

Class 10

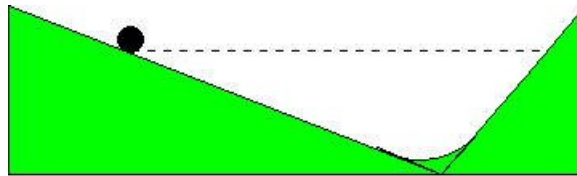
The Natural State of Motion --- Aristotle and Galileo

Until Galileo physics was primarily based on *observation* of the world.

Based on observation Aristotle asserted that object stay in motion only if they are pushed, but left to themselves object come to a state of rest. So the state of “rest” is the natural state of motion to which all things return.

If I push a book across a desk I find no reason to object to Aristotle's view. As soon as I stop pushing the book it comes to rest.

Galileo looked at the problem differently. He rolled a down one inclined plane and up another and observed that the ball always returned to the same *height* . He then made the incline of one plane less and less steep, and the same effect worked, although frictional effects made it not quite exact.



The Leap to the Ideal

Galileo now come to the conclusion that if he could make the less steep ramp go toward the actual horizontal the ball would roll forever.

Just as in the case with the concept of the *instant*, we are dealing with an *ideal limit* which is not observable in the real world.

What is the point of such an assertion which is unverifiable?

The mathematical and simple state of nature is only accessible through by means of this idealization of actual reality.

The idea is that the natural state of motion is not rest but uniform velocity.

This ideal of Galileo is formally stated by Newton as the **First Law of Motion**.

Every object continues in its state of rest or of uniform velocity in a straight line as long as no net force acts on it.

Class 10

Certainly in the days of Newton and Galileo none every observed an object moving at constant velocity with no net force on it.

Note that the above formulation has the notion of *force* in it which we have not defined. However, since it enters only in the sense of something which is *absent* let's let it go for now.

This assertion represents a *limiting ideal* similarly to the idea of the limit in the idea of the *instant*.

With Galileo, the goal of physics ceases to be a *description* of the world as we see it and becomes describing the *ideal* world in which the simple physical laws operate.

Inertial Reference frame.

Imagine I am sitting at a table in a train with a steel ball in the center of the table. When the train begins to accelerate the ball will spontaneously move in the direction to the direction of the train's motion.

This is a violation of the Newton's first law of motion. A physical system in which Newton's first law does not hold is called a **Non-inertial reference frame.** Conversely a system in which Newton's first law *does* hold is called an ***Inertial reference frame.*** A bus which puts on its breaks, and the passengers are thrown toward the front of the bus is a non-inertial reference frame.

To a very good approximation, a system such as a laboratory at rest on the surface of the earth is an inertial reference frame. However very precise measurements can measure the departure from a true inertial reference frame due to the accelerated motion of the Earth's rotation.

Mass

Imagine that you are walking down the street and you see a small box lying on the street, and you find you have the desire to kick it. You might think "If the box has only styrofoam in it I can safely kick it. But what if the box has lead bricks in it, then I would break my foot.

What accounts for the difference? When I kick the box I am going to try to *accelerate* the box by applying a *force*. However, whereas styrofoam is easily accelerated, lead is very hard to accelerate.

The quality which an object has which causes it to resist being accelerated is called *mass*.

Mass is measured in fundamental units called *grams* or in units of thousand grams called *kilograms*.

Class 10

Force

To determine if the box has styrofoam or lead in it I have to kick it, that is I have to apply a *force*.

Force is what causes an object to accelerate. Mass is what causes an object to resist acceleration.

The concepts of *force* and *mass* are defined in a circular way, so that the definition of one makes no sense without the definition of the other.

The co-definition of force and mass is called Newton's Second Law of Motion

$$\Sigma \vec{F} = m \vec{a}$$

There are several important things to observe about this important relationship.

1. It is a vector equation, and as such is it short-hand for equations in the 3 spatial dimensions

$$\Sigma F_x = m a_x \qquad \Sigma F_y = m a_y \qquad \Sigma F_z = m a_z$$

2. It has the Σ symbol in it, which means that the *sum* of all the forces determines the acceleration.

3. It defines the *unit* by which we measure force. If we examine the units of the right hand side of Newton's Second Law we have

$$\frac{kg * m}{s^2}$$

This is the fundamental unit of force and is named after Isaac Newton, the Newton.

Class 10

EXAMPLE 4-3 Force to stop a car. What average net force is required to bring a 1500-kg car to rest from a speed of 100 km/h within a distance of 55 m?

APPROACH We can use Newton's second law, $\Sigma F = ma$, to determine the force if we know the mass and acceleration of the car. We are given the mass, but we will have to calculate the acceleration a . We assume the acceleration is constant, so we can use the kinematic equations, Eqs. 2-11, to calculate it.

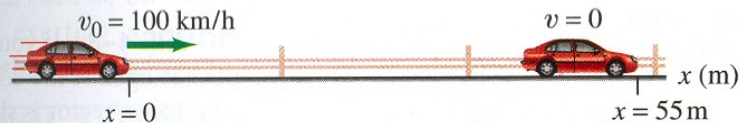


FIGURE 4-6 Example 4-3.

