5.2 KINETICS

Kinetics is the study of motion of bodies by considering the forces acting on them. In rectilinear motion, acceleration is caused by unbalanced force.

KINETICS - NEWTON'S SECOND LAW OF MOTION

Newton's second law is used to find acceleration of bodies which are treated as particles. Once acceleration of the body is known.

Newton's Second Law of Motion

• Newton's second law of motion can be stated as follows:

• *The acceleration of a particle is directly proportional to magnitude of the resultant force acting on it and is in the direction of resultant force.*

• Mathematically, it can be written as,

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

Where, *m* is the mass of the particle. The above equation in two dimensions can be written in scalar form as

$$\sum F_x = ma_x$$

$$\sum F_y = ma_y$$

We can rewrite equation (9.2.1) as,

$$\sum \vec{F} + (-m\vec{a}) = 0$$

• This equation indicates that if a vector $-m\vec{a}$ is added to the forces acting on the particle, we get an equation that resembles equilibrium.

• The vector $-m\vec{a}$, which has same magnitude as $m\vec{a}$ but opposite direction, is called the **inertia vector.**

• We can say that the particle is in a state of dynamic equilibrium. This is called **D'Alembert's principle of dynamic equilibrium.**

• The inertia vector is a measure of the opposition that is offered by an object when we try to change its state of rest or of uniform motion along a straight line.

•. The inertia force will be used for pseudo forces which are experienced by objects when kept inside/on other accelerated objects.

• For example, if a bus accelerates forward, a man inside the bus experiences a force in the backward direction. This force experienced by the man is a product of mass of man and acceleration of bus and acts in a direction opposite to the direction of acceleration of the bus. We will use the term 'inertia force' to represent such forces.

• Problems on kinetics of particles in rectilinear motion can be classified broadly into the following types:

1) Variable force: When atleast one of the forces acting on the particle is variable, the acceleration will be variable. Methods discussed for variable acceleration in Chapter 10 then have to be used for further analysis.

2) Constant forces: If all forces acting on the object are constant, the acceleration will be constant. For further analysis we have to use kinematical equations

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

3) Dependent motion: If objects are connected by cords/cables then the accelerations of such objects are related. Equations relating accelerations of connected objects can be obtained using methods discussed in section 9.1.5. The tensile tes are related using the equilibrium of pulleys and the concept that tensile force throughout a given string is constant in absence of friction. Pulleys can be considered to be equilibrium eventhough they may be accelerated as their mass will be considered negligible. Hence,

$$\sum \vec{F} = m\vec{a} = 0$$

4) Relative motion: When an object is kept inside/on another object, the acceleration of the first object can be obtained with respect to the second. Then, knowing the absolute acceleration of the second object, the absolute acceleration of the first object can be obtained.

General Procedure for Solving Problems

1) Draw free body diagram of the objects in statics. The additional term now that has to be shown is the $m\vec{a}$ term, which is the effect. To differentiate the effect from the causes, we will show the effect with a double arrow (→)

2) Choose co-ordinate axes parallel and perpendicular to the direction in which motion can take place. For example, if an object is moving on an inclined plane, choose x-axis parallel to inclined plane and y-axis perpendicular to it.

3) Use $\sum F_x = ma_x$ and $\sum F_y = ma_y$

to find acceleration of the object.

4) If objects are connected through cables, relate their acceleration and tensile forces in connecting cables.

5) Take $m\vec{a}$ term in the direction of motion so that if '*a*' comes out to be negative it will indicate deceleration.

Solved Examples

1.A rigid body is acted upon by a force of 100 N, the velocity of body changes from 15 m/s to 25 m/s during a period of 50 s. Find the mass of body and the distance moved by the body during the time interval.

Solution :

