example, 2 miles per hour per minute, the acceleration is constant. A falling body is a good illustration of uniformly accelerated motion. The body gains in velocity 32 ft. per second each second that it falls. A loaded sled on the side of a hill will slide to the bottom, and its velocity will increase uniformly as it goes. When it reaches the bottom of the hill, the velocity will decrease. The acceleration has now become negative.

17. Motion of Bodies with Constant Velocity.—The velocity of a body which is moving uniformly has already been defined as the space passed over in unit time. This relation may be written as

$$v = \frac{s}{t},$$

in which v represents the velocity, s the distance, and t the time during which the body was moving. This equation may be written in the form,

$$s = vt.$$

In this form the equation gives the space passed over in the time t by a body moving with constant velocity v. If it happens that the body is moving with variable velocity, the space passed over may be found by multiplying the average velocity by the time.

Example.—The velocity of an automobile is 15 miles per hour. How far will it move in 3 hr.?

Space passed over = velocity × time
= 15 × 3 = 45 miles.

Example.—The average velocity of a falling body for 5 sec. is 80 ft per second. How far does the body fall in that time?

Space passed over = average velocity × time
= 80 × 5 = 400 ft.

18. Motion of Bodies with Constant Acceleration Starting from Rest.—Suppose that a body starts from rest with an acceleration a. At the end of the first second its velocity is a (Fig. 3), at the end of the second second it is $2a$, at the end of the third second it is $3a$, and a velocity equal to a will be added during each second the body moves. At the end of t seconds its velocity will be at.

Final velocity = rate of change of velocity × time

$$= at.$$

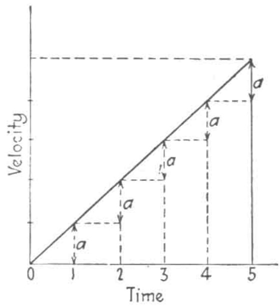

FIG. 3.—Relation between time and velocity when the initial velocity is zero.

The average velocity over this time is

$$\frac{\text{Initial velocity} + \text{final velocity}}{2} = \frac{0 + at}{2} = \frac{1}{2}at.$$

The space passed over = average velocity × time

$$= \frac{1}{2}\,at \times t = \frac{1}{2}at^2.$$

In the case of bodies falling freely under the action of gravity the acceleration is 980 cm. per second per second, or 32.2 ft. per second per second. For this special case these relations then become

$$v = 32.2t \text{ ft. per second}$$
$$= 980t \text{ cm. per second}$$
$$s = \frac{1}{2} \cdot 32.2t^2 \text{ ft.}$$
$$= \frac{1}{2} \cdot 980t^2 \text{ cm.}$$

Example.—A ball which is thrown upward leaves the hand of the thrower with a velocity of 80 ft. per second. How long before it comes to rest?

Time to come to rest

$$= \frac{\text{initial velocity}}{\text{rate of losing velocity}} = \frac{\text{initial velocity}}{\text{acceleration}} = \frac{80}{32.2} = 2.5 \text{ sec.}$$

Example.—A body starts from rest and falls freely for 10 sec. Find the space passed over in this time.

Final velocity = acceleration × time = 980 × 10 = 9,800 cm. per second.

$$\text{Average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

$$= \frac{0 + 9{,}800}{2} = 4{,}900 \text{ cm. per second.}$$

Space passed over = average velocity × time = 4,900 × 10 = 49,000 cm.

19. Motion of Bodies with Constant Acceleration and Initial Velocity.—In the preceding discussion it was assumed that the body started from rest and moved with a constant acceleration. In such cases the velocity of the body at the end of a given time is the velocity with which it started plus or minus its change in velocity during this time. To find the final velocity in these cases (Fig. 4), it is only necessary to take the initial velocity and add to it or subtract from it the change in velocity. For example, a body is thrown directly downward from the top of a tower with a velocity of 80 ft. per second. What is its velocity at the end of 10 sec.? During each second the velocity increases 32.2 ft. per second. In 10 sec. the increase will be 322 ft. per second. Hence the final velocity will be 80 + 322 = 402 ft. per second.

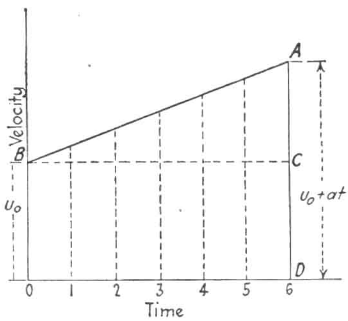

FIG. 4.—Relation between time and velocity when there is an initial velocity.

Let u = the initial velocity.
v = the final velocity.
t = the time.
a = the acceleration.
$v = u + at$, when the velocity is increasing.
$v = u - at$, when the velocity is decreasing.

