DYNAMICS

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REFERENCES

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Preface

• Mechanics is a branch of the physical sciences that is concerned with the state of motion of bodies subjected to the action of forces.Dynamics, deals with the accelerated motion of a body. The subject of dynamics will be present in two parts:

1. Kinematics: treats only the geometric aspects of the motion, or deals with the motion of particles, lines, and bodies without consideration of the forces required to produce or maintain the motion.

Note: Knowledge of the relations between position, time, velocity, acceleration, displacement, and distance traveled for particles, lines, and bodies is essential to the study of the effects of unbalanced force systems on bodies.

2. Kinetics: deals with the force system that produce accelerated motion of bodies, the inertial properties of the bodies, and the resulting motion of the bodies.

• Definitions:

• Length (Space): Length is use to locate the position of a point in a space and thereby describe the size of a physical system;

• Time: measure of succession of events basic

Quantity in Dynamics;

• Mass: quantity of matter in a body that is use to compare the action of one body with that of another. Provides a measure of inertia of a body its resistance to change in movement state of the bodies; it’s a scalar quantity

• Force: represents the action of one body on another characterized by its magnitude, direction of its action, and its point of application, it is a vector quantity.

Notes:

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1. Length, time, and Mass are absolute concepts independent of each other;

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2. Force is a derived concept independent of the other fundamental concepts. Force acting on a body is relate to the mass of the body and the variation of its velocity with time.

3. Mass is a property of matter that does not change from one location to another.3. Weight refers to the gravitational attraction of the earth on a body or quantity of mass. Its magnitude depends upon the elevation at which the mass is located; Weight of a body is the gravitational force acting on it.

CHAPTER OBJECTIVES

■ To state Newton’s Second Law of Motion and to define mass and weight.

■ To analyze the accelerated motion of a particle using the equation of motion with different coordinate systems.

■ To investigate central-force motion and apply it to problems in space mechanic.

1.1 Newton’s Second Law of Motion

Kinetics is a branch of dynamics that deals with the relationship between the change in motion of a body and the forces that cause this change. The basis for kinetics is Newton’s second law, which states that when an unbalanced force acts on a particle, the particle will accelerate in the direction of the force with a magnitude that is proportional to the force. this law can be verified experimentally by applying a known unbalanced force F to a particle, and then measuring the acceleration a. Since the force and acceleration are directly proportional, the constant of proportionality, m, may be determined from the ratio m = F/a. This positive scalar m is called the mass of the particle. Being constant during any acceleration, m provides a quantitative measure of the resistance of the particle to a change in its velocity, which is its inertia.

The jeep leans backward due to its inertia, which resists its forward acceleration.

If the mass of the particle is *m*, Newton's second law of motion may be written in mathematical form as:

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

The above equation, which is referred to as the equation of motion, is one of the most important formulations in mechanics.* as previously stated, its validity is based solely on experimental evidence. In 1905, however, Albert Einstein developed the theory of relativity and placed limitations on the use of Newton's second law for describing general particle motion. Through experiments, it was proven that time is not an absolute quantity as assumed by Newton; and as a result, the equation of motion fails to predict the exact behavior of a particle, especially when the particle's speed approaches the speed of light (0.3 Gm/s). Developments of the theory of quantum mechanics by Erwin Schrödinger and others indicate further that conclusions drawn from using this equation are also invalid when particles are the size of an atom and move close to one another. For the most part, however, these requirement regarding particle speed and size are not encountered in engineering problems, so their effects will not be considered in this book.

Newton's Law of Gravitational Attraction. Shortly after formulating his three laws of motion, Newton postulated a law governing the mutual attraction between any two particles. In mathematical form this law can be express as:

$$\boxed{F_G = G\frac{m_1 m_2}{r^2}} \qquad (1\text{-}1)$$

Where

F_G = force of attraction between the two particles.

G = universal constant of gravitation; according to experimental evidence.

$G = 6.673\times10^{-11}\ N.m^2/kg^2$

m_1, m_2= mass of each of the two particles.

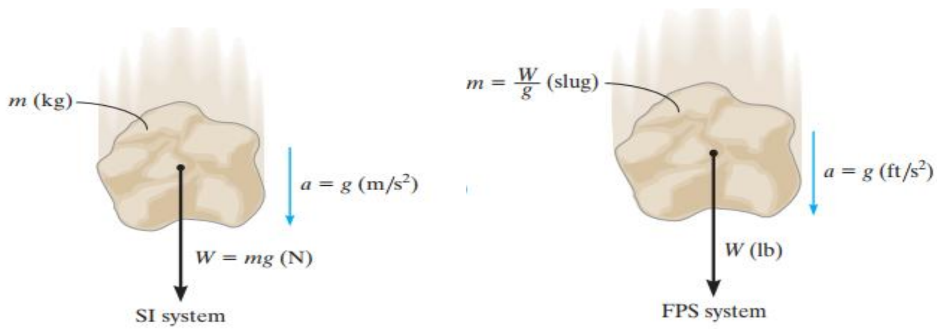
r= distance between the centers of the two particles.