$$a = \frac{v-u}{t} = \frac{25-15}{50}$$

$$\therefore \quad a = 0.2 \text{ m/s}^2$$

$$F = ma$$

$$\therefore \quad 100 = m \times 0.2$$

$$\therefore \quad \boxed{m = 500 \text{ kg}}$$

$$v^2 = u^2 + 2as:$$

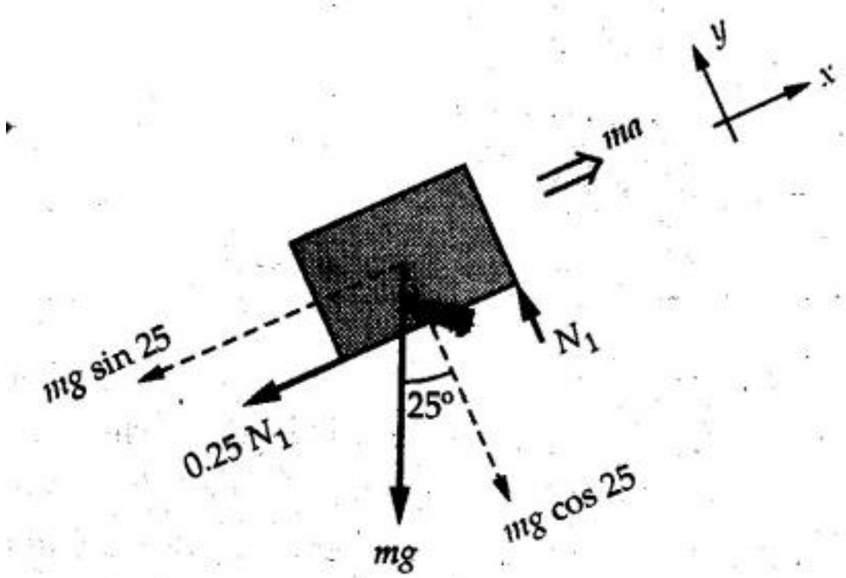
$$25^2 = 15^2 + 2(0.2)s$$

$$\therefore \quad \boxed{s = 1000 \text{ m}}$$

2. A body of mass 'm' is projected up a 25° inclined plane with an initial velocity of 15 m/s. If the coefficient of friction μ_k = 0.25, determine how far the body will move up the plane and the time required to reach the highest point.

Solution:

From Fig.



$$\sum F_y = 0 :$$

$$N_1 - mg \cos 25 = 0$$

$$\therefore \quad N_1 = mg \cos 25$$

$$\sum F_x = ma_x :$$

$$-mg \sin 25 - 0.25 N_1 = ma$$

$$-mg \sin 25 - 0.25\, mg \cos 25 = ma$$

$$a = -9.81 (\sin 25 + 0.25 \cos 25)$$

$$\therefore \quad a = -6.369 \text{ m/s}^2$$

$$u = 15 \text{ m/s}, \quad v = 0$$

$$v = u + at :$$

$$0 = 15 + (-6.369)\, t$$

$$\therefore \quad \boxed{t = 2.355 \text{ s}}$$

$$v^2 = u^2 + 2as :$$

$$0 = 15^2 + 2(-6.369)\, s$$

$$\therefore \quad \boxed{s = 17.66 \text{ m}}$$

3.Determine the minimum stopping distance 's' and the corresponding time 't' required by a truck, if a crate kept on the horizontal flat bed of the truck is not to slip forward. Take $\mu_s = 0.4$ and $\mu_k = 0.3$ between the crate and the flat bed of the truck which has a speed of 90 km/h.

Solution:

Assuming that the truck is moving to the right and brakes are applied causing deceleration of magnitude '*a*', the crate will be subjected to inertia force ma to the right as shown in Fig. 9.2.15. If the crate does not move on the truck, its acceleration with respect to the truck is zero."

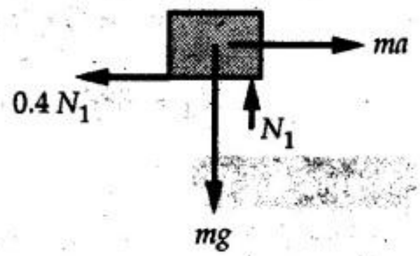


Fig. 9.2.15

$$\sum F_y = 0 :$$

$$N_1 - mg = 0$$

$$N_1 = mg$$

$$\sum F_x = 0 :$$

$$ma - 0.4 N_1 = 0$$

$$ma = 0.4\ mg$$

$$a = 3.924\ \text{m/s}^2$$

For the truck, $u = 90 \times \frac{5}{18} = 25$ m/s , $v = 0$

$$a = -3.924\ \text{m/s}^2 .$$

$$v = u + at :$$

$$0 = 25 + (-3.924)\ t$$

$$\therefore \quad \boxed{t = 6.3715}$$

$$v^2 = u^2 + 2as ;$$

$$0 = 25^2 + 2\,(-3.924)\ s$$

$$\therefore \quad \boxed{s = 79.64\ \text{m}}$$