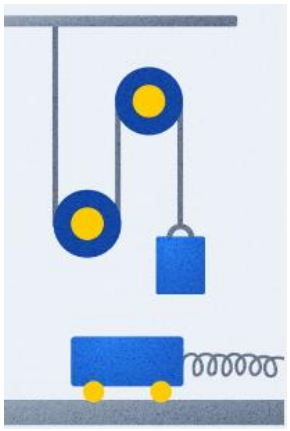
PHYSICS

Level 1 – First Semester
Building and Construction Technology Engineering Department



Dr. Mohammed Tareq Khaleel

What is Physics

Physics is a branch of science. The word science comes from a Latin word that means **having knowledge**, and refers the knowledge of how the physical world operates, based on objective evidence determined through observation and experimentation.

The Scope of Physics

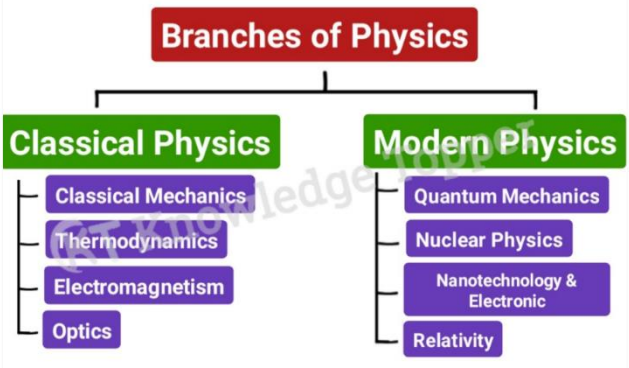
- Physics describes a wide range of phenomena within the physical sciences, ranging from the behaviour of microscopic particles that make up matter to the evolution of the entire Universe.

The Goal of Physics

- The goal of physics is to develop theories from which mathematical models can be derived to describe our observations.
- One of the ambitious goals of physicists is to develop a single theory that describes all of nature, instead of having multiple theories to describe different categories of phenomena. That is, physicists hope that there exists one single mathematical theory that describes the entire physical world.

Branches of Physics

We often distinguish between "**classical**" and "**modern**" physics depending on when the theories were developed.



• Classical Physics

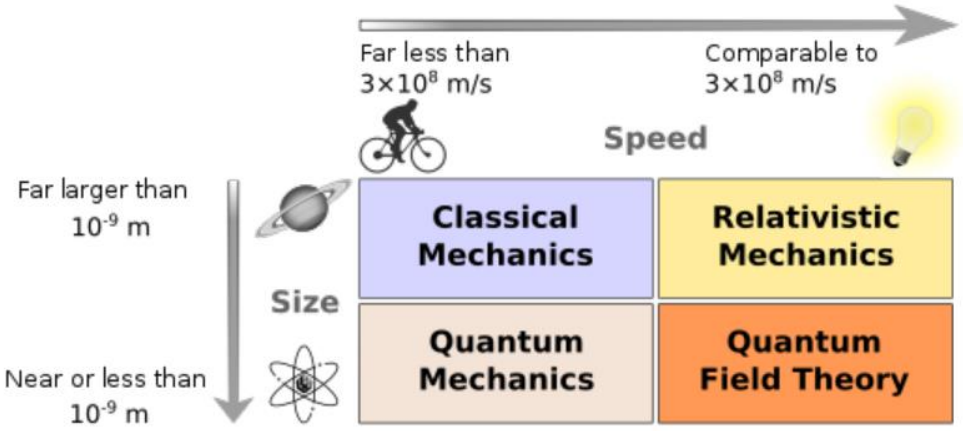
This course is focused on classical physics, which corresponds to the theories that were developed before 1905.

- Classical Mechanics describes most of our everyday experiences, such as how **objects move**, including how **planets** move under the influence of gravity.
- Isaac Newton was the first to formally develop a theory of mechanics, using his "Three Laws" to describe the behaviour of objects in our everyday experience.
- Is classical physics accurate?
  The classical mechanics (as known as Newtonian mechanics) **provides extremely accurate results as long as the domain of study is restricted to large objects and the speeds involved do not approach the speed of light**.

• Modern Physics

- In 1905, Albert Einstein set the foundation for what we now call "Modern Physics".

- Quantum mechanics is a theory that was developed in the 1920s to incorporate Einstein's conclusion that light is made of particles and describe nature at the smallest scales.

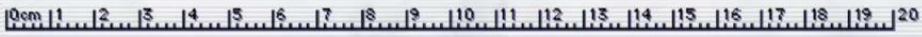


H.W.#1

Create your personal dictionary (English – English or English Arabic) that including the important physical and mathematical terms? (due time: within 2-3 weeks).

Scale of Things

Length:



Distance	Length (m)
Radius of visible universe	1×10^{26}
To Andromeda Galaxy	2×10^{22}
To nearest star	4×10^{16}
Earth to Sun	1.5×10^{11}
Radius of Earth	6.4×10^{6}
Sears Tower	4.5×10^{2}
Football field	1.0×10^{2}
Tall person	2×10^{0}
Thickness of paper	1×10^{-4}
Wavelength of blue light	4×10^{-7}
Diameter of hydrogen atom	1×10^{-10}
Diameter of proton	1×10^{-15}

Time:

Interval	Time (s)
Age of universe	5×10^{17}
Age of Grand Canyon	3×10^{14}
32 years	1×10^{9}
One year	3.2×10^{7}
One hour	3.6×10^{3}
Light travel from Earth to Moon	1.3×10^{0}
One cycle of guitar A string	2×10^{-3}
One cycle of FM radio wave	6×10^{-8}
Lifetime of neutral pi meson	1×10^{-16}
Lifetime of top quark	4×10^{-25}

Mass:

Object	Mass (kg)
Milky Way Galaxy	4×10^{41}
Sun	2×10^{30}
Earth	6×10^{24}
Boeing 747	4×10^{5}
Car	1×10^{3}
Student	7×10^{1}
Dust particle	1×10^{-9}
Top quark	3×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}
Neutrino	1×10^{-38}

