UNIT 1 MECHANICS

PHYS:1200 LECTURE 2 – MECHANICS (1)

The topic of lecture 2 is the subject of mechanics – the science of how and why objects move. The subject of **mechanics** encompasses two topics:

- **kinematics:** the description of how objects move, usually expressed in terms of simple mathematical formulas, and
- **dynamics:** the study of what causes objects to move.

Kinematics deals with the concepts of position (where an object is relative to some agreed upon coordinate system, velocity (the rate at which an object moves), and acceleration (the rate at which the velocity of an object changes). Position, velocity, and acceleration are all specified with respect to time. These concepts have the usual meaning as they are generally understood in everyday use. In subsequent lectures clear definitions of these quantities will be provided. Although the everyday meaning of certain concepts are acceptable, it will be necessary to give precise definitions of every concept that is introduced, along with a specification for how the quantities are measured and in what units they are given.

As we begin to discuss how and why objects move, it is important to understand that the discussion of motion also includes objects that are not moving, i.e., objects that are “at rest”, and what is required to make them move, or if they are moving what causes them to stop moving.

2-1. Historical Perspective.—Historically (at least in the western world) the thinking on motion was dominated by the ideas expressed by **Aristotle** going back more than two centuries ago. His influenced dominated thought up to the 17th century. Aristotle *believed* that the natural state of an object was to be at rest. This means that if an object is moving, some influence (what we now call a force) must be acting on the object to maintain its motion. Then, if the influence is removed, the object will return to its natural state of rest. As we shall see shortly, **Aristotle’s ideas on motion were wrong**. The problem with Aristotle’s analysis was that it was not based on observation. His conclusions were based on thinking alone and were not informed by observation. We now realize that motion is a phenomenon of nature and to understand it we must first observe it and perform quantitative measurements on it – this is part of what is called the scientific method. The facts about phenomenon cannot be imagined, they must be discovered in nature itself.

2-2. Galileo's Principle of Inertia.—The realization and application of the scientific approach to understanding nature was first made by *Galileo* in the 16th century. Galileo was the first person to realize that to understand nature, you must first observe it – for this he is known as the Father of Modern Science. The major discovery of Galileo was the **principle of inertia**. **Inertia** is an inherent property of matter (all objects) that affects its state of motion. We will give a working definition of inertia shortly, but for now it is sufficient to state that the inertia of an object is a measure of how much "stuff" is there; in terms of the atomic picture of matter (which will be discussed later), the inertia of an object depends on how many atoms or molecules it has.

The laws of Mechanics are formally known as Newton's Laws and were developed by him in the 17th century. Newton's first law, however was actually stated by Galileo as the principle of inertia. All objects have a property called inertia which is the tendency of the object to resist any ***change*** in its state of motion:

- a body at rest it tends to remain at rest
- a body in motion tends to remain in motion.

The practical consequence of the law of inertia is that you do not have to keep pushing an object to keep it moving with constant velocity.

a. Experiments demonstrating the principle of inertia.—Galileo performed simple experiments that led him to the principle of inertia. Suppose you have a block sitting (at rest) on a table. You can make the object move by continually pushing it. Although this is true, it is misleading because we need to recognize that there is always an effect present that will cause an object to slow down → friction. If you continuously push on an object, you are essentially always working against friction, and if you push just hard enough to overcome friction, the object will move. So it seems, without analyzing the situation more carefully, that you do need to keep pushing to keep it moving as Aristotle believed. However a simple extension of the experiment can disprove this. Suppose that instead of continually pushing the object you give it an initial big push or kick to get it moving. The object will certainly move even after you let go, although it will eventually stop because of friction. Galileo realized that friction was the effect that was "interfering" with the motion of the object. He performed experiment after experiment in which he tried to reduce the effect of friction. He did various things like make the surfaces smoother and smoother, or coated them with some lubricating material. He found that as friction was reduced, an object given an initial kick would go farther and farther before it came to rest. Then he made a bold assertion based on these experiments: If you could entirely remove the effect of friction, an object given an initial kick would move forever in a straight line with constant speed --- in other words, the effect of the object's inertial will cause it to continue moving (not *change* its state of motion) indefinitely, or until some other force intervened to change the motion. We now have the capability to nearly eliminate friction using a device known as the air track. The air track has tiny holes through which air flows allowing a car to glide on an air layer rather than being in direct contact with its surface. On the air track, you give the car an initial push and it then moves with constant velocity. If the track were infinitely long, the car would move forever with constant velocity. Of course, the track is finite in length and when the car hits the far end a force is exerted on it which changes its state of motion – reverses its direction. Several examples of the law of inertia are illustrated by demonstrations in class – as summarized on slide 10. So the answer to the question "why does something move" is "because nothing stops it." It continues to move because it has this thing called inertia which causes it to resist any *changes* in its state of motion.

b. Measurement of inertia.—Now as mentioned earlier, any concept introduced in physics must be accompanied by a procedure of how to measure it and a specification of the units in which it is expressed. The concept of "units" is simply the practical information on how to communicate the results of measurements. Some quantities are specified simply by giving a number and no units are required. For example—how many marbles are in the box? You just count the number of marbles and report the number, say 57. Some quantities require a unit to make sense.

