Mechanics: Force and Motion - INTRODUCTION

The universe is full of motion caused by forces. The Sun moves around our galaxy and the Earth moves around the Sun, and we move around on the Earth. This movement never stops.

Force and motion are part of all engineering disciplines. Civil engineers to understand the forces and motions of buildings and bridges subject to high wind loads, mechatronic engineers to understand the forces and motions of robots.

Mechanics, the science of Force and Motion can be divided into three parts

Statics is the study of forces on objects that do not experience an acceleration.

دراسة تأثير القوى على الأجسام غير المتسارعة (الساكنة أو منتظمة الحركة) فتثبتها و/أو تشووها.

Dynamics is the study of forces on the motion of objects that are accelerating.

دراسة تأثير القوى على الأجسام المتسارعة لتحديد وجهتها ومساراتها.

Kinematics is the geometric study of the motion without considering the mass or the forces.

دراسة الحركة جيومتريا ومع الزمن دون الاهتمام بالكتلة المعيقة أو بالقوى المسببة.

WHAT IS A FORCE?

The word ***force*** is used in many ways. The force of law, brute force, police force, driving force, nuclear force, electromagnetic force, & the force of gravity are all examples of its use.

In engineering, a force is something that pushes or pulls and can cause an object to change speed, direction, or shape.

Newton’s laws of force and motion are very important for engineers because they are involved in a wide variety of technologies. These laws tell us things like how cars work, how water flows, how planes fly, how bridges are supported, and basically describe the motion of everything around us. Newton’s three physical laws can be summarized as follows:

NEWTON'S FIRST LAW (STATICS) Newton's First Law of motion can be stated as

An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

يبقى جسمٌ ساكنٌ في حالة سكونه هذه؛ ويستمر جسمٌ متحركٌ في حالة حركة منتظمة (أي ذات سرعة ثابتة مقدارا واتجاها)، إلا إذا أثرت عليه قوة غير موازنة.

This can be written mathematically as:

$$\sum_{External} Forces = 0 \;\; \Rightarrow \boldsymbol{v} = \text{constant}$$

Consequently,

- An object at rest will stay at rest unless an unbalanced force acts upon it.
- An object in motion will not change its speed unless an unbalanced force acts upon it.

NEWTON'S SECOND LAW (DYNAMICS) Newton's Second Law can be stated as

An object will accelerate if the net force on the object is not zero.
The direction of the acceleration is the same as the direction of the net force.
The magnitude of the acceleration is directly proportional to the magnitude of the net force, and inversely proportional to the mass of the object.

تتسارع حركة جسم ما إذا كانت القوة المحصلة للقوى المؤثرة عليه غير معدومة. يكون اتجاه تسارع الجسم مطابقا لاتجاه القوة المحصلة. أما شدة تسارع الجسم فتكون متناسبة طردا مع شدة القوة المحصلة وعكسا مع كتلته.

Central to any scientific set of units is the definition of **force.** According to Newton's Second Law, force is proportional to mass and acceleration and can be written mathematically as

$$F \propto ma$$

To convert the proportionality in Newton's Second Law into an "equality," we need to introduce a **constant of proportionality,** K, such that

$$F = K\,ma$$

where $\boldsymbol{a}$ is the **acceleration** of mass $\boldsymbol{m}$. . Acceleration is simply the rate of change of velocity (speed), so Newton's Second Law can be written for bodies of constant mass as $F \propto m\left(\frac{\Delta v}{\Delta t}\right)$ with Δv being the change in the speed and Δt being the change in the time during the change in speed.

The magnitude and the dimensions of the proportionality constant K depend on the unit system as we can see in the next table.

A Comparison of Various Common Unit Systems Using $F = Kma$

System Name	Force Unit	Mass Unit	Length Unit	Time Unit	K Value & Unit
SI (Système International)	Newton[a] [N]	Kilogram [kg]	Meter [m]	Second [s]	K=1 [0] dimensionless
Engineering English (EE)	Pound force [lbf]	Pound mass [lbm]	Foot [ft]	Second [s]	1/32.174 [lbf·s²/lbm·ft]
Technical English (TE)	Pound force [lbf]	Slug[b] [slug]	Foot [ft]	Second [s]	K=1 [0] dimensionless

[a]Note that 1 newton= 1 N= 1 kg.m/s² which is useful when balancing units in an equation.
[b]A slug is a lbf·s²/ft and since K= 1 and dimensionless, 1 slug weighs 32.174 lbf at standard gravity.

In SI & in Technical English System, Newton's second law takes the familiar form

$$F=ma$$

The concept of weight always has the *local gravity* associated with it. The weight of a body of mass m at a point in space, where the local acceleration of gravity is g, in the SI or TE is

$$F=W=mg$$

But in the Engineering English, the weight is:

$$F=W=Kmg$$

EXAMPLES

1. What is the force in newtons on a mass 1.00 kg that is accelerated by gravity at 9.81 m/s²?

Solution:

$F = ma = 1[\text{kg}] \times 9.81[\text{m/s}^2] = 9.81$ N.

2. The mass of one small apple is 0.102 kg. What is its weight in newtons in the Earth's gravity of 9.81 m/s^2?

Solution:

Weight = $W = mg$ = (0.102 [kg])(9.81 [m/s^2]=1.00062 kg·m/s^2 =1.00 kg·m/s^2 = 1.00 N;

In other words, one newton is just about the weight of a small apple here on Earth! Perhaps this will help you mentally visualize the magnitude of a force given in newtons (e.g., 10 N ≈ weight of 10 apples).