Table 2.1 SOME SPEEDS

Light	3.0×10^8 m/s
Recession of fastest known quasar	2.7×10^8 m/s
Electron around nucleus (hydrogen)	2.2×10^6 m/s
Earth around Sun	3.0×10^3 m/s
SST airliner (Tu-144, maximum airspeed)	7.1×10^2 m/s
Rifle bullet (muzzle velocity)	$\sim 7 \times 10^2$ m/s
Rotation of Earth (at equator)	4.6×10^2 m/s
Random motion of molecules in air (average)	4.5×10^2 m/s
Sound	3.3×10^2 m/s
Jet airliner (Boeing 747, maximum airspeed)	2.7×10^2 m/s
Cheetah (maximum)	28 m/s
Federal highway speed limit (55 mi/h)	25 m/s
Man (maximum)	12 m/s
Man (walking briskly)	1.3 m/s
Snail	$\sim 10^{-3}$ m/s
Glacier	$\sim 10^{-6}$ m/s
Rate of growth of hair (human)	3×10^{-9} m/s
Continental drift	$\sim 10^{-9}$ m/s
Rate of subsidence of Southeast England	$\sim 10^{-10}$ m/s

Orders of Magnitude

One of the most straightforward ways to estimate if a model makes sense is to ask whether it predicts the correct order of magnitude for a quantity.

Group Work #1

Fill in the following table, giving the order of magnitude (in meters) of the sizes of different physical objects. Feel free to look these up on the internet!

Object	Order of Magnitude
Proton	
Nucleus of atom	
Hydrogen atom	
Virus	
Human skin cell	
Width of human hair	

Object	Order of Magnitude
Human	1 m
Height of Mt. Everset	
Radius of the Earth	
Radius of the Sun	
Radius of the Milky Way	

H.W. #2

Create a table showing the scale of 15 things (you select them) ranging from 1×10^{-7} to 1×10^{7} meters.

FYI: Scale of the Universe
https://scaleofuniverse.com/

Converting Units between different systems of measurement

Metric to English	English to Metric
Length: 1millimeter (m) = 0.04 inches (in) 1 centimeter (cm) = 0.39 inches (in) 1 meter (m) = 39.37 inches = 3.28 feet (ft) 1 meter (m) = 1.09 yard (yd) 1 kilometer (km) = 0.62 miles (mi)	Length: 1 inch (in) = 2.54 centimeters (cm) 1 foot (ft) = 30.48 cm = 0.305 meters (m) 1 yard (yd) = 0.914 meters (m) 1 mile (mi) = 1.609 kilometer (km)
Weight: 1 gram (g) = 0.035 ounces (oz) 1 liter (l) = 1.057 quart (qt)	Weight: 1 ounces (oz) = 28.350 grams (g) 1 pound (lb) = 0.453 kilograms (kg)
Capacity: 1 milliliter (ml) = 0.2 teaspoon (tsp) 1 liter (l) = 1.057 quart (qt)	Capacity: 1 teaspoon (tsp) = 5 milliliters (ml) 1 cup (c) = 236 milliliters (ml) 1 quart (qt) = 0.9461 liter (l) 1 gallon (gal) = 3.785 liter (l)

Common Prefixes in SI Units

Common Prefixes used with SI Units			
Prefix	Symbol	Meaning	Order of Magnitude
giga-	G	1 000 000 000	10^{9}
mega-	M	1 000 000	10^{6}
kilo-	k	1 000	10^{3}
hecto-	h	100	10^{2}
deka-	da	10	10^{1}
	base unit	1	10^{0}
deci-	d	0.1	10^{-1}
centi-	c	0.01	10^{-2}
milli-	m	0.001	10^{-3}
micro-	μ	0.000 001	10^{-6}
nano-	n	0.000 000 001	10^{-9}

Units

System	Mass	Time	Length	Force
Standard International (S.I)	**Kg**	**sec**	**m**	**N**
French: Centimetre–gram–second (C.G.S) *	gm	sec	cm	dyne
British (English)	**slug**	**sec**	**ft**	**lbf**
Kilogram Weight system *	kg	sec	m	kg_w

* Not required

Basic and Derived Physical Quantities

- **Basic Quantities** (Length, Mass, Time, etc.)
- **Derived Quantities (**Velocity, Acceleration, Force, Pressure, Area, etc.)

Base Dimensions and their SI units

In order to facilitate communication of scientific information, the International System of units (SI) was developed.

From the **Base** dimensions and units, we can obtain "**Derived**" dimensions and the corresponding SI unit.

Dimension	SI Unit
Length $[L]$	meter $[m]$
Time $[T]$	second $[s]$
Mass $[M]$	kilogram $[kg]$
Temperature $[\theta]$	kelvin $[K]$
Electric Current $[I]$	ampere $[A]$
Amount of Substance $[N]$	mole $[mol]$
Luminous Intensity $[J]$	candela $[cd]$
Dimensionless $[l]$	unitless $[]$

***Table 2.2.1**: Base dimensions and their SI units with abbreviations.*

Dimension	SI unit	SI base units
Speed $[L/T]$	meter per second $[m/s]$	$[m/s]$
Frequency $[1/T]$	hertz $[Hz]$	$[1/s]$
Force $[M \cdot L \cdot T^{-2}]$	newton $[N]$	$[kg \cdot m \cdot s^{-2}]$
Energy $[M \cdot L^2 \cdot T^{-2}]$	joule $[J]$	$[N \cdot m = kg \cdot m^2 \cdot s^{-2}]$
Power $[M \cdot L^2 \cdot T^{-3}]$	watt $[W]$	$[J/s = kg \cdot m^2 \cdot s^{-3}]$
Electric Charge $[I \cdot T]$	coulomb $[C]$	$[A \cdot s]$
Voltage $[M \cdot L^2 \cdot T^{-3} \cdot I^{-1}]$	volt $[V]$	$[J/C = kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}]$

***Table 2.2.2**: Example of derived dimensions and their SI units with abbreviations.*

What are the "Precision", "Accuracy" and "Uncertainty"?

- **Accuracy** indicates how close the measurement is to the actual measurement.
- **Precision** determined how close a single measurement is to others.
- **Uncertainty** is a quantitative measure of how much your measured values deviate from a standard or expected value.

How is Precision and Accuracy connected to Uncertainty?

