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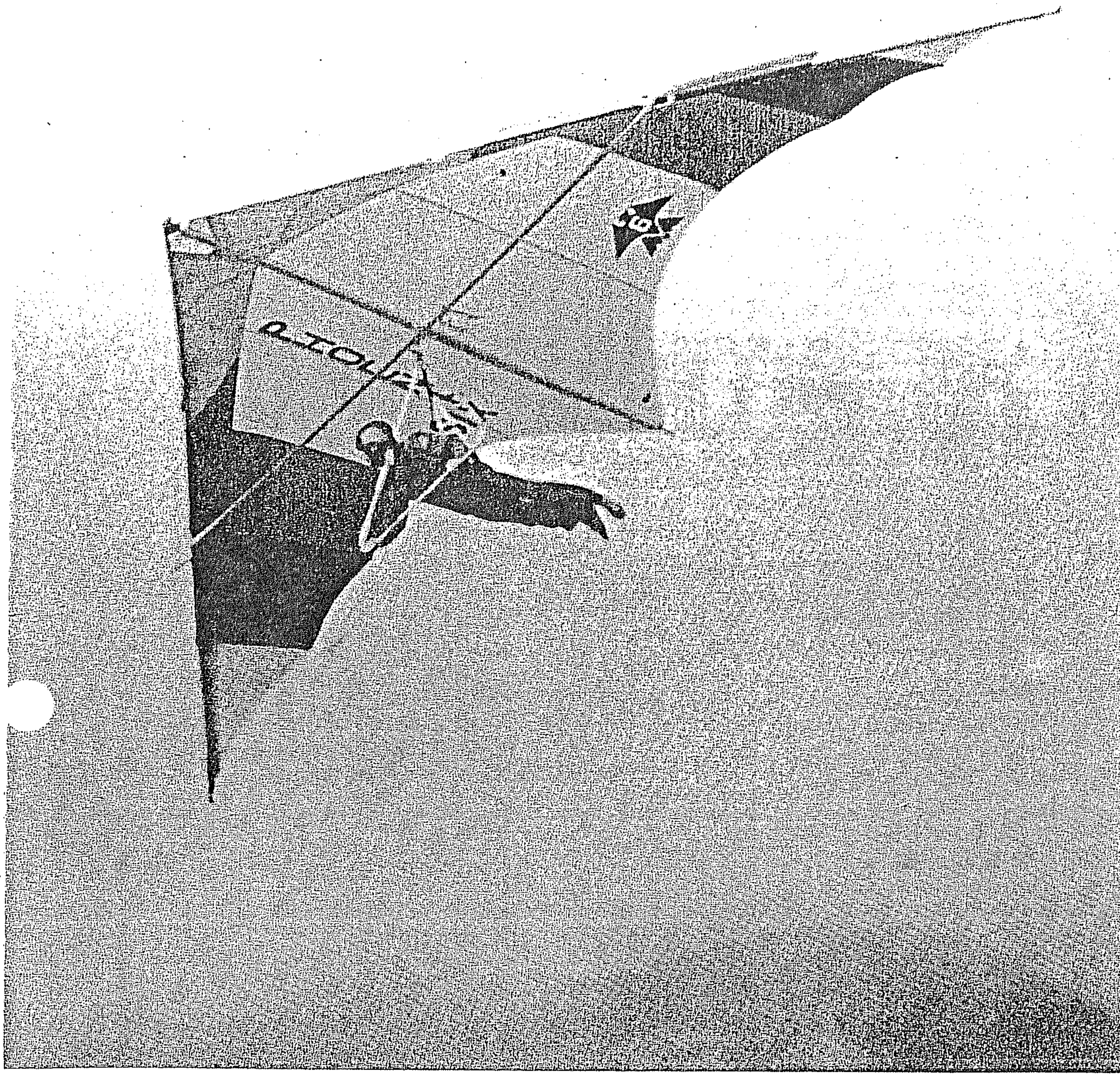

Through the centuries, humans have dreamed of soaring into space like a bird. One ancient legend tells of a person who built wings of wax, flew too close to the sun, and fell into the sea when the wax wings melted. Modern attempts at flight have been much more successful. Through observation and experimentation, we have learned much about the relationships between forces and the motions of bodies. What forces contribute to the successful flight of this hang glider?