SOLUTION We assume the motion is along the $+x$ axis (Fig. 4-6). We are given the initial velocity $v_0 = 100 \text{ km/h} = 28 \text{ m/s}$ (Section 1-6), the final velocity $v = 0$, and the distance traveled $x - x_0 = 55 \text{ m}$. From Eq. 2-11c, we have

$$v^2 = v_0^2 + 2a(x - x_0),$$

so

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{0 - (28 \text{ m/s})^2}{2(55 \text{ m})} = -7.1 \text{ m/s}^2.$$

The net force required is then

$$\Sigma F = ma = (1500 \text{ kg})(-7.1 \text{ m/s}^2) = -1.1 \times 10^4 \text{ N}.$$

The force must be exerted in the direction *opposite* to the initial velocity, which is what the negative sign means.

Clicker #1

Calculate the force required to bring a 1000 kg car to a stop from a speed of 80 km/hr in a distance of 40m.

- a. $2.4 \times 10^3 \text{ N}$ b. $3.4 \times 10^3 \text{ N}$ c. $5.6 \times 10^3 \text{ N}$ d. $6.2 \times 10^3 \text{ N}$ e. none.

Class 10

Forces Come in Pairs --- Newton's Third Law

We have seen how forces cause acceleration, but we have not discussed where forces come from.

The forces we see commonly around us are forces which come about when one object come in direct contact with another object. So we see that 2 *objects* are required for a force to exist.

The relationship of the forces on 2 objects, which exert force on each other is stated in Newton's Third Law

When object A exerts a force on object B, then object B exerts a force on object A which is equal in magnitude and opposite in direction.

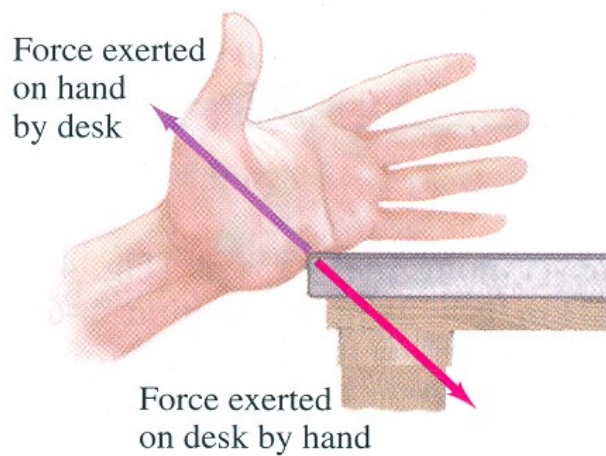
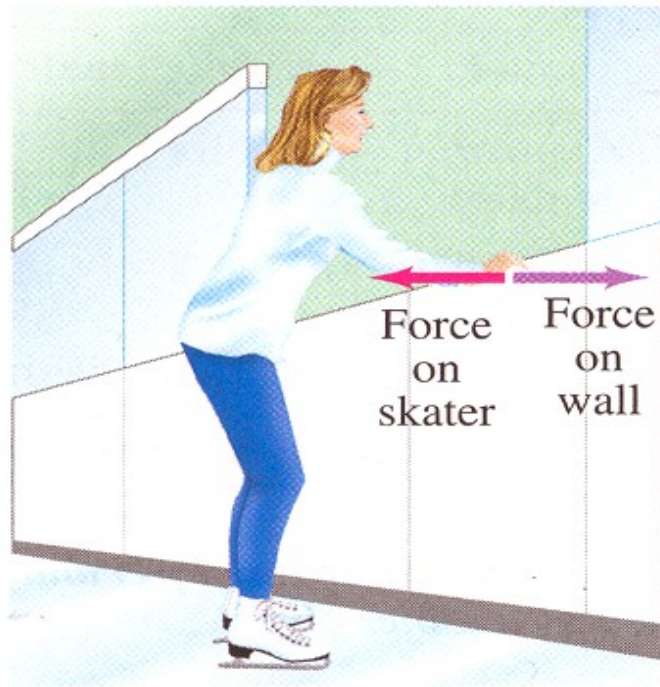


FIGURE 4-8 If your hand pushes against the edge of a desk (the force vector is shown in red), the desk pushes back against your hand (this force vector is shown in a different color, violet, to remind us that this force acts on a different object).

Class 10

FIGURE 4–9 An example of Newton's third law: when an ice skater pushes against the wall, the wall pushes back and this force causes her to accelerate away.



Class 10

FIGURE 4–12 Example 4–5, showing only horizontal forces. Seventy-year-old Michelangelo has selected a fine block of marble for his next sculpture. Shown here is his assistant pulling it on a sled away from the quarry. Forces on the assistant are shown as red (magenta) arrows. Forces on the sled are purple arrows. Forces acting on the ground are orange arrows. Action–reaction forces that are equal and opposite are labeled by the same subscripts but reversed (such as \vec{F}_{GA} and \vec{F}_{AG}) and are of different colors because they act on different objects.