If your measurements are not very accurate or precise, then the uncertainty of your values will be very high. In more general terms, uncertainty can be thought of as a disclaimer for your measured values.

Table 2.3.3: Different types of measurements and how to assign central values uncertainties.

Type of measurement	How to determine central value and uncertainty
Repeated measurements	Mean and standard deviation
Single measurement with a graduated scale (e.g. ruler, digital scale, analogue meter)	Closest value and half of the smallest division
Counted quantity	Counted value and square root of the value

Significant Figures (or Significant Digits)

The Significant Figures of a given number are **those significant or important digits, which convey the meaning according to its accuracy**. These substantial figures provide precision to the numbers.
(Certain and Necessary digits in any measurements)

Classical (Newtonian) Mechanics

*Predict **Future** & given **Present***
***Present -** info. of a system at initial time (t_o), initial position (x_o), etc.*
***Future -** info. of a system at final time (t), final position (x), etc.*



Kinematics

The description of **how** objects move.

- Kinematics in one dimension: describing an object that moves along a straight line path, which is one dimensional motion.
- Kinematics in two dimensions: the description of the motion of objects that move in paths in two (or three) dimensions.

Dynamics

Deals with **force** and **why** objects move as they do.
In this part we will solve the following questions:

- What makes an object at rest begin to move?
- What causes a body to accelerate or decelerate?
- What is involved when an object moves in a circle?

We can answer in each case that a **FORCE** is required.

Mathematical Point – is the simplest Object that will be used as the moving Object.

Kinematics – Terms and Concepts

The following are some important terms which you need to know

- Reference Frames
- Distance
- Displacement
- Speed
- Average Velocity
- Instantaneous Velocity
- Average Acceleration
- Instantaneous Acceleration

1. Reference Frames:
Any measurement of position, distance or speed must be made with respect to a frame of reference.

Reference Frames, Coordinate Systems
• Every measurement must be made with respect to a reference frame.
• Usually, speed is relative to the Earth.

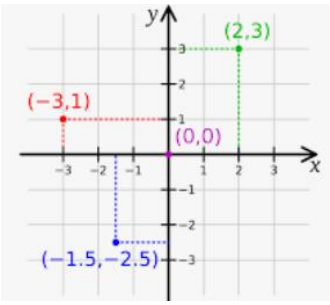
• When specifying speed, always specify the frame of reference unless its obvious (“with respect to the Earth”).

• Distances are also measured in a reference frame.

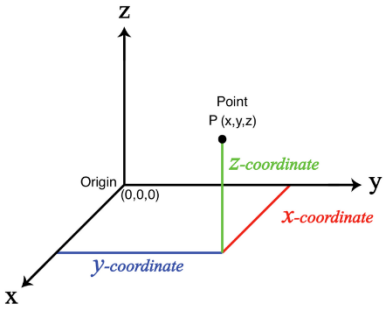
• When specifying speed or distance, we also need to specify DIRECTION.

Coordinate Axes

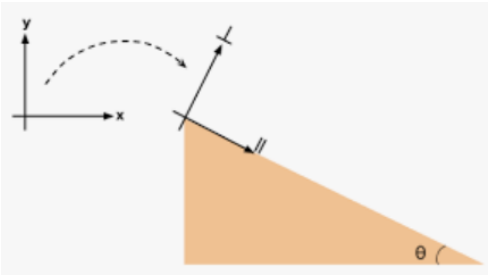
- Define reference frame using a standard coordinate axes.
- 2 Dimensions x,y



- 3 Dimensions x,y,z



- For inclined plane problems, tilted axes will be used (for convenience):



Important Definitions

Definition

Position: The distance between the defined coordinate system's origin and an object. SI units: $[\mathrm{m}]$. Common variable(s): $\vec{x}, \vec{r}$.

Definition

Velocity: The rate at which position changes with respect to time. SI units: $[\mathrm{ms}^{-1}]$. Common variable(s): $\vec{v}$.

Definition

Acceleration: the rate at which velocity changes with respect to time. SI units: $[\mathrm{ms}^{-2}]$. Common variable(s): $\vec{a}$.

2. **Distance:** The length of the actual path or total path length.

3. **Displacement:** The change in position of the object.

4. Average Speed

$$[\text{average speed}] = \frac{[\text{distance traveled}]}{[\text{time taken}]} \qquad (1)$$

5. Average Velocity in One Dimension

Average Velocity is a **Vector quantity**, with unit (m/s)

Suppose that at time t_1 the particle is at position x_1 and at a subsequent time t_2 the particle is at position x_2. The **average velocity** of the particle in this time interval is then defined as the change of position divided by the change of time,

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1} \qquad (2)$$

This expression may also be written as

$$\bar{v} = \frac{\Delta x}{\Delta t} \qquad (3)$$

Average velocity

where $\Delta x = x_2 - x_1$ represents the change of position, and $\Delta t = t_2 - t_1$ the change in time. The velocity can be positive or negative, depending on whether x_2 is larger or smaller than x_1; thus the sign of the velocity indicates the direction of motion.

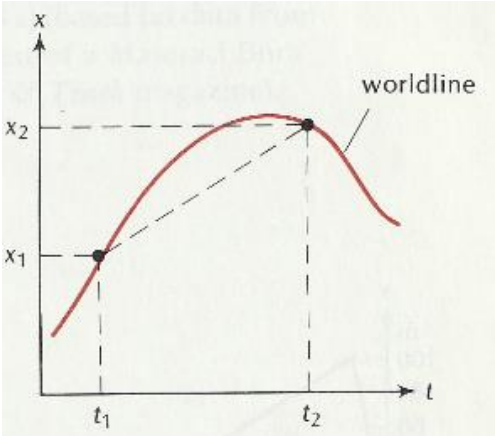
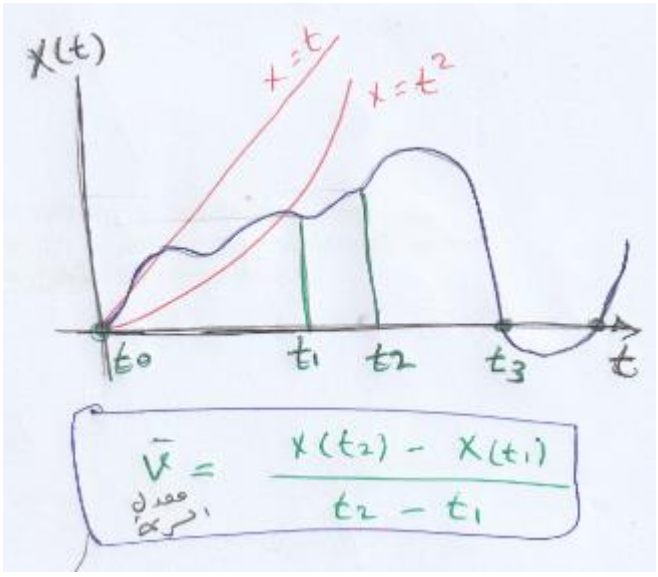