The average velocity during the time t is

$$\frac{\text{Initial velocity} + \text{final velocity}}{2} = \frac{u + v}{2}.$$

Space passed over = average velocity × time.

$$= \frac{u + u + at}{2}t = ut + \frac{1}{2}at^2.$$

In the case of freely falling bodies, a may be replaced by g, where g is 32.2 ft. per second per second in the English system and 980 cm. per second per second in the C.G.S. system. (C.G.S. is an abbreviation for centimeter-gram-second, appropriately descriptive of the metric system.) The equations for freely falling bodies then become

$$v = u + gt.$$
$$s = ut + \frac{1}{2}gt^2.$$

Example.—A body is thrown on ice with a velocity of 60 ft. per second. It has a negative acceleration of 6 ft. per second per second. Find the velocity at the end of 5 sec. and the space passed over in that time.

$$\begin{aligned}\text{Final velocity} &= \text{initial velocity} - \text{loss in velocity}\\ &= \text{initial velocity} - \text{acceleration} \times \text{time}\\ &= 60 - 6 \times 5 = 30 \text{ ft. per second.}\end{aligned}$$

$$\begin{aligned}\text{Space passed over} &= \text{average velocity} \times \text{time}\\ &= \frac{\text{initial velocity} + \text{final velocity}}{2} \times \text{time}\\ &= \frac{60 + 30}{2} \times 5 = 45 \times 5 = 225 \text{ ft.}\end{aligned}$$

Problems

1. A body at a certain time has a speed of 16 ft. per second and 15 sec. later it has a speed of 46 ft. per second. Find the acceleration.

2. A body is thrown vertically upward with a velocity of 128 ft. per second. How high will it rise and how soon will it reach the ground?

3. What initial velocity must a body have in order to rise 640 ft. against gravity?

4. A stone is thrown from the top of a cliff which is 260 ft. high with a downward velocity of 50 ft. per second. How long will it take the stone to reach the ground?

5. A body is thrown vertically upward with a velocity of 180 ft. per second. At what height will its velocity be 60 ft. per second?

6. A sled sliding down a frictionless inclined plane has a velocity of 40 ft. per second at the end of 4 sec. How far will it slide in 15 sec.?

7. A lump of coal drops from a bucket in the shaft of a mine. The bucket, which is 250 ft. from the bottom of the shaft, is rising with a velocity of 15 ft. per second. In what time will the coal reach the bottom of the shaft?

8. A train running at the rate of 40 miles per hour comes to rest in 15 sec. Find the acceleration in feet per second per second.

9. A train starts from rest and travels 300 m. in 15 sec. Find its acceleration, average speed, and final speed.

10. A body travels 300 yd. in 20 sec. with a constant acceleration. If its final speed is 20 yd. per second, what is its initial speed and its acceleration?

11. A stone is projected vertically upward from the top of a tower with a velocity of 64 ft. per second. If the tower is 150 ft. high, how long before the stone reaches the ground?

12. A rifle ball is fired downward from a balloon with a muzzle velocity of 80,000 cm. per second. How far will it go in 7 sec.?

CHAPTER II

LAWS OF MOTION

In the preceding paragraphs, various cases of motion have been discussed without considering the influences which affect these motions. It is necessary now to consider the way in which the motions of bodies may be changed and the laws which govern these changes. Such changes arise out of the application of forces.

20. Force.—Our first ideas of force come from muscular effort exerted to produce change in the motion of a body. If a ball is thrown into the air or a heavy stone lifted into a wagon, a certain muscular effort is required. This muscular effort is greater for large bodies than for small ones. When bodies are once set in motion, they require muscular effort to stop them; and the more rapid their motion, the greater is the force required to bring them to rest in a given time.

A force is an action exerted by one body on another tending to change the state of motion of the body acted upon. Thus a loaded wagon is drawn by a team of horses or an automobile is driven forward by its engine. When a man lifts a bucket of water, his hand exerts a force on the bucket which changes the state of motion of the bucket. It may happen that the force exerted on the bucket is not sufficient to lift it. In that case the force only tends to change the state of motion of the body.

The primary effects of a force are two in number. A force may cause a displacement of one part of the body with respect to another. If a body is free to move, a force can cause a change in its velocity. This change in velocity may consist either in a change in the direction of motion or a change in the magnitude of the velocity.

21. Representation of a Force.—There are three respects in which forces differ from each other. These are (1) the *magnitude* or intensity of the force, (2) the *direction* of the line along which the force acts, and (3) the *sense* in which the force is exerted, that is, from left to right, upward or downward. Since a force has both magnitude and direction, it belongs to that class of quantities known as vector quantities, and may therefore be conveniently represented by a straight line. The length of the line represents the magnitude of the force; the direction of the line, the line of action of the force; and the head of an arrow on the line shows in which sense the force is exerted.

22. Gravitational Units of Force.—The most familiar force in nature is that arising from the pull of the earth on bodies which are on or near its surface. So important is this force and so easily can it be observed that it is convenient to make it the basis for a system of units in which to measure other forces. For this reason the weight of a gram or a pound is often used as a unit of force. Although the attraction of the earth for a given mass varies from place to place on the surface of the earth, this attraction at a given place is constant and can be used as a standard. Such units of force are known as **gravitational units of force.**

A force of a pound is defined as a force as large as the force with which the earth attracts a mass of 1 lb. Since the attraction of the earth for a mass of 1 lb. is not the same at all points, it is necessary to give the latitude of the place at which this standard pound is used.