DYNAMICS

chapter 6

GOAL: You will gain knowledge and understanding of Newton's first two laws of motion and of the distinction between mass and weight.

This chapter introduces the most basic of all scientific concepts, the interaction between forces and matter. If the magnitude and direction of a force are known, the effect on a given mass can be determined. This is done by using two laws first stated by Sir Isaac Newton.

Newton's laws of motion are basic to the study of **dynamics** (dy NAM iks). Dynamics deals with the causes of motion (forces) rather than motion itself. In this chapter we will study Newton's first two laws of motion. In Chapter 7 we will study his third law of motion.

Dynamics is the study of forces which cause motion.

Sir Isaac Newton (1642–1727) was born in the same year that Galileo died. By the age of eighteen, he had discovered the binomial theorem. He then went on to develop the law of universal gravitation and to explain the motions of the planets, comets, and the moon. Newton also explained the nature of light and invented a system of calculus. Few scientists have contributed as much to science as has Sir Isaac Newton.

6:1 Forces

Forces are needed to produce all the motions that we see every day. Most people observe thousands of forces every day of their lives. But, there are not a large number of different forces. In fact, there are only five forces known to science. Three of these —*gravitational, electric,* and *magnetic*—cause most observable interactions. The other two forces are the *nuclear* and *weak interaction* forces. They are rarely observed because they exist only inside the nucleus.

The five forces known to scientists are the gravitational, electric, magnetic, nuclear, and weak interaction forces.

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An electric force results from the electron repulsion of two objects.

The force that appears when you push on something with your hand is an electric force. This electric force of repulsion develops as the electrons of the hand are brought close to the electrons of an object. In the same way, the force between an automobile's tires and the road is an electric force.

Gravitational force is the weakest of the five forces.

Gravitational force is an extremely weak force in comparison to the other forces. If two tennis balls are held one meter apart, the gravitational force between them is only 0.000 000 000 01 newton. Electric forces, on the other hand, can be very large. If one extra electron could be added to each of the atoms in the two tennis balls, the resulting electric force between them would be 500 000 000 000 000 000 000 newtons. We could never put such a charge on the tennis balls. They would be forced apart long before the charging was completed.

Magnetic and electric forces are closely related.

Magnetic forces, like electric forces, are very large in comparison to gravitational forces. In fact, magnetic forces are produced by moving electric charges. Electric and magnetic forces are very closely related. At the present time, this relationship is not completely understood.

A nuclear force is the strongest of the five forces. It holds the ɘus of an atom together.

Nuclear forces are much stronger than any of the other forces. The nuclear force holds the nucleus of an atom together in spite of the strong electric force of repulsion between its protons. Sometimes nuclei of atoms change by gaining or losing particles. When this happens, a huge amount of nuclear energy is released. Today, nuclear power plants use this energy to provide electricity for some cities.

Scientists believe that a second force exists inside the nucleus. This is called the weak interaction force. It is believed to be the force that causes some atoms to break apart. We know little about the process involved. It is hard to find out what happens inside the extremely small nucleus of an atom.

Forces act through a distance.

One unusual thing about forces is their ability to act through distances. The gravitational force between the earth and the moon keeps the moon in its orbital path over a distance of roughly 400 000 kilometers. Likewise, one magnet can affect a second magnet through a distance. This ability of forces to act through empty space is one of nature's most puzzling phenomena.

6:2 Newton's First Law

Galileo was the first to introduce the idea of acceleration. Galileo guessed that the speed of falling bodies increases uniformly with time. But, at that time, precise clocks had not yet been invented. Thus, Galileo had no way to measure the speeds of falling bodies. He got around this difficulty by rolling metal balls down smooth ramps. When the ramps formed small angles with the