Fig. 2.1 Position as a function of time for a particle moving along the x axis. The curve in this plot is called the *worldline*. The straight line connecting the two points on the worldline has a slope $(x_2 - x_1)/(t_2 - t_1)$; this slope is the average velocity.



EXAMPLE 3. A runner runs 100 m on a straight track in 10 s and then walks back in 80 s. What are the average velocity and the average speed for each part of this motion and for the complete motion?

SOLUTION: The worldline of the runner is shown in Figure 2.2. The motion has two parts: the run ($0\ \text{s} \le t \le 10\ \text{s}$) and the walk ($10\ \text{s} \le t \le 90\ \text{s}$). The average velocity for the run is

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{+100\ \text{m}}{10\ \text{s}} = +10\ \text{m/s}$$

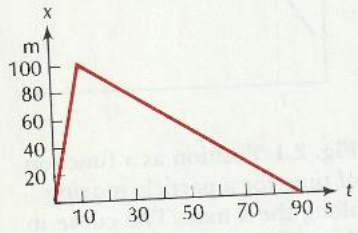


Fig. 2.2 Worldline of a runner.

The average velocity for the walk is

$$\bar{v} = \frac{-100\ \text{m}}{80\ \text{s}} = -1.2\ \text{m/s}$$

The average velocity for the entire motion is

$$\bar{v} = \frac{0\ \text{m}}{90\ \text{s}} = 0\ \text{m/s}$$

This is zero because the net change of position is zero.

The average speeds for the run and walk are, respectively, 10 m/s and 1.2 m/s. The average speed for the entire motion is

$$\frac{200\ \text{m}}{90\ \text{s}} = 2.2\ \text{m/s}$$

6. Instantaneous Velocity:

The instantaneous velocity is the velocity at any instant of time.
In general, the instantaneous velocity at any moment is defined as the average velocity over an infinitesimally short time interval.

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \qquad (7)$$

In the notation of differential calculus this limit is written as

$$v = \frac{dx}{dt} \qquad (8)$$

Instantaneous velocity as derivative

and is called the *derivative of x with respect to t.* Thus, the **instantaneous velocity** is the derivative of the position with respect to time.

7. Acceleration:

Acceleration is the rate of change of velocity.

8. Average Acceleration

Is the *change of velocity* divided by the *change of time.*

Average acceleration

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t} \qquad (11)$$

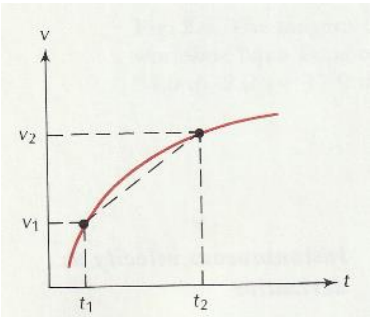
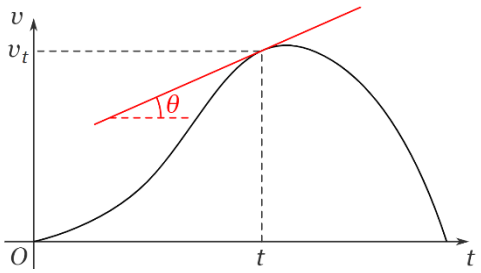
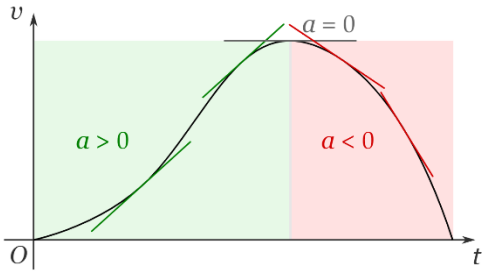


Fig. 2.8 The solid curve shows the instantaneous velocity as a function of time. The slope of the dashed line is the average acceleration.

9. Instantaneous Acceleration

- The instantaneous acceleration is the acceleration at any instant of time.
- In general, the instantaneous acceleration at any moment is defined as the average acceleration over an infinitesimally short time interval.
- The Instantaneous Acceleration is the slope of the tangent to the velocity curve in a plot of velocity vs. time.





- The Instantaneous Acceleration is the derivative of Instantaneous Velocity with respect to time.

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} \qquad (12)$$

$$\boxed{a = \frac{dv}{dt}} \qquad (13)$$ ***Instantaneous acceleration***

Equivalently, we can say that the acceleration is the second derivative of x with respect to time,

$$a = \frac{d}{dt}\left(\frac{dx}{dt}\right) \quad \text{or} \quad a = \frac{d^2x}{dt^2} \qquad (14)$$

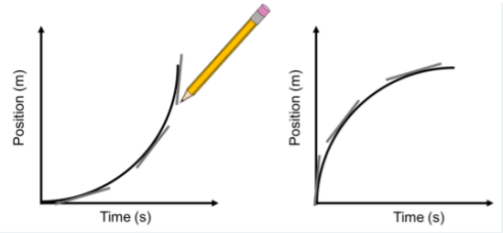


Figure 3.3.1: Two graphs of $x(t)$ showing tangent lines. Left: the object is speeding up (positive velocity, positive acceleration). Right: the object is slowing down (positive velocity, negative acceleration).

Constant Acceleration Examples

For better visualization of the concept, the table showing speed change and figures 1 and 2 present examples of constant acceleration.

