PHY 121 Mechanics *S.G. Rajeev*

Lecture 6

Newton's Laws of Mechanics

•Newton's first law of motion states:

An isolated body will move with constant velocity.

•What do we mean by an *isolated* body? We could move it far enough away from all other bodies so that their effect will be small. Or observe it for such a short time interval that the effect of the other bodies is small.

•Our common sense seems to tell us something quite different: that something needs to be pushed in order to keep moving at constant velocity.

•That is because we are not usually dealing with isolated bodies. A car needs to be pulled by an engine to move at constant velocity on a highway because the friction on the wheels would slow it down otherwise.

•It is important that not only the *magnitude* but also the *direction of velocity* of an isolated body remains a constant. For example, an isolated body cannot do uniform circular motion: there is an acceleration pointed towards the center.

Force

•What makes a body accelerate (deviate from motion with constant velocity) is the effect of some other body on it. This effect is called *Force*.

•Our common sense says that the more matter a body contains the harder it is to move. The *greater* the mass the *smaller* the *acceleration* for the same force. If you kick a bowling ball and a baseball with the same force, the baseball will accelerate more.

• *Force* is a *vector*. It acts in a certain direction with a certain magnitude.

Newton's Second Law of Motion

•Now we can state Newton's second law of motion:

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

where $\mathbf{F}$ is the *force*, m the *mass* and $\mathbf{a}$ the *acceleration*.

•There are several ways of verifying this law. We can make two different bodies of known masses move under the same force and see if the accelerations are inversely proportional to the masses. Or we can double the force and see if the acceleration doubles.

Unit of Force

•Note that *force* has units of $kg\, m\, s^{-2}$ in m.k.s. units. This *unit of force* is called a *Newton*. In c.g.s. units, the unit of force is $g\ cm\ s^{-2}$ and that is called a *dyne*. Clearly,

$$1\ N = 10^5 \text{ dynes}.$$

•The *weight* of a body is the force exerted on it by the Earth due to gravity. It is pointed downward (i.e., towards the *center of the Earth*) and has magnitude mg where m is the mass of the body and g the *acceleration due to gravity*.

•Thus an object of mass $1\ kg$ has a weight of $9.8\ N$.

Demonstration of Newton's Laws Using Air Table

•We have set up an air table with a pulley system so that different forces can be applied to the air carts. The timers are set up so that we can measure the time it takes for a cart to accelerate from rest from the first point and pass the second.

•If D is the distance between the points, and t the time it takes, the acceleration can be obtained from

$$D = \frac{1}{2}at^2.$$

In other words, the experimentally measured value of the acceleration is

$$a_{\rm exp} = \frac{2D}{t^2}$$

•If we attach a weight m to the string, the force of gravity on it is

$$F = mg$$

which is transmitted by the pullies and string to the air cart. Let M be the mass of the air cart. The acceleration a of the air cart should be given by Newton's law

$$F = (M + m)a$$

since $m + M$ is the total mass of the system. If $m << M$, we can approximate $m + M$ by M.

•The theoretical value of the acceleration is thus

$$a_{\rm th} = \frac{m}{M + m}g.$$

•We will measure the acceleration

for different values of the force mg and mass of the cart M.

Numerical Values

•The masses M of the air carts were measured to be $.750\ kg$ and $1.456\ kg$. The two masses m we will use to provide the forces were measured to be $.022\ kg$ and $0.044\ kg$. The distance between the timers is set at $1\ m$. Thus we can calculate the values of acceleration as given by Newton's law:

$$m = 0.022\ kg, \quad M = .750\ kg, \\ \Rightarrow a_{\mathrm{th}} = 0.28\ ms^{-2}$$

$$m = 0.022\ kg, \quad M = 1.456\ kg, \\ \Rightarrow a_{\mathrm{th}} = 0.15\ ms^{-2}$$

$$m = 0.044\ kg, \quad M = 1.456\ kg,$$

$$\Rightarrow a_{\mathrm{th}} = .29\ ms^{-2}$$

$$m = 0.044\ kg, \quad M = .750\ kg, \\ \Rightarrow a_{\mathrm{th}} = .56\ ms^{-2}$$

Newton's Third Law of Motion

The force due to body A on body B is equal, in magnitude, and opposite, in direction, of the force on B due to A .

•If one of the bodies is much heavier than the other it will appear not to be affected by this force. If I were to jump out of a window, I exert a force equal to my weight, about $60\ kg \times 9.8\ ms^{-2}$, on the Earth which will cause it to accelerate towards me at a rate of $10^{-22}\ ms^{-2}$: a fantastically small number. That is why the Earth doesn't seem to move towards me at all.