Dick Smith

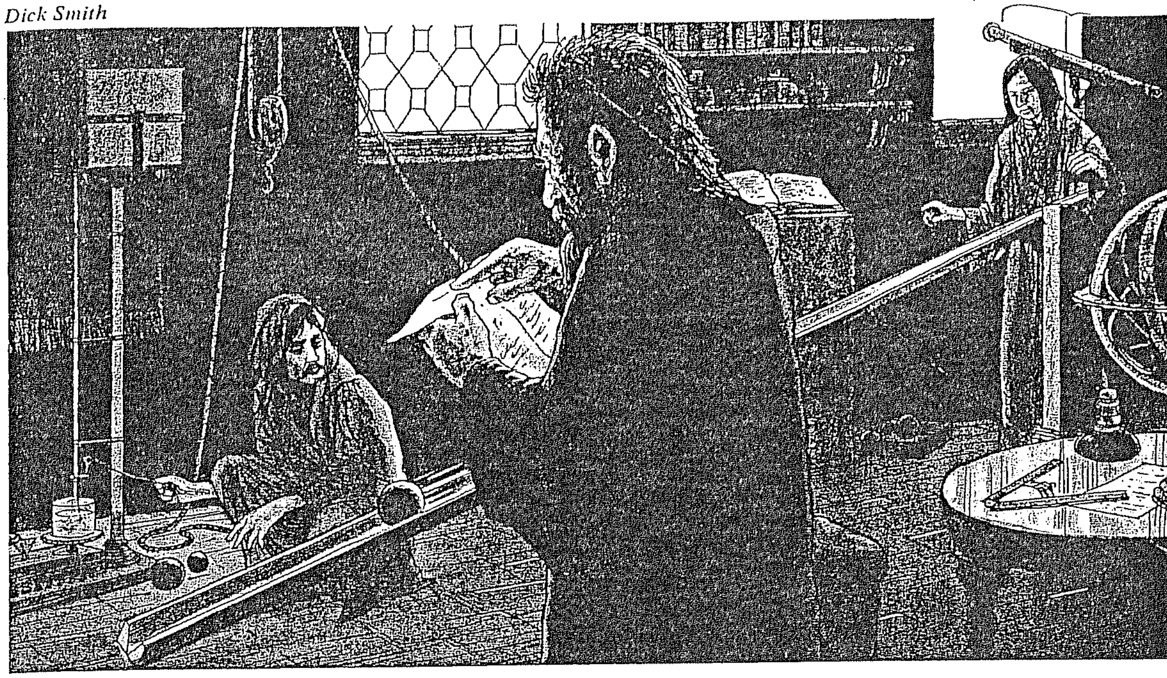

FIGURE 6-1. Galileo studied acceleration due to gravity by rolling metal balls down smooth ramps and timing them with a water clock.

horizontal, the speeds of the rolling balls were slow enough to measure by using a water clock. For different time intervals, he measured both the speeds of the balls and the distances traveled. In this way Galileo was able to prove that the balls gained speed uniformly with time. Gradually he worked out the equations of motion we studied in Chapter 3. These relationships are basic to **kinematics** (kin uh MAT iks), the study of motion.

Kinematics is the study of motion.

Galileo noticed that when a ball left one of the ramps it rolled for a long distance. The ball lost very little speed as it rolled across the stone floor. Galileo reasoned that if the floor were frictionless and endless, the ball would never stop moving. This observation required a remarkable amount of insight because nothing on the earth behaves in this way. Friction is an ever-present force. Friction always causes a moving body to come to rest unless a propelling force is constantly applied to the body. Friction thus creates the false idea that it is a "natural tendency" for a body in motion to come to rest. Galileo introduced the idea of **inertia** (in UHR shuh). Inertia is the tendency of a body to resist a change in its motion.

Inertia is a body's resistance to change in motion.

Newton's **first law of motion** states: *A body continues in its state of rest, or of uniform motion in a straight line, unless it is acted upon by a net external force.* This laws says that it is the natural tendency of a body to retain the motion it has. A body will resist any change in its state of motion. The first law also makes the function of forces very clear. A force is capable of changing the state of motion of a body.

Newton's first law of motion is also known as the law of inertia.

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6:3 Newton's Second Law

Newton's first law of motion implies that there is no fundamental difference between a body at rest and one that is moving with uniform velocity. Consider the two cars in Figure 6-1. One car is at rest while the other one moves in a straight line at a constant 60 km/hr. The car at rest is acted upon by two forces. The force of gravity pulls it downward. The force of the road pushes it upward. The two forces are equal and opposite. Therefore, their vector sum is zero and the car is in equilibrium.