Velocity magnitude (m/s)	Time elapsed (s)	Acceleration (m/s/s)
0	0	2
2	1	2
4	2	2
6	3	2
8	4	2
10	5	2

The table displays information about a straight-line motion with constant acceleration (2 m/s/s). Consequently, velocity magnitude changes uniformly at a rate of 2 m/s for each second.

The graph in figure 1 shows the uniform growth of speed for a constantly accelerated object.

The graph in figure 2 shows a constant acceleration. It maintains its value as time goes by.

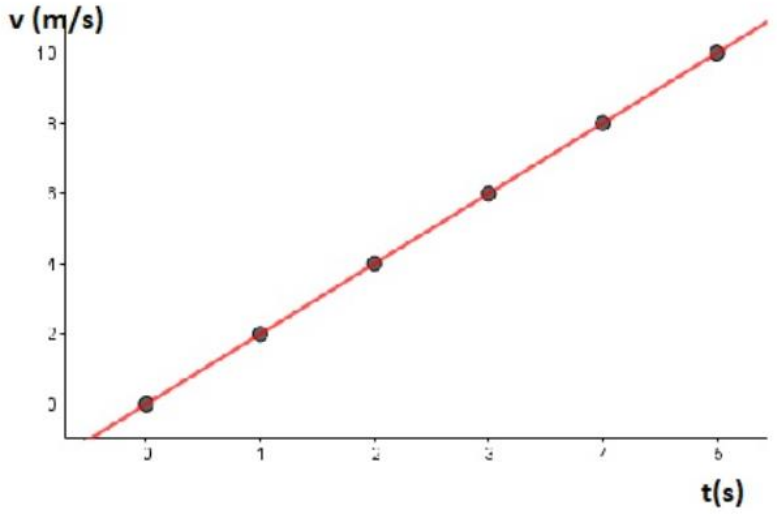


Figure 1: vXt graph.

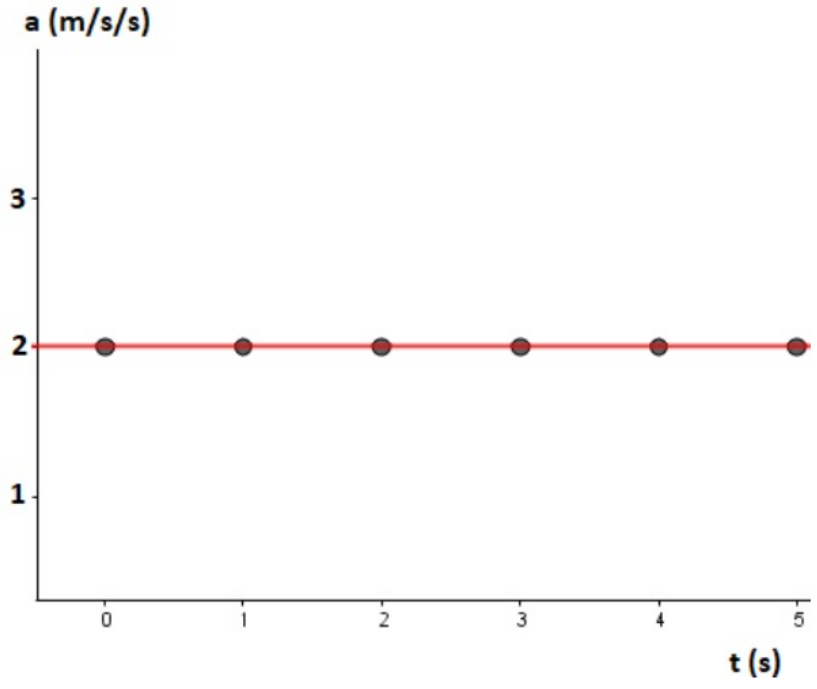


Figure 2: aXt graph.

Non-Constant Acceleration Examples

In a case where acceleration is not constant, for a straight-line motion, speed will vary according to the changes in acceleration, in a non-uniform way. Figure 3 shows the example (graph vXt) of a car during part of a commute. In real life, the car needs to stop for pedestrians and red lights. It also needs to change its velocity according to the traffic.

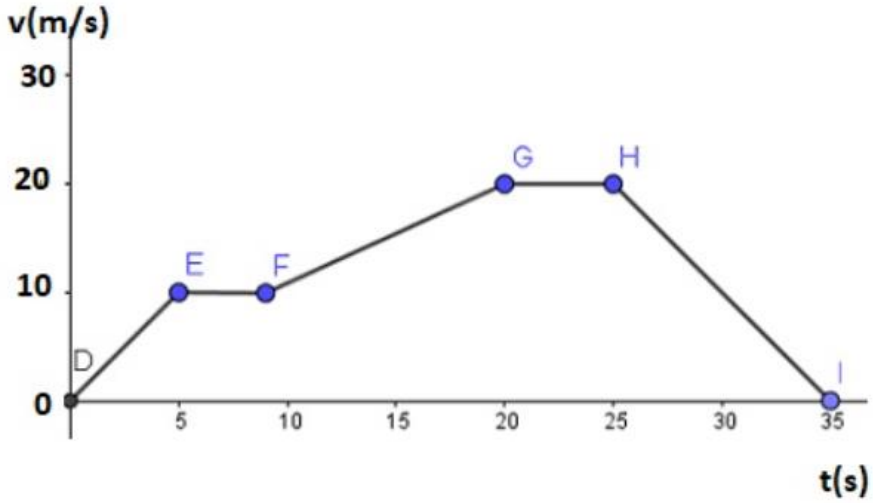


Figure 3: vXt graph for a non-constant accelerated motion.

From points D to E, the car changed its speed from 0 to 10 m/s in 5 seconds. Between points F and G it went from 10 m/s to 20 m/s in 10 seconds. From point E to point F, and from G to H, the speed did not change (null acceleration). In the end, between points H and I, the acceleration was negative since the car slowed down from 20 m/s to 0 in 10 seconds.