*Since m is constant, we can also write $F = \frac{d}{dt}(mv)$, where mv is the particle's linear momentum. Here the unbalanced force acting on the particle is proportional to the time rate of change of the pa $\boxed{W = mg}$ omentum, In the case of a particle located at or near the surface of the earth, the only gravitational force having any sizable magnitude is that between the earth and the particle. This force is termed the "weight" and, for our purpose, it will be the only gravitational force considered. From Eq. 1–1, we can develop a general expression for finding the weight W of a particle having a mass m_1=m. and Let we consider m_2 = Me be the mass of the earth and r the distance between the earth's center and the particle. Then, if $g = GMe/r^2$ m/s^2, we have

(1-2)

By comparison with F=ma, we term g the acceleration due to gravity. For most engineering calculations g is measured at a point on the surface of the earth at sea level, and at a latitude of 45°, which is considered the "standard location." Here the values g = 9.81 m/s^2 = 32.2 ft/s^2 will be used for calculations. In the SI system, the mass of the body is specified in kilograms, and the weight must be calculated using the above equation, Fig. 1–1a. Thus, As a result, a body of mass 1 kg has a weight of 9.81 N; a 2 kg body weighs 19.62 N; and so on. In the FPS system the weight of the body is specified in pounds. The mass is measured in slugs, a term derived from "sluggish" which refers to the body's inertia. It must be calculated, Fig. 1–1, 1

lb using



(a) (b)

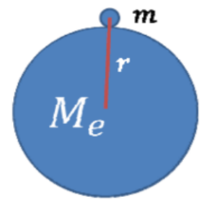
w = mg (N) (g = 9.81 m/s^2) w=mg (slug) (g=32.2 ft/s^2)

Therefore, a body weighing 32.2 lb has a mass of 1 slug; a 64.4-lb body has a mass of 2 slugs; and so on.

Homework

If you know the diameter of the earth D=12742Km, and mass of it 5.97×10^{24} kg , calculate the gravitation acceleration of the Earth at its surface?

Solution: Let we consider the particle mass $m=m_1$ and the earth $m_2=Me$



R=D/2=6371 Km and we have w = F_G, ∴ $mg = G\,\frac{mMe}{R^2}$

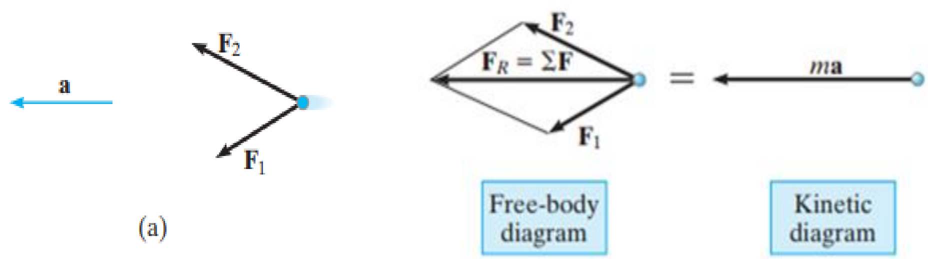
$$g = G\frac{Me}{R^2} = 6.67\times10^{-11}\times\frac{5.97\times10^{24}}{(6.371\times10^{6})^2} = 9.81\ m/s^2$$

1.2 The Equation of Motion

When more than one force acts on a particle, the resultant force is determined by a vector summation of all the forces; i.e., F_R = F. For this more general case, the equation of motion may be written as:

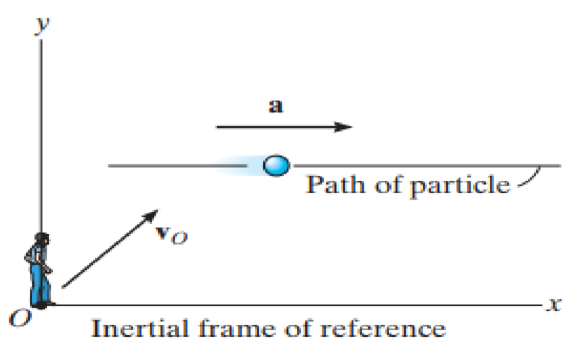
$$\boxed{\sum F = ma} \qquad (1\text{-}3)$$

To illustrate application of this equation, consider the particle shown in Fig. 1–2a, which has a mass m and is subjected to the action of two forces, F_1 and F_2. We can graphically account for the magnitude and direction of each force acting on the particle by drawing the particle's free-body diagram, Fig. 1–2b. Since the resultant of these forces produces the vector ma, its magnitude and direction can be represented graphically on the kinetic diagram, shown in Fig. 1–2c.*



The equal sign written between the diagrams symbolizes the graphical equivalency between the free-body diagram and the kinetic diagram; i.e., F = ma. In particular, note that if $F_R = \sum F = 0$, then the acceleration is also zero, so that the particle will either remain at rest or move along a straight-line path with constant velocity. Such are the conditions of static equilibrium, Newton's first law of motion.