An object at rest is in equilibrium.

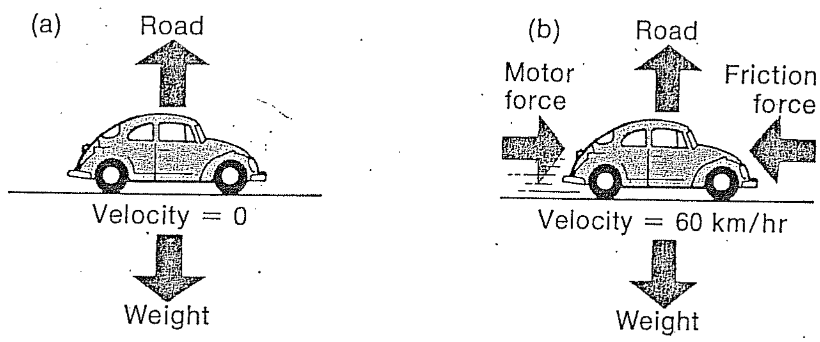

FIGURE 6-2. When forces are in equilibrium, there is no acceleration.

ı object moving at a constant .ocity is in equilibrium.

Four forces act on the car that moves in a straight line at a constant 60 km/hr. In the vertical direction, the same two forces are present that act on the car at rest. They are equal and opposite. In the horizontal direction, the force of the motor drives the car forward while the force of friction opposes the forward motion. These two forces must be equal and opposite because the velocity of the car is constant. By Newton's laws, a net force would accelerate the car. Thus, the motor force and the friction force are equal and opposite. The vector sum of all of the forces is zero. The moving car and the car at rest are both in equilibrium. If the driver changes the motor force, the car will accelerate or decelerate. Just as Newton's first law of motion states, any unbalanced force causes acceleration.

Newton's second law of motion tells us that an unbalanced force causes acceleration.

Newton was the first to recognize that a net force always causes acceleration and not just motion. Newton then formulated his **second law of motion:** *When an unbalanced force acts on a body, the body will be accelerated.* The acceleration will vary directly with the applied force and will be in the same direction as the applied force. It will vary inversely with the mass of the body. The mathematical expression of Newton's second law is

$$a = \frac{F}{m}$$

More often, Newton's second law of motion is written:

$$F = ma$$

6:4 Units of Force

A force accelerates a mass. A force is measured in terms of the acceleration it gives to a standard mass. Suppose a 1-kg mass is located on a frictionless, horizontal surface. The force that will cause this 1-kg mass to accelerate at the rate of 1 m/sec² is called one newton.

$$F = ma$$
$$= 1\text{ kg} \times 1\text{ m/sec}^2$$
$$= 1\text{ newton}$$

The **newton** (N) is the MKS unit of force.

A force of one newton will accelerate a 1-kg mass at the rate of 1 m/sec².

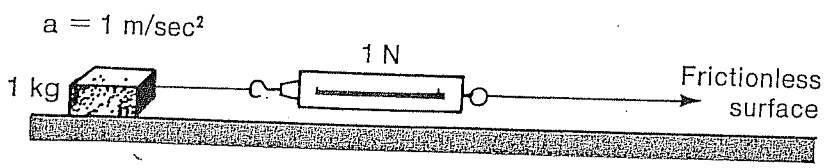

FIGURE 6-3. Units of force are defined in terms of the acceleration they give to standard masses.

Example: Using Newton's Second Law to Find Force

A force gives a 2-kg mass an acceleration of 5 m/sec². What is the magnitude of the force?

Solution:

$$F = ma$$
$$= 2\text{ kg} \times 5\text{ m/sec}^2$$
$$= 10\text{ kg-m/sec}^2$$
$$= 10\text{ N}$$

Example: Using Newton's Second Law to Find Mass

A force of 20 N gives a stone an acceleration of 4 m/sec². What is the mass of the stone?