SUMMARY

Average speed: $\dfrac{\text{[distance traveled]}}{\text{[time taken]}}$

Average velocity: $\bar{v} = \dfrac{\Delta x}{\Delta t}$

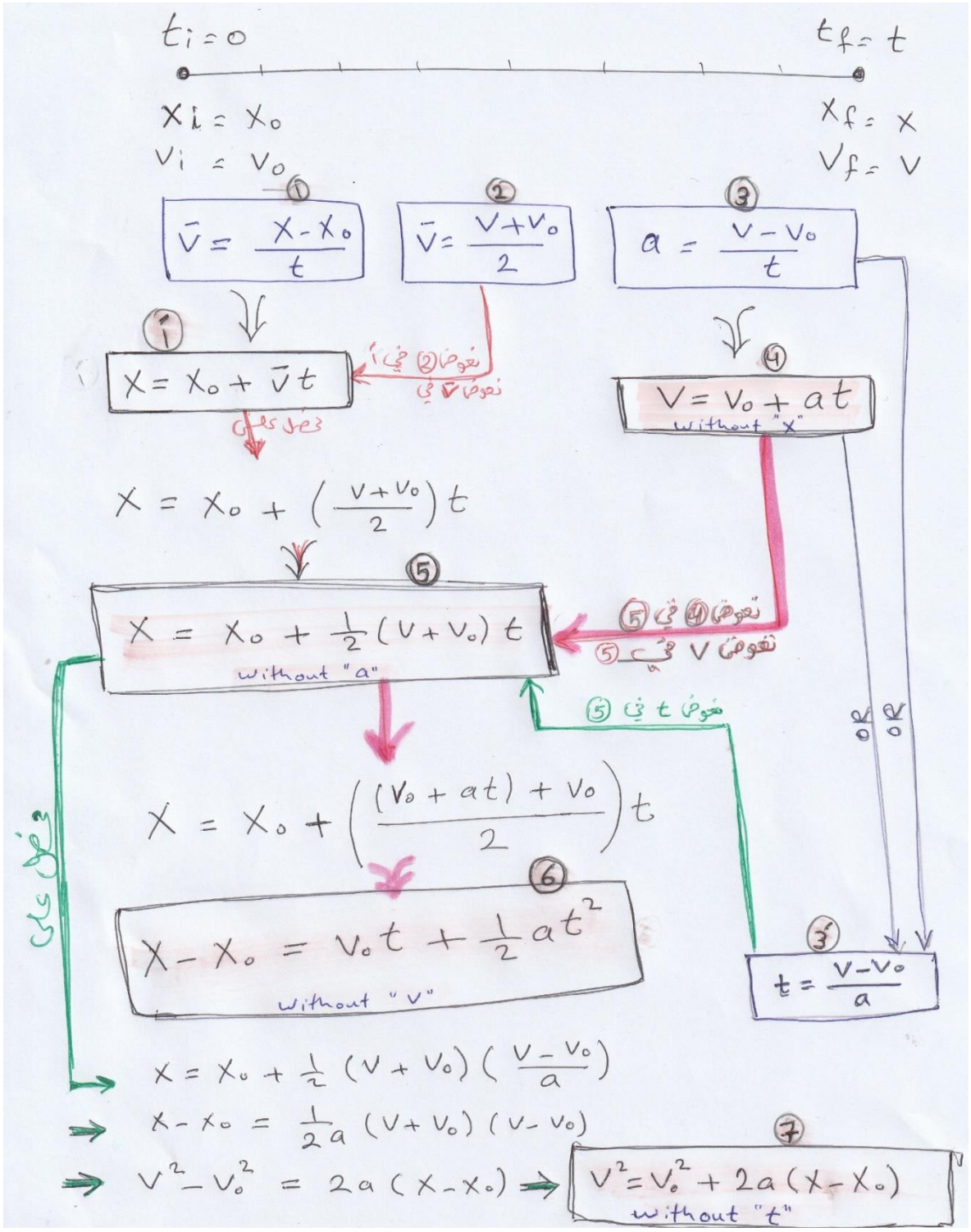
Instantaneous velocity: $v = \dfrac{dx}{dt}$

Average acceleration: $\bar{a} = \dfrac{\Delta v}{\Delta t}$

Instantaneous acceleration: $a = \dfrac{dv}{dt} = \dfrac{d^2x}{dt^2}$

Motion with Constant Acceleration

All equations that will be derived, are used to describe **ONLY** the motions with **Constant Acceleration**.



Motion with constant acceleration: $v = v_0 + at$

$$x = x_0 + v_0 t + \tfrac{1}{2}at^2$$

$$a(x - x_0) = \tfrac{1}{2}(v^2 - v_0^2)$$

Acceleration of gravity: $g \cong 9.81\ \text{m/s}^2$

$\cong 32.2\ \text{ft/s}^2$

Free Fall Motion

To describe vertical free-fall motion, take the x axis in the upward direction. Then $a = -g$ and Eqs. (17), (21), and (25) become

$$v = v_0 - gt \tag{27}$$

$$x = x_0 + v_0 t - \tfrac{1}{2}gt^2 \tag{28}$$

$$-g(x - x_0) = \tfrac{1}{2}(v^2 - v_0^2) \tag{29}$$

Free Fall

- Free fall is a motion under the influence of gravitational pull (gravity) only.
- The direction of gravitational acceleration is ALWAYS toward the center of the earth, which we normally call (**-y**); where up and down direction is indicated as the variable "**y**".

In the absence of air resistance, all objects fall towards the earth with the same constant acceleration (a = -g = -9.8 m/s^2), due to gravity.

Summary

$v = v_o + at$	(v, a, t)	without the "x"
$x - x_o = v_o t + \frac{1}{2}at^2$	(x, a, t)	without the "v"
$x - x_o = \frac{1}{2}(v + v_o)t$	(x, v, t)	without the "a"
$v^2 = v_o^2 + 2a(x - x_o)$	(x, v, a)	without the "t"

Free fall motions: Summary

$$v = v_o - gt$$

$$y - y_o = v_o t - \frac{1}{2}gt^2$$

$$y - y_o = \frac{1}{2}(v + v_o)t$$

$$v^2 = v_o^2 - 2g(y - y_o)$$

Examples:

EX.2. A jet plane accelerates on a runway from rest at 4 m/s^2, determine the distance and the velocity of the jet after 5 sec.

$$x = v_o t + \frac{1}{2} a t^2 = 50\ m$$
$$v = v_o + at = 20\ m/s$$

OR

$$v^2 = v_o^2 + 2a(x - x_o)$$ $v^2 = 0^2 + 2\ (4)\ (50 - 0)$ → $v = 20$ m/s

EXAMPLE 6. A powerful bow, such as used to establish world records in archery, can launch an arrow at a velocity of 90 m/s. How high will such an arrow rise if aimed vertically upward? How long will it take to return to the ground? How fast will it be going when it hits the ground? Ignore friction.