Inertial Reference Frame. When applying the equation of motion, it is important that the acceleration of the particle be measure with respect to a reference frame that either is fixed or move with a constant velocity. In this way, the observer will not accelerate and measurements of the particle's acceleration will be the same from any reference of this type. Such a frame of reference is common known as a Newtonian or inertial reference frame, Fig. 1–3.



(1-3)

When studying the motions of rockets and satellites, it is justifiable to consider the inertial reference frame as fixed to the stars, whereas dynamics problems concerned with motions on or near the surface of the earth may be solved by using an inertial frame which is assumed fixed to the earth. Even though the earth both rotates about its own axis and revolves about the sun, the accelerations created by these rotations are relatively small and so they can be neglected for most applications.

*Recall the free-body diagram considers the particle to be free of its surrounding supports and shows all the forces acting on the particle. The kinetic diagram pertains to the particle's motion as caused by the forces.

*The equation of motion can also be rewritten in the form F - ma = 0. The vector -ma is referred to as the inertia force vector. If it is treated in the same way as a force vector.

1.3 Equation of Motion for a System of Particles

The equation of motion will now be extend to include a system of particles isolated within an enclosed region in space, as shown in Fig.1–4a. In particular, there is no restriction in the way the particles are connected, so the following analysis applies equally well to the motion of a solid, liquid, or gas system. At the instant considered, the arbitrary i-th particle, having a mass mi, is subjected to a system of internal forces and a resultant external force. The internal force, represented symbolically as fi, is the resultant of all the forces the other particles exert on the ith particle. The resultant external force Fi represents, for example, the effect of gravitational, electrical, magnetic, or contact forces between the ith particle and adjacent bodies or particles not included within the system. The free-body and kinetic diagrams for the ith particle are shown in Fig. 1–4b. Applying the equation of motion, $\sum F = ma$; $F_i + f_i = m_i a_i$

When the equation of motion is applied to each of the other particles of the system, similar equations will result. And, if all these equations are added together vector ally, we obtain

$$\boxed{\sum Fi + \sum f_i = \sum ma_i} \qquad (1\text{-}4)$$

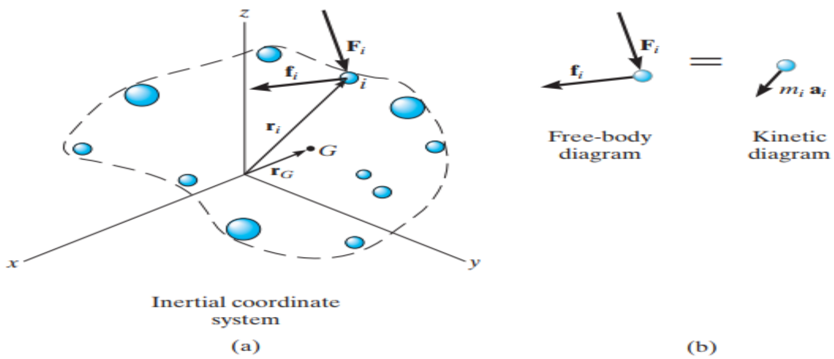


Fig.1 -4

The summation of the internal forces, if carried out, will equal zero, since internal forces between any two particles occur in equal but opposite collinear pairs. Consequently, only the sum of the external forces will remain, and therefore the equation of motion, written for the system of particles, becomes.

$$\boxed{\sum F_i = \sum m_i a_i} \qquad (1\text{-}5)$$

If $\mathbf{r}_G$ is a position vector which locates the center of mass G of the particles, Fig. 1–4a, then by definition of the center of mass, m.$\mathbf{r}_G = \sum miri$ where $m = \sum mi$ is the total mass of all the particles. Differentiating this equation twice with respect to time, assuming that no mass is entering or leaving the system, yields

$$m\mathbf{a}_G = \sum mi\mathbf{a}i$$

Substituting this result into Eq. 1–5, we obtain

$$\boxed{\sum F = ma_G} \qquad (1\text{-}6)$$