

## Force and Motion - I



## 5-1 | WHAT IS PHYSICS?

To study the motion of an object
$\square$
We usually study the acceleration of this object


Acceleration is the changing in velocity

The cause of this changing is a Force


The scientist who first understood the relation between a force and the acceleration it causes was Isaac Newton

## 5-2 | Newtonian Mechanics

Newtonian mechanics does not apply to :

1- A very large speeds such as the speed of light, and instead it replaced with Einstein's mechanics.

2- The scale of atomic structure, and instead it replaced with the Quantum mechanics.

## 5-3 | Newton's First Law

## If No Force acts on a body, the body's velocity cannot change; that is, the body cannot Accelerate.

if the body is at rest, it stays at rest
if the body is in motion, it stays in motion with the same velocity (same speed and direction)

## 5-4 | Force

- The SI unit of force is Newton (N).

- 1Newton is the force that accelerates a body of 1 kg with an acceleration of magnitude $1 \frac{\mathrm{~m}}{\mathrm{~s}^{2}}$
- Forces are vector quantities they combine according to the vector rules.
- A force is represented with a symbol as $\vec{F}$
- Forces follow the principle of superposition for forces.


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## 5-5 | Mass

- Mass is an intrinsic characteristic of a body that relates a force F applied on the body and the resulting acceleration a.
- SI Unit is Kg.
- It is a scalar quantity.



## 5-6 | Newton's Second Law

Newton's Second Law: The net force on a body is equal to the product of the body's mass and its acceleration.

## In equation form,

$$
\vec{F}_{\mathrm{net}}=m \vec{a} \quad \text { (Newton's second law) }
$$



The acceleration component along a given axis is caused only by the sum of the force components along that same axis, and not by force components along any other axis.

From Newton's second law the SI unit of force is

$$
1 \mathrm{~N}=(1 \mathrm{~kg})\left(1 \mathrm{~m} / \mathrm{s}^{2}\right)=1 \mathrm{~kg} \cdot \mathrm{~m} / \mathrm{s}^{2}
$$

To solve problems with Newton's second law, we often draw a free-body diagram in which the only body shown is the one for which we are summing forces.

Free-body diagram

1. Draw $x$ and $y$ coordinates.
2. The body is represented by a dot at the origin.
3. Each Force on the body is drawn as a vector arrow with its tail on the body.

## Sample Problem

Figures 5-3a to $c$ show three situations in which one or two forces act on a puck that moves over frictionless ice along an $x$ axis, in one-dimensional motion. The puck's mass is $m=0.20 \mathrm{~kg}$. Forces $\vec{F}_{1}$ and $\vec{F}_{2}$ are directed along the axis and have magnitudes $F_{1}=4.0 \mathrm{~N}$ and $F_{2}=$ 2.0 N . Force $\vec{F}_{3}$ is directed at angle $\theta=30^{\circ}$ and has magnitude $F_{3}=1.0 \mathrm{~N}$. In each situation, what is the
 acceleration of the puck?

Free -body diagram


$$
\frac{\mathbf{C}}{\substack{\vec{F}_{2} \\\left\langle=F_{3}\right.}} \underset{\substack{\vec{F}_{3} \\(c)}}{ } x
$$

In the overhead view of Fig. $5-4 a$, a 2.0 kg cookie tin is accelerated at $3.0 \mathrm{~m} / \mathrm{s}^{2}$ in the direction shown by $\vec{a}$, over a frictionless horizontal surface. The acceleration is caused by three horizontal forces, only two of which are shown: $\vec{F}_{1}$ of magnitude 10 N and $\vec{F}_{2}$ of magnitude 20 N . What is the third force $\vec{F}_{3}$ in unit-vector notation and in magnitude-angle notation?


## 5-7 | Some Particular Forces

## Some particular forces

|  |  |  |  |
| :---: | :---: | :---: | :---: |
| Gravitational force | Normal force | Friction | Tension |
| It is the force that the Earth exerts on any object. It is directed toward the center of the Earth. | When a body presses against a surface, the surface deforms and pushes on the body with a normal force perpendicular to the contact surface. | The force that opposes the motion. | This is the force exerted by a rope or a cable attached to an object. |



## Gravitational force

- It is the force that the Earth exerts on any object .It is directed toward the center of the Earth.

$$
\begin{gathered}
F_{\text {net. } y}=m a_{y} \quad-F_{g}=m(-g) \quad F_{g}=m g \\
\vec{F}_{g}=-F_{g} \hat{\mathrm{j}}=-m g \hat{\mathrm{j}}=m \vec{g}
\end{gathered}
$$

The weight $W$ of a body is equal to the magnitude $F_{g}$ of the gravitational force on the body.

$$
\text { mass } \quad w=\left|\vec{F}_{g}\right|=m g
$$

## weight

- mass is constant.
- Unit: kg.
- weight is changeable, It depends
- on g.
- Unit: N.