SOLUTION: At the highest point of the motion, the velocity is $v = 0$. Hence for the upward motion, we can regard the initial and final velocities as known. The height reached and the time are unknown. Equation (29) gives us the height in terms of the known quantities,

$$x - x_0 = \frac{-(v^2 - v_0^2)}{2g} = \frac{-0 - (90\ \text{m/s})^2}{2 \times 9.8\ \text{m/s}^2} = 4.1 \times 10^2\ \text{m}$$

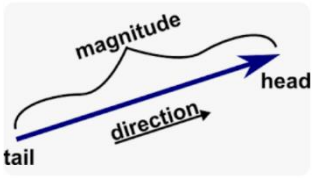
Equation (27) gives us the time for the upward motion:

$$t = \frac{v_0 - v}{g} = \frac{90\ \text{m/s} - 0}{9.8\ \text{m/s}^2} = 9.2\ \text{s}$$

The downward motion takes exactly as long as the upward motion; hence the time for the arrow to return to its starting point is $2 \times 9.2\ \text{s} = 18.4\ \text{s}$.

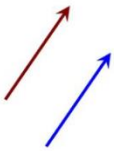
Since we are ignoring friction, the downward motion is simply the reverse of the upward motion. The velocity of the arrow when it hits the ground must therefore be the same as its initial velocity, except for sign; i.e., it must be -90 m/s. We can also see this from Eq. (29). With $x = x_0$, this equation yields $v^2 = v_0^2$, or $v = \pm v_0 = \pm 90$ m/s; the plus sign is for the upward motion, the minus sign for the downward motion.

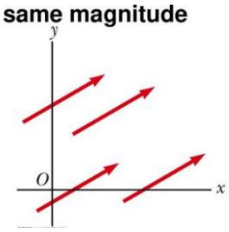
Vectors



- **Vectors are labeled either a or $\vec{a}$**
- **Vector magnitude is labeled either |a| or a**

- **Two (or more) vectors having the same magnitude and direction are identical**





مثلا اذا تحرك عنصر مسافة 50 م يمينا ثم تحرك 20 م غربا. اذا ذكرنا فقط المسافات دون ذكر الاتجاه سوف لن نعرف الى وصل العنصر المتحرك.

Scalar: described by a real number with units
examples - mass, charge, energy, etc.

Vector: described by a scalar (the magnitude) and a direction in space
examples - displacement, velocity, force, etc.

Physical Quantities can be divided into two categories:

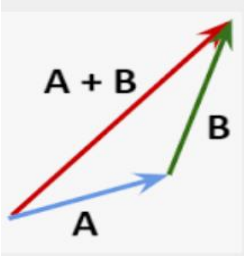
1. Vector Quantities
Need **Magnitude** and **Direction** to describe it, such as Displacement, Velocity, Acceleration and Force. *Ex. Position of the car is 9.6 km, south.*

2. Scalar Quantities
Need only **Magnitude** to describe them, such as Mass, Time, Temperature, Work and Power.
Ex. Temperature of the copper bar is 188 C^o.

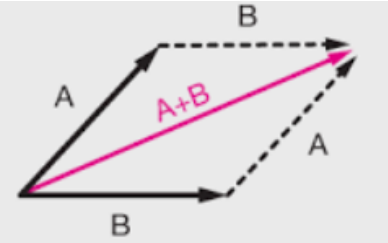
Vector-Addition/Subtraction

1. **Graphical method** (Tail to Head method and Parallelogram method)
2. **Components method**

Tail to Head (Tip) Method

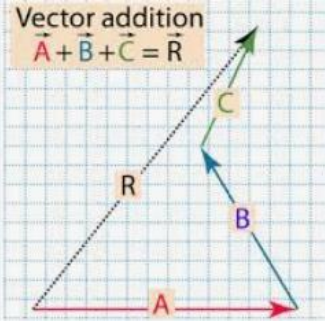


Parallelogram method



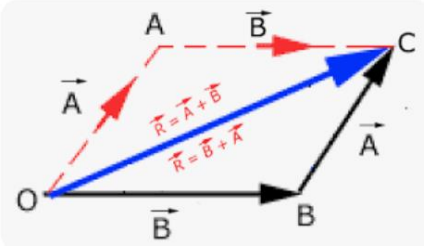
Where **A+B** or **C** is the Resultant Vector.

Adding several vectors:

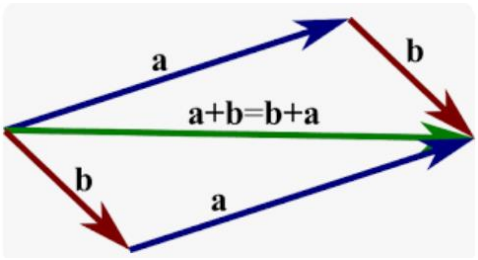


PROPERTIES OF VECTOR

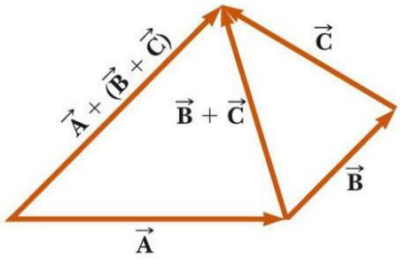
Commutative Law of vector addition: **A + B = B + A** الاستبدال

