PPP0101
PRINCIPLES OF PHYSICS

Foundation in Information

Technology

ONLINE NOTES

Chapter 3
Dynamics

3.1 Newton's Laws of motion

<u>Force and net force.</u>

1. **Force**, **F** is the cause of acceleration, and it is the technical term for what we commonly calls a push, pull, kick or shove.
2. Force is a vector quantity because force has both magnitude and direction.
3. There must be net force acting on an object for the object to change its velocity (either magnitude or direction) or to accelerate.
4. **Net Force,** $\sum F$ **,** is the vector sum, the resultant, or the unbalanced force acting on an object.

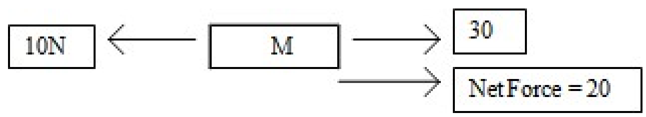


Diagram 1

5. For example, in the diagram 1, two forces 10 N and 30 N each are acting on an object in opposite directions. There are two forces on the object. However, there is only one net force (the resultant of the sum of the two forces) of 20 N (to the right) acting on the object.
   a. The object accelerate only if the net force acting on it not equal to zero
   b. If the net force is equal to zero, acceleration is zero and the velocity is constant.
   c. The object either remains at rest or continues to move with constant velocity
   d. When the velocity is constant or the body is at rest, the object is in equilibrium.

Note: The net force is ***not*** a separate force. It is simply the vector sum of the individual forces.

6. To analyze the forces acting on an object, you should draw a **free-body diagram**. This is done by
   a. Isolating the object of interest (this should be the only object in the diagram)
   b. Drawing all the forces acting on the object as vectors (including directions)

7. If there are *no forces* acting on an object, or if there *are equal and opposite forces* acting on it, the net force *is zero* and the object *will not* accelerate.
8. This state on motion is called translational equilibrium.

<u>Notes:</u>

- **The symbol $\sum$ means "the sum of".**
- **The symbol $\sum F$ means the vector sum of forces.**
- **The unit of force in SI is a combination of the fundamental units of mass, length, and time and it called Newton (N).**

- **1N is the net force required to accelerate a 1-kg mass with an acceleration of 1 m/s ^{2} or, 1N = 1 kgm/s^2**

Newton's First law

An object at rest will remain at rest and an object in motion will keep moving with constant velocity if the net force on the object is zero.

1. This law describes the state of motion of an object when there is ***no net force*** (net force equals zero) acting on the object.
2. An object at rest has no change in velocity and so its acceleration is zero.
3. An object moving with constant velocity (same speed and same direction) has no change in velocity either and its acceleration is also zero.
4. Therefore, Newton's first law can be summarized in a very simple mathematical relation:

If $\sum F = 0$

Then

v = constant

a = 0

Notes:

- Newton's first law is often called the law of inertia.
- Inertia is the property of an object that resists acceleration or change in motion and it is measured quantitatively by its mass(or the tendency of a body to maintain its state of rest or of uniform motion in a straight line is called inertia).

Newton's Second law

1. This law states that the acceleration depends on the net force $\sum$**F** and on the mass *m* of the object .
2. Mathematically formula is represented as

$$\boxed{\begin{gathered} a = \frac{\sum F}{m} \\ \sum F = ma \end{gathered}}$$

3. Acceleration is proportional to the force acting on it
4. Acceleration inversely proportional to its mass.
5. These relationships can be summarized as follows:
    - **a. The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.**
    - **b.** The acceleration, **a,** has the same direction as the resultant force **F.**
    - c. The vector equation F = ma can be written in terms of component as

$$\sum F_x = \mathrm{ma}_x \quad \sum F_y = ma_y = \mathrm{ma}_y \quad \sum F_z = ma_z$$

where the forces are the components of the external forces acting on the object.