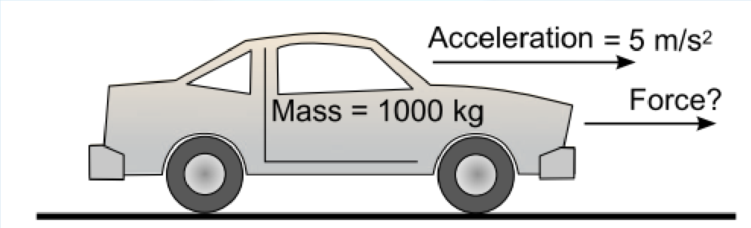
3. How much horizontal force is required to accelerate a 1000. kg car at *exactly* 5 m/s^2?

Need: The unbalanced force required to accelerate the car *exactly* 5 m/s^2?

Know: The mass of the car is 1000 kg.

How: Newton's Second Law, in SI units.

Solve: Newton's Second Law relates an object's mass, the unbalanced force on it, and its acceleration: $F = mg = (1000\ [kg])(5\ [m/s^2]) = 5 \times 10^3$ N.



NEWTON'S THIRD LAW

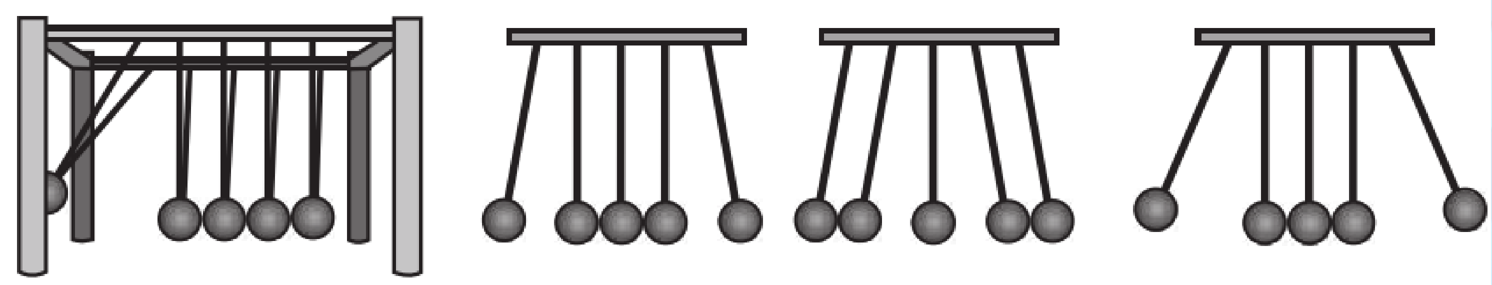
Newton's Third Law can be simply stated as:

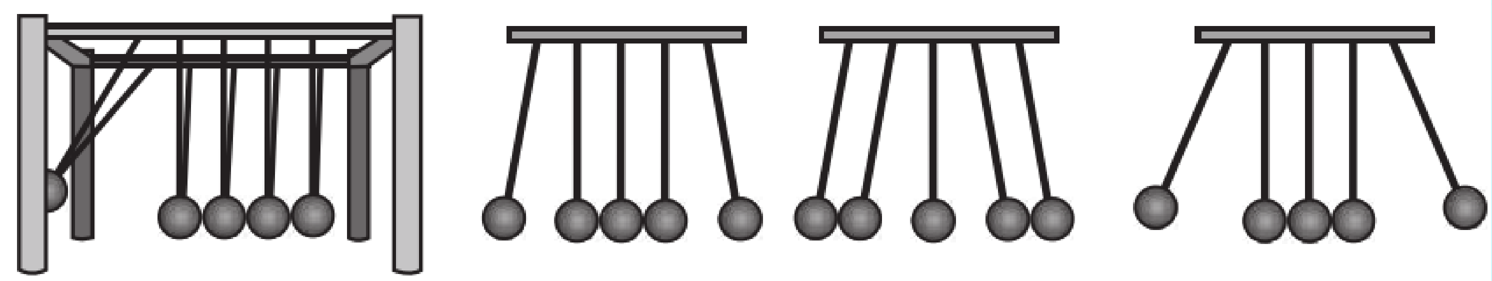
For every action, there is an equal and opposite reaction.

لكل فعل رد فعل يعاكسه في الاتجاه ويساويه في الشدة

For example, Newton's Third Law states that a force on object A that is due to the presence of a second object B is automatically accompanied by an equal and opposite force on object B due to the presence of object A. That is, any pair of forces between any two isolated objects does not cause the center of mass of these objects to accelerate. These objects can accelerate toward or away from each other, but their center of mass cannot accelerate.

A common demonstration of Newton's Third Law, called *Newton's Cradle,* is shown in Fig.





If one or more spheres is pulled away then released, it strikes the next sphere in the series and comes to (nearly) a complete stop. The impact force is transmitted through the group of spheres until an equal number of spheres on the opposite end is lifted by the reaction force. More than half the spheres can be set in motion. For example, three out of five spheres result in the central sphere swinging without any apparent interruption.

EXAMPLE

The total weight of a new US space transport (vehicle and launch rockets) at liftoff is 19.6×10^6 N and the liftoff thrust is 30.2×10^6 N. What is the unbalanced force on the shuttle at the moment of liftoff ? What's the rocket's initial acceleration ?