Solution:

$$F = ma$$
$$m = \frac{F}{a}$$
$$= \frac{20\text{ N}}{4\text{ m/sec}^2}$$
$$= \frac{20\text{ kg-m/sec}^2}{4\text{ m/sec}^2}$$
$$= 5\text{ kg}$$

PROBLEMS

1. A net force of 25 N is applied to a 10-kg mass. What is the acceleration given to the mass?

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car's mass? (b) What is its initial momentum? (c) What change in the car's momentum does the force bring about? (d) How long does the braking force act on the car to bring it to a halt?

7. A constant force acts on a 600-kg mass for 68 sec. The speed of the mass is 10 m/sec before the force is applied. Its final speed is 44 m/sec. (a) What change in momentum does the force produce? (b) What is the magnitude of the force?

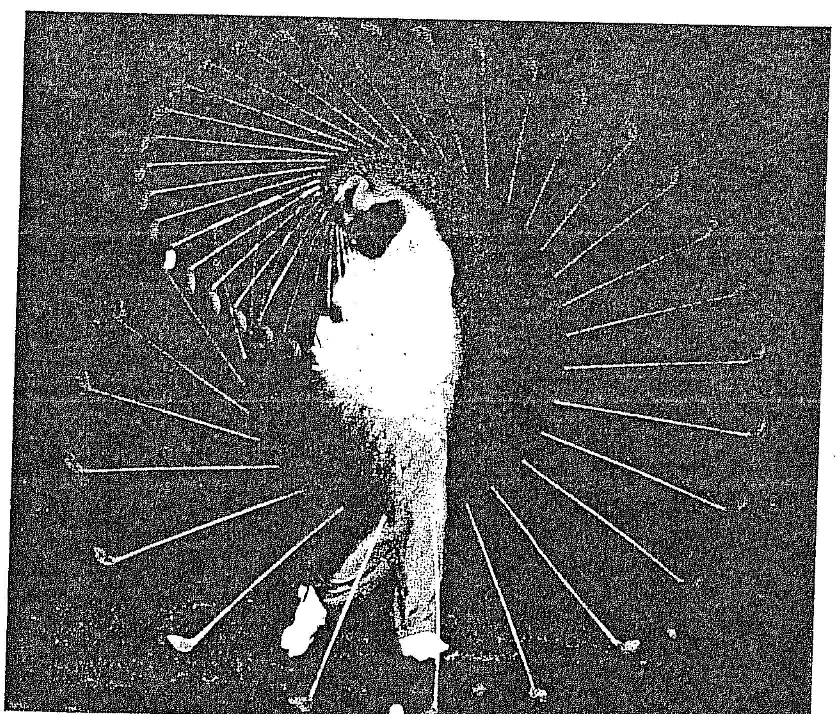
7:2 Newton's Third Law of Motion

Newton's third law of motion is also known as the law of action and reaction.

A single force can never exist. Every force is accompanied by an equal and opposite force.

Newton's first two laws of motion were introduced in Chapter 6. Newton's **third law of motion** is called the law of action and reaction. It states that *every force is accompanied by an equal and opposite force.* According to this law, there is no such thing as a single force. A body can produce a force only if there is some other body to exert its force upon. Your hand pushes a ball. A magnet repels a second magnet. A charged body repels another charged body. Every interaction involves at least two bodies.

Newton's second law of motion states that when one body exerts a force on another, the second body accelerates. But, a fact often overlooked is that the body exerting the force also accelerates. For example, a golf ball is hit with a golf club. The ball is



Courtesy of Harold E. Edgerton, Massachusetts Institute of Technology

FIGURE 7-3. At the same time the golf club exerts a force on the golf ball, the golf ball exerts a force on the golf club.

DYNAMICS

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Write all answers in complete sentences on a separate sheet of paper.

1. Define the term Dynamics.
2. Name 4 major accomplishments that Sir Isaac Newton contributed to the field of science.
3. Name the 5 main forces known to science.
4. Which of the 5 main forces are most observable?
5. Where do the nuclear and weak interaction forces occur?
6. What is one unusual thing about all forces?
7. What is inertia?
8. State Newton's 1st law of motion in words.
9. What is another name for Newton's 1st law of motion?
10. State Newton's 2nd law of motion in words.
11. Write this 2nd law of motion as a formula and state what the letters in the equation stand for.
12. State Newton's 3rd law of motion in words.