6. If you think of inertia as the qualitative term for the property of a body that resists acceleration, then mass (a scalar quantity) is the quantitative measure of inertia. If the mass is large, the acceleration produced by a given net force will be small.
7. If you apply Newton's second law to gravity near the Earth's surface, you get the relation among weight *w* (gravitational force) , mass *m*, and gravitational acceleration *g* is $w = mg$

<u>Newton's Third law</u>

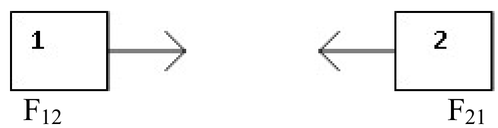


Diagram 2

1. This Law states that if object 1 exerts a force on object 2, then object 2 exerts an equal and opposite force on object 1, as in diagram 2
2. In mathematical terms, it can be written as

$$F_{12} = -F_{21}$$

3. The force by object 1 is *on* object 2, and the force by object 2 is *on* object 1, and so the two forces are always acting on *two* different objects.
4. Therefore, even though these two forces are equal and opposite, they do not cancel out each other because of this fact.
5. If you analyze only object 1 in the diagram, there is only one force acting on it and object 1 will accelerate.
6. This is often called the *Law of Action and Reaction.* Notice that the action and reaction forces act on the two different interacting objects.

3.2 Apparent Weight / Weightlessness

1. The **weight** of a body is a force that pulls the body directly toward the earth. (or the force of gravity acting on a body)
2. Consider only situation in which a body with mass, *m* is located at a point where the free-fall acceleration has magnitude , *g*.

$$W = mg$$

Unit: Newton.

3. Its magnitude at any given location depends on the value of *g* there.
4. Astronauts in stable orbit float freely in their cabin and are usually referred to as being ***"weightless***".

5. A spacecraft in orbit is in free-fall just as much as an elevator whose supporting cable has broken, and so the situation is similar to that of a person in a freely falling elevator.
6. When the acceleration of the person and the enclosure are equal, the person is ***apparently weightless***, even though the (true) weight is not zero.
7. True weight (W = mg) does not depend on the acceleration of the elevator, but the apparent weight does.
8. To help understanding this effect, consider an analogous situation of a person standing on a scale in an elevator.
9. The "weight" measurement that the scale registers is actually the reaction force or normal force of the scale on the person
10. In a non-accelerating elevator ($a = 0$), we have $R= mg = W$, and R is equal to the true weight of the individual Diagram 3.

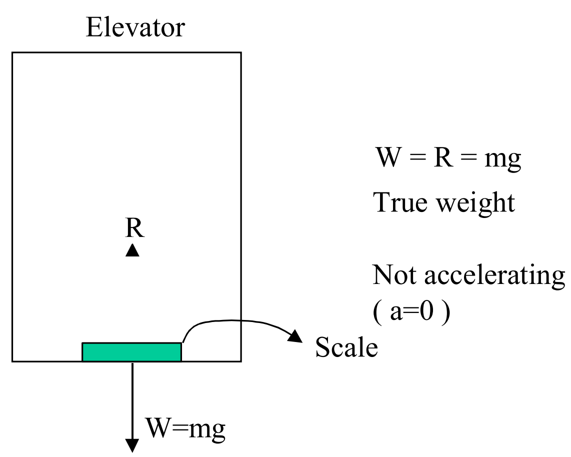


Diagram 3

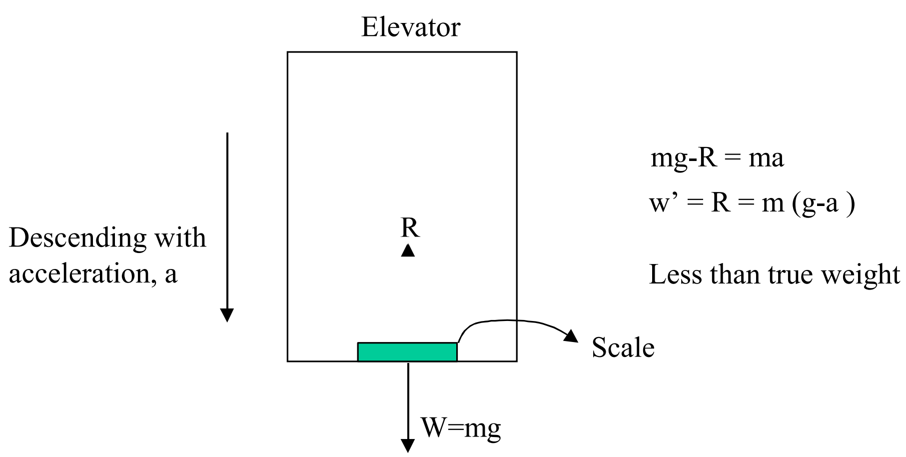


Diagram 4

11. However, suppose the elevator is descending with an acceleration a, and $a < g$. As can be seen by the vector diagram in the diagram 4,