Similarly, **a kilogram of force is defined as a force equal to the attraction of the earth for a mass of 1 kg., and a force of 1 g.** as **a force equal to the attraction of the earth for a mass of 1 g.**

23. Mass and Weight.—It is important to distinguish between the mass and the weight of a body. The mass is in a sense the body itself or the amount of matter which it contains. Hence the **mass** is independent of the position of the body on the earth. It is the same whether the body is on this planet or on some other planet. The **weight** is a measure of the attraction of the earth for the mass which the body contains. The weight of a body at a particular place on the surface of the earth is proportional to its mass, but the weight depends on where the body happens to be located with respect to the earth.

One of the most convenient methods of determining the mass of a body is to measure the attraction of the earth for it. This is such a familiar method that it has become a general practice to use the same word to denote the unit of mass and the corresponding unit of force. Thus the word pound or gram is used to denote a certain amount of matter and also the attraction of the earth for this matter; that is, its weight. In order to avoid confusion, it is necessary to specify whether we mean a pound of mass or a pound of force, a gram of mass or a gram of force. When pound is used as a unit of force, and there is any danger of ambiguity, it will be called a **pound weight;** and when it is used as a unit of mass, it will be referred to simply as a **pound.** The corresponding distinction will be recognized in the case of the **gram** and the **kilogram.**

24. Inertia.—One often observes that in stepping from a moving car, it requires effort to stop at the desired place. In other words, there is a marked tendency for the man to keep on moving after he has left the car. On the other hand, a man finds it easier to jump onto a moving car if he is running forward at about the rate at which the car is running. This is an illustration of an important law discovered by Newton. This law states that there is a tendency of matter to keep moving when it has once been set in motion and a tendency of matter to remain at rest unless it is caused to move by the application of a force. In like manner, it is found that if a heavy flywheel is standing still, it requires a considerable effort to set it in rotation about its axis. When, however, it is once in rotation, it tends to keep on rotating about its axis until some force, suitably applied, brings it to rest.

That property of matter by virtue of which a body tends to remain at rest or to keep in motion in a straight line is called inertia. There will be two kinds of inertia as there are two general types of motion—translation and rotation. Bodies show opposition to being translated and also opposition to being rotated. The former opposition is called **inertia;** the latter is called **rotary inertia.** The inertia of a body for motions of translation is proportional to the mass of the body, but rotary inertia depends also on the distribution of the mass about the axis of rotation.

25. Newton's First Law of Motion.—Every body continues in a state of rest or uniform motion in a straight line, unless it is compelled to change that state by the application of some external force. This form of statement applies to motions of translation. For motions of rotation the law states **that every body continues in a state of uniform motion of rotation about a fixed axis unless acted upon by some impressed force applied at some point not on the axis of rotation.** This law states in effect that a stone lying on the ground will remain there until some outside force compels it to move. When a ball is thrown into the air, it would move on indefinitely unless some outside force offered a resistance to its motion and caused it to stop. A flywheel which is standing still will not start unless a force is applied to it in such a way that it will produce rotation, and when it once starts, it will continue indefinitely unless some force operates to stop it. Even after the force has been applied, it requires time to put the mass in motion or to bring it to rest. The change in motion is not immediate.

26. Momentum.—Certain properties of moving bodies depend jointly on the mass and the velocity. Thus the time for a locomotive to start a train depends on the mass of the train and the velocity which is given to it. It is more difficult to give a freight train a speed of 10 miles per hour than it is to give a passenger train that speed. It is convenient to have a name for this property and to define it accurately. This property is called the **momentum** of the body and **it is defined as the product of the mass and the velocity.** Since the velocity has direction as well as magnitude and the mass has only magnitude, the momentum will be a directed quantity and due regard must be paid to its sign.

Example.—A tractor weighing 7,500 lb. has a velocity of 8 ft. per second. What is its momentum?

Momentum = mass × velocity

= 7,500 × 8 = 60,000 lb.-ft. per second.

27. Newton's Second Law of Motion.—We have been discussing the motion of a body in which the velocity is changing the same amount each second. To produce such a change, a constant force must act on the body. This force produces an acceleration which is always in the direction in which the force is acting. The acceleration produced by the force is proportional to the force; that is, the greater the force the greater is the acceleration. For example, let a force of 32 lb. act on a load of 64 lb. The load will have an acceleration in the direction of the force, and if the force is increased to 64 lb., the acceleration will be doubled. The force effective in producing this acceleration is not the entire force acting on the body, but the unbalanced force. By an unbalanced force is meant the amount by which the pull or push in one direction exceeds the pull or push in the opposite direction. When the engine in a tractor exerts a force on the tractor, there is, besides this force on the tractor, the forces due