Example 2.1: How high is that mountain? You must report a number and a unit – for example, 10,000 feet, 2 miles, or 5 kilometers. The same is true for velocity.

Example 2.2: How fast were you going? You must answer giving a number and the units, e.g., 100 km/hr or 65 miles per hour.

So how is inertia measured? The inertia of an object is measured by giving its mass, m. In the scientific system of units that we will use mass is measured in **kilograms** (kg). Mass depends on how many atoms or molecules are in the object. The mass of an object is not the same as the weight of the object. This is a point of confusion that we will deal with later.

2-3. Speed and Velocity.—How are **speed** and **velocity** defined, and what is the difference between these quantities. Your speed the answer to the question: how fast am I going? It tells us how much distance you travel in a given interval of time, so it is measured as a distance quantity divided by time, e.g., miles per hour, feet per second, km per hour, inches per day, and millimeters per century.

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{d}{t} . \qquad [1]$$

The most standard unit for velocity in the scientific system of units is meters per sec, or m/s. Note that formula [1] can also be expressed in a form that allows you to calculate the distance travelled if you know the speed and time, $d = v\, t$.

Example 2.3: How far would you go if you travelled for half an hour at 50 km per hour?

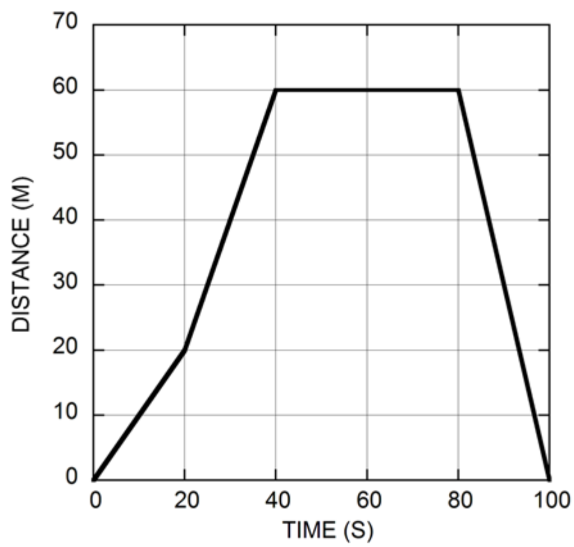
Answer: $d = 50$ km/h x 0.5 h = 25 km.

Now to fully describe the state of motion of an object it is necessary to know not only how fast it is moving but in what **direction** it is moving. This is just common sense – when you give someone directions on how to get somewhere you must tell them how far to go and in what direction. Velocity is a quantity that specifies both **how fast and in what direction** the object moves. So, for example, we might say 50 mph east. The quantity velocity is one of a class of physical quantities that we call **vectors**. Vectors are quantities that require both a magnitude and direction for complete specification. Quantities that require only a magnitude are called **scalars**.

Mass is a scalar quantity—e.g. the mass of this object is 50 kg. Another example of a scalar quantity is temperature. What is the temperature? Answer: 90 degrees F (25 degrees C).

The motion of an object is very conveniently summarized by showing a graph of its position on the vertical axis versus time on the horizontal axis. Examples are shown in slides 22 and 23.

Example 2.4: A distance – time plot of an object is shown below. Describe quantitatively the motion of this object.



(a) The object starts at position labelled 0, than over the next 20 s it moves a distance of 20 m, so that in this time interval 0→20 s, its speed is v = 20 m/20 s = 1 m/s.

(b) From t = 20 s to t = 40 s, it moves a distance of 60 m – 20 m = 40 m, so that its speed in this time interval 20 s → 40 s is v = 40 m/20 s = 2 m/s.

(c) From t = 40 s to t = 80 s, the object stays at the position of 60 m from where it started, so in this interval t = 40 s → t = 80 s, its speed is zero.

(d) From t = 80 s to t = 100 s, the object moves from position 60 m back to its starting point 0 m. Its speed in this interval t = 80 s → t = 100 s is v = 60 m/20 s = 3 m/s.

Notice that the steeper the line between 2 points, the higher the speed.
A horizontal line (40 s → 80 s) represents a speed of zero.