$mg - R = ma$
and the apparent weight w' is
$w' = R = m(g-a) < mg$

12. Where the downward direction is taken as positive in this instance. With a downward acceleration *a,* we see that R is less than mg, hence the scale indicates that the person weighs less than the true weight.
13. Note that the ***apparent acceleration*** due to gravity is $g' = g - a$.
14. Suppose the elevator is ascending with an acceleration a, and a > g.

$$
\begin{aligned}
R - mg &= ma \\
R &= ma + mg \\
&= m(a + g)
\end{aligned}
$$

and the apparent weight w' is
$w' = R = m(a + g) > mg$

15. With an upward acceleration, a we see that R is more than mg, hence the scale indicates that the person weights more than the true weight.
16. Now suppose the elevator were in free fall with $a = g$. As you can see, R and the apparent weight w' would be zero.

$w' = R = 0$ (Descending with a = g)
the object would be apparently weightless.

17. The condition of apparent weightlessness occurs when an object is in free-fall.

3.3 FRICTION FORCE

1. When a body is in motion either on a surface or through a viscous medium such as air or water, there is resistance to the motion because the body interacts with its surroundings.
   Resistance ⇒ force of friction.
2. There are two kinds of friction forces:
   a. Static friction force
   b. Kinetic friction force
3. Static friction force ($f_s \le \mu_s N$) is parallel to the contact surface when there is **no relative motion** between the contact surfaces
4. Kinetic friction force ($f_k = \mu_k N$) is also parallel to the contact surface when there is **relative motion** between the contact surfaces.
5. Here μ_s or μ_k is called the coefficient of static friction or kinetic friction, which is a measure of the strength of the molecular interaction, and N, is the normal force.

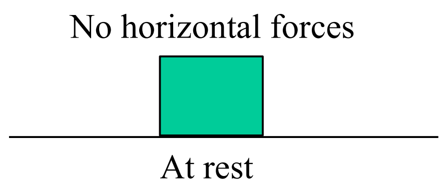


Diagram 5

6. If a block is at rest , as in diagram 5, no forces with horizontal components are applied to the block, there is no static friction force.

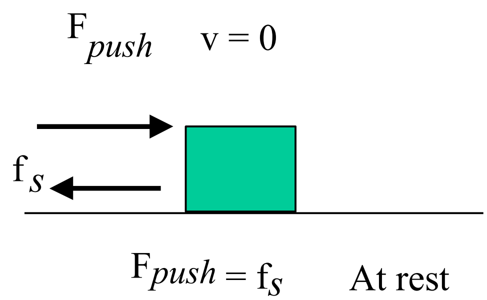


Diagram 6

7. Apply an external horizontal force, F to the block, as in diagram 6, the block remains stationary (at rest).
8. Conclude that an equal and opposite force acts on the block to prevent it from moving . This is the static friction force.
9. The static friction force is not a fixed value but it always equal to the applied force.
10. As long as the block is not moving, $F = f_s$

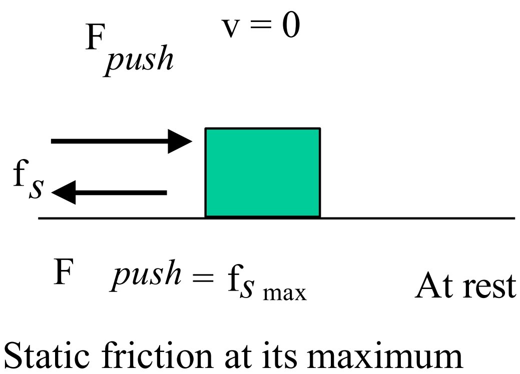


Diagram 7

11. If increased the horizontal applied force, the static friction force will increase by the same amount until it reached its maximum value $f_s = \mu_s N$

12. Increase the magnitude of F, the block eventually slips, $\Rightarrow f_{s\,\max}$. When F exceeds $f_{s\,\max}$ the block moves and accelerate! (as in diagram 8)