Normal force

The body at rest or moving with constant velocity.

$$
\begin{gathered}
a=0 \\
\nabla \\
\vec{F}_{n e t}=m \vec{a}
\end{gathered}
$$

$$
F_{n e t, y}=m a_{y}
$$

$$
F_{N}-F_{g}=0
$$

$$
F_{N}=F_{g}=m g
$$



The body is moving with acceleration
$\uparrow \begin{aligned} & \text { Direction } \\ & \text { of motion }\end{aligned}$

$$
\begin{aligned}
& \vec{F}_{n e t}=m \vec{a} \\
& F_{n e t, y}=m a_{y}
\end{aligned}
$$

$$
F_{N}-F_{g}=a_{y}
$$

$$
F_{N}=F_{g}+m q_{y}
$$

$$
\begin{gathered}
=m g+m a_{y} \\
F_{N}=\left(g+a_{y}\right) m
\end{gathered}
$$

## Tension

Tension has the following characteristics:

1. It is always directed along the rope.
2. It is always pulling the object.
3. It has the same value along the rope.

(a)

(b)

(c)
(0)

## 5-8| Newton's Third Law

## When two bodies interact by exerting forces on each other, the forces are equal in magnitude and opposite in direction.

The force on the book from the crate denoted by $\vec{F}_{B C}$
and the force on the crate from the book denoted by $\vec{F}_{C B}$

$$
\begin{gathered}
F_{B C}=F_{C B} \quad \text { (equal magnitude) } \\
\vec{F}_{B C}=-\vec{F}_{C B} \quad \text { (equal magnitude and opposite direction) }
\end{gathered}
$$

Why the action and reaction force do not cancel each other?
(a)


Action and reaction are called third-law force pair


## 5-9 | Applying Newton's Laws

\section*{| Sample Problem | $5-9$ | Build your skill |
| :--- | :--- | :--- |}

In Fig. 5-20a, a constant horizontal force $\vec{F}_{\text {app }}$ of magnitude 20 N is applied to block $A$ of mass $m_{A}=4.0 \mathrm{~kg}$, which pushes against block $B$ of mass $m_{B}=6.0 \mathrm{~kg}$. The blocks slide over a frictionless surface, along an $x$ axis.
(a) What is the acceleration of the blocks?


Free -body diagram
(b) What is the (horizontal) force $\vec{F}_{B A}$ on block $B$ from block $A$

## How to apply Newton's Laws for a single particle?

1. Identify all the forces that act on the system. Label them on the diagram and the direction of motion of the object if it is moving.
2. Draw a free-body diagram for the object.
3. Check if there is any force needs to be resolved.
4. Write Newton's Second law.
5. Decide how many equations do you need, if its one-dimension, need one equation, two-dimension, you need two equations.
6. If the object stationary (at rest) or moving with constant velocity, then the acceleration is zero $(a=0)$ along that axis, otherwise it a has a value.
7. Add all the components of the forces along the axis
8. solve the equation to find the unknown.

## How to apply Newton's Laws for a system of particles?

1. Identify all the forces that act on the system. Label them on the diagram and the direction of motion of each object if they are moving.
2. Remember that the system of two objects moves with the same acceleration.
3. Choose one object to start with and follow the steps below:
a) Draw a free-body diagram for the object.
b) Check if there is any force need to be resolved.
c) Write Newton 2ed law.
d) decide how many equations do you need, if its one-dimension, need one equation, twodimension ,you need two equations.
e) If the object at rest or moving with constant velocity, then $(a=0)$ the acceleration is zero along that axis, otherwise a has a value.
f) simplify the equation you get and label it (1)
4. Now Apply step( 3) to the other object till you get another equation and label (2).
5. Solve the two Equations to find the unknown.

## Sample Problem $\mid 5$ 5-4 Build your skill

Figure 5-13 shows a block $S$ (the sliding block) with mass $M=3.3 \mathrm{~kg}$. The block is free to move along a horizontal frictionless surface and connected, by a cord that wraps over a frictionless pulley, to a second block $H$ (the hanging block), with mass $m=2.1 \mathrm{~kg}$. The cord and pulley have negligible masses compared to the blocks (they are "massless"). The hanging block $H$ falls as the sliding block $S$ accelerates to the right.
Find (a) the acceleration of block $S$, (b) the acceleration of block


Free -body diagram $H$, and (c) the tension in the cord.

## Sample Problem 5 -5

In Fig. 5-16a, a cord pulls on a box of sea biscuits up along a frictionless plane inclined at $\theta=30^{\circ}$. The box has mass $m=5.00 \mathrm{~kg}$, and the force from the cord has magnitude $T=25.0 \mathrm{~N}$. What is the box's acceleration component $a$ along the inclined plane?


Free -body diagram

## Sample Problem $\quad$ 5-8 $\quad$ Build your skill

In Fig. 5-19a, a passenger of mass $m=72.2 \mathrm{~kg}$ stands on a platform scale in an elevator cab. We are concerned with the scale readings when the cab is stationary and when it is moving up or down.
(a) Find a general solution for the scale reading, whatever the vertical motion of the cab.

(b) What does the scale read if the cab is stationary or moving upward at a constant $0.50 \mathrm{~m} / \mathrm{s}$ ?
(c) What does the scale read if the cab accelerates upward at $3.20 \mathrm{~m} / \mathrm{s}^{2}$ and downward at $3.20 \mathrm{~m} / \mathrm{s}^{2}$ ?

## The End


[^0]:    Newton's First Law: If no net force acts on a body ( $\vec{F}_{\text {net }}=0$ ), the body's velocity cannot change; that is, the body cannot accelerate.