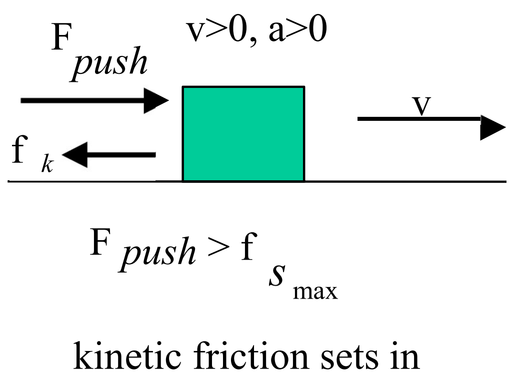


Diagram 8

13. When the block is in motion, the retarding friction force becomes less than $f_{s\,\max}$

14. The retarding force $\Rightarrow$ kinetic friction force, f_k

15. The value of f_k is smaller than the maximum value of f_s

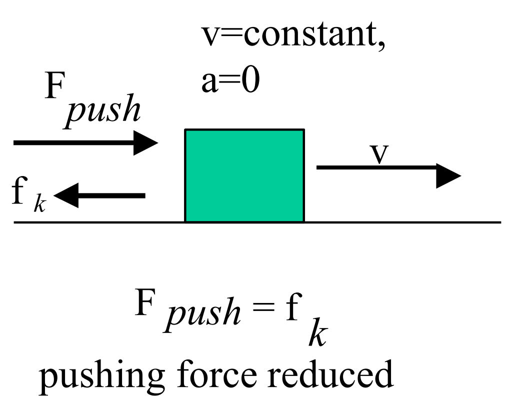
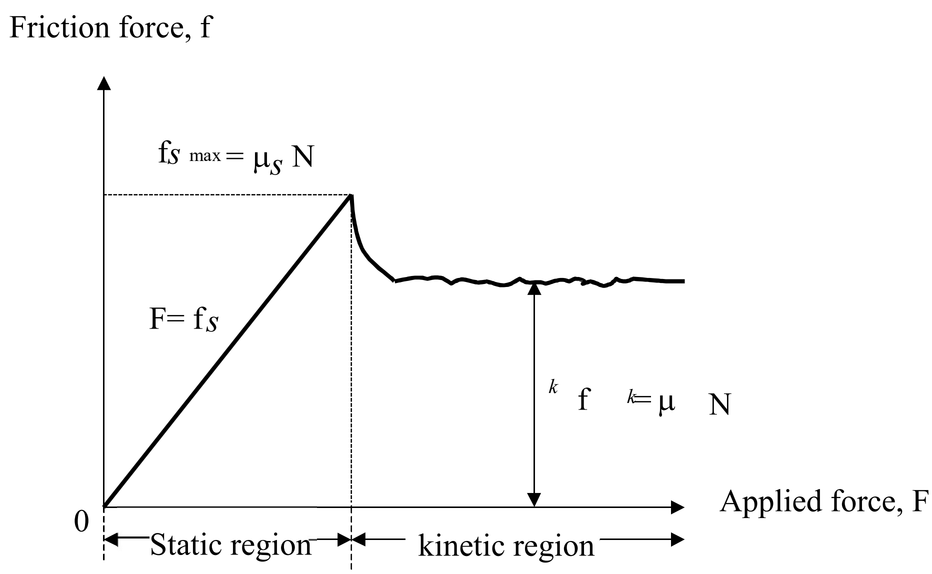


Diagram 9

16. If $F = f_k$, block moves with constant velocity. (as in diagram 9)

17. If F is removed, the friction force acting to the left, accelerate the block in the –x direction and eventually bring it to rest !



Graph 1 A graph of the frictional force versus the applied force.

- μ_k, μ_s are dimensionless and determined experimentally.
- Their values depends on certain properties of both the body and the surface.
- μ_k, μ_s independent of the area contact

3.4 LINEAR MOMENTUM AND COLLISIONS.

Linear momentum

1. The linear momentum of a particle is a vector ***p***
   p = m***v***
   m : mass
   v : velovity

   Units: kgm/s

2. We can call linear momentum as " The rate of change of the momentum of particle is equal to the net force applied to it."

$$\sum F = \frac{\Delta p}{\Delta t}$$

where, Δp is the resulting momentum change that occurs during the time interval, Δt

$$\sum F = \frac{\Delta p}{\Delta t} = \frac{mv - mv_0}{\Delta t} = \frac{m(v - v_0)}{\Delta t}$$

Δt

$= m \frac{\Delta v}{\Delta t} = ma$

(Newton's Second Law)

<u>Conservation of linear momentum</u>

"The total momentum of an isolated system of bodies remains constant."

1. By a system, we simply mean a set of objects that interact with each other. An isolated system is one in which the only forces present are those between the objects of the system.

Note : Momentum is a vector quantity. You must use vector addition when applying the conservation of linear momentum.

3.5 Collision

1. A collision is an isolated event in which two or more bodies (the colliding bodies) exert reactively strong forces on each other for a relatively short time.
2. Momentum is always conserved in a collision, as long as the net external force is zero on the system, which is approximately true at least during the small time interval of the collision.

<u>Elastic and Inelastic Collision</u>

1. In an elastic collision the kinetic energy of each colliding body can change, but the total kinetic energy of the system does not change.
2. In other words, in an elastic collision, kinetic energy is conserved while in an inelastic collision, kinetic energy is not conserved.

<u>Note:</u> when kinetic energy is not conserved as is the usual case, this does not mean the total energy is not conserved. Some of the kinetic energy is converted to heat, sound, etc. during a collision.

3. If the bodies/objects in a system stick together after collision, the collision is called completely inelastic. In an inelastic collision, the kinetic energy of the system before the collision is always greater than the kinetic energy of the system after the collision. Why?
4. The conservation of linear momentum principle can often be used to analyze the motion of systems of colliding objects.
5. The only criterion for its validity is that no **external** forces act on the system of objects during the collision.
6. Practically, collisions are often of such short duration that external forces such as gravity and friction have little time to influence the motion and may be neglected.
7. In these cases, the conservation of linear momentum principle may be applied to the motion **immediately before** and **immediately after** the collision.
8. In collision and explosions, the vector sum of the moment just before the event equals the vector sum of the moment just after the event.

9. The vector sum of the moment of the objects involved does not change during the collision or explosion.
10. Thus, when the two bodies of masses m_1 and m_2 collide,

    Total momentum before impact = total momentum after impact
    $m_1\mathbf{u}_1 + m_2\mathbf{u}_2 = m_1\mathbf{v}_1 + m_2\mathbf{v}_2$

    Where $\mathbf{u}_1$ and $\mathbf{u}_2$ are the velocities before impact, and $\mathbf{v}_1$ and $\mathbf{v}_2$ are the velocities after .

11. A perfectly elastic collision is one in which the sum of the translational KEs of the objects is not changed during the collision. In the case of two bodies,

    $\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$

3.6 EXPLOSION

1. It is a reverse action of perfectly inelastic collision.)
2. The initial object of mass M = $m_1 + m_2$ at rest, ***breaks up*** into two objects m_1 and m_2 moving with velocity such that the momentum is still zero.
   $m_1 v_{1f} + m_2 v_{2f} = 0$

3. Energy Conservation :- an explosion is possible as long as there is an initial potential as long as there is an initial potential energy ie

   $$PE = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$$

   An explosion does have potential energy stored in its molecules.
   Example: Unstable atomic nucleus disintegrates.

3.7 IMPULSE AND IMPULSIVE FORCE

1. **Impulse (**of a force) is the product of the average force and the time interval during which the force acts. Impulse is a vector quantity

   Impulse = (force) (length of time the force acts)
   Impulse = $\mathbf{F}\,\Delta t$

2. An impulse causes a change in momentum. The change of momentum produced by an impulse is equal to the impulse on both magnitude and direction. Thus, if a constant force **F** acting for a time Δt on a body of mass *m* changes its velocity from an initial value $\mathbf{v}_i$ to a final value $\mathbf{v}_f$**,** then

Impulse = change in momentum
$\mathbf{F}\, \Delta\, t = m\, (\mathbf{v}_f - \mathbf{v}_i)$

Newton's Second Law as he gave it, is $\mathbf{F} = \Delta\, \mathbf{p} / \Delta\, t$
from which it follows that $\mathbf{F}\, \Delta\, t = \Delta\, \mathbf{p}$ **.**
Moreover, $\mathbf{F}\, \Delta\, t = \Delta\, (m\mathbf{v})$ and if m is constant
$\mathbf{F}\, \Delta\, t = m\, (\mathbf{v}_f - \mathbf{v}_i)$

3. In many physical situations, we shall use the so-called impulse approximation. Assume that one of the forces exerted on a particle acts for a short time but is much larger than any other force present.
4. This approximation is especially useful in treating collisions, where the duration of the collision is very short. When this approximation is made we refer to the force as an impulsive force. Or in other words, **Impulsive force** *are forces that are very strong compared with other forces on the system and usually act for a very short time, as in the case of collision.*

End of Chapter 3