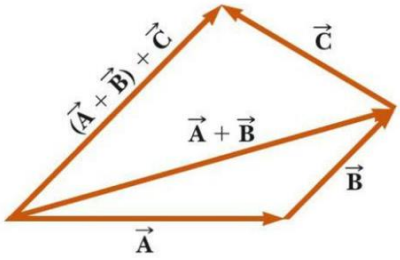


Or

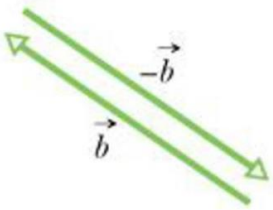


Associative Law of vector addition: **A+(B+C) = (A+B)+C** التجميع

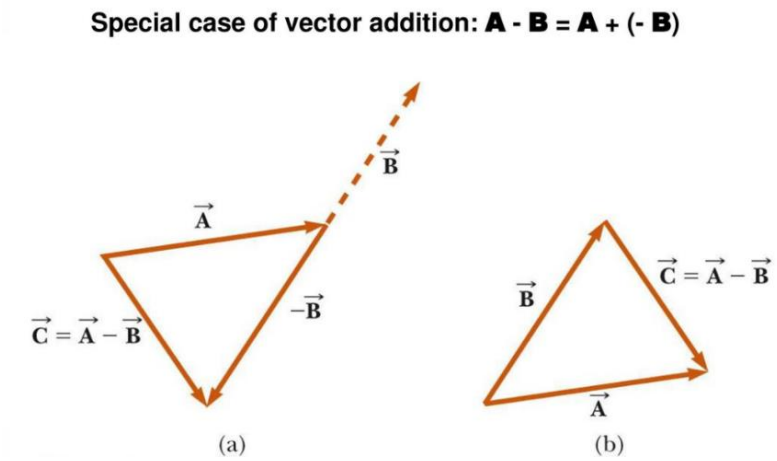




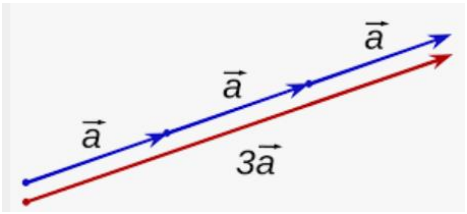
Negative Vectors: Vector (- b) has the same magnitude as b but opposite direction.



Vector Subtraction (Head to Head)



Multiplying a Vector by a Scalar



- The result of the multiplication is a vector

$$c\,\mathbf{A} = \mathbf{B}$$

- Vector magnitude of the product is multiplied by the scalar

$$|c|\,|\mathbf{A}| = |\mathbf{B}|$$

- If the scalar is positive (negative), the direction of the result is the same as (opposite to that) of the original vector

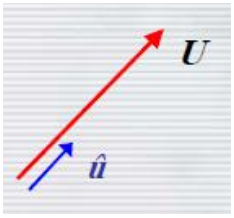
Unit Vectors

A **vector** is a quantity that has both magnitude, as well as direction.

A **Unit Vector** is a vector having length (magnitude) 1 and no units.

- It is used to specify a direction.
- Unit vector u points in the direction of U.

Often denoted with a "hat": u = û



$$|\hat{u}| = 1$$

For example, vector v = (1,3) is **not** a unit vector, because its magnitude is not equal to 1, i.e., $|v| = \sqrt{(1^2+3^2)} \neq 1$. Any vector can become a unit vector by dividing it by the magnitude of the given vector.

Unit Vector Symbol

Unit Vector is represented by the symbol '^', which is called a cap or hat, such as: â. It is given by $\hat{a} = \frac{a}{|a|}$

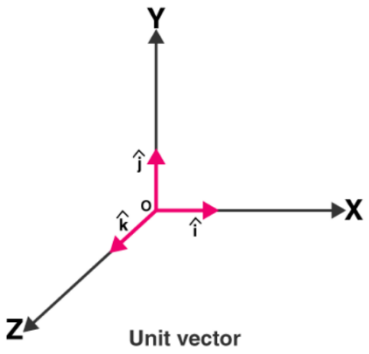
Where |a| is for norm or magnitude of vector a.

Summary

- **Unit vector:**

A) Has a magnitude of 1 (unity)
B) Lacks both dimension and unit
C) Specifies a direction

$$\hat{a} = \frac{a}{|a|}$$



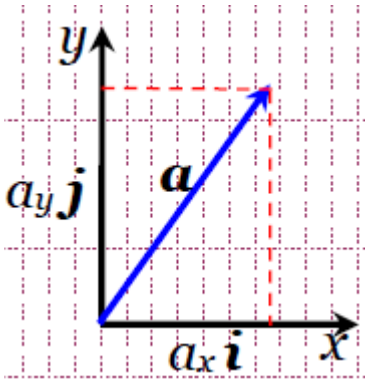
The vector can be represented in 3-D Cartesian coordinates as follow

$$\boldsymbol{a} = a_x\,\boldsymbol{i} + a_y\,\boldsymbol{j} + a_z\,\boldsymbol{k}$$

The vector can be represented in 2-D Cartesian coordinates as follow

$$\boldsymbol{a} = a_x\,\boldsymbol{i} + a_y\,\boldsymbol{j}$$

Where $\boldsymbol{a_x}$, $\boldsymbol{a_y}$, $\boldsymbol{a_z}$ are the components of vector $\boldsymbol{a}$

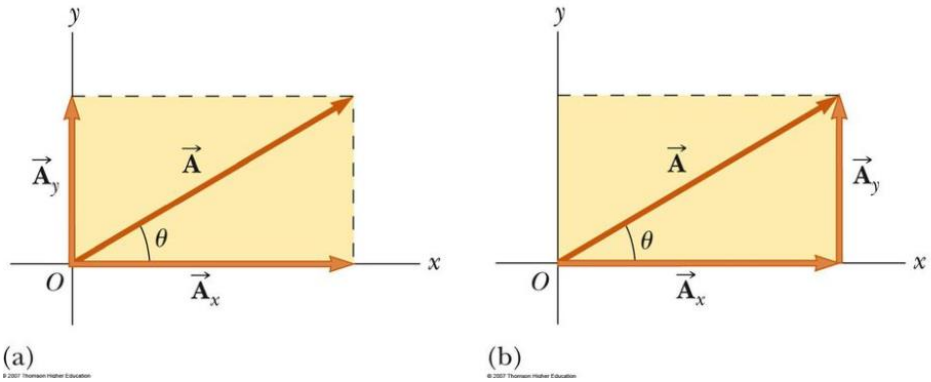


Vector components in terms of the Unit Vector

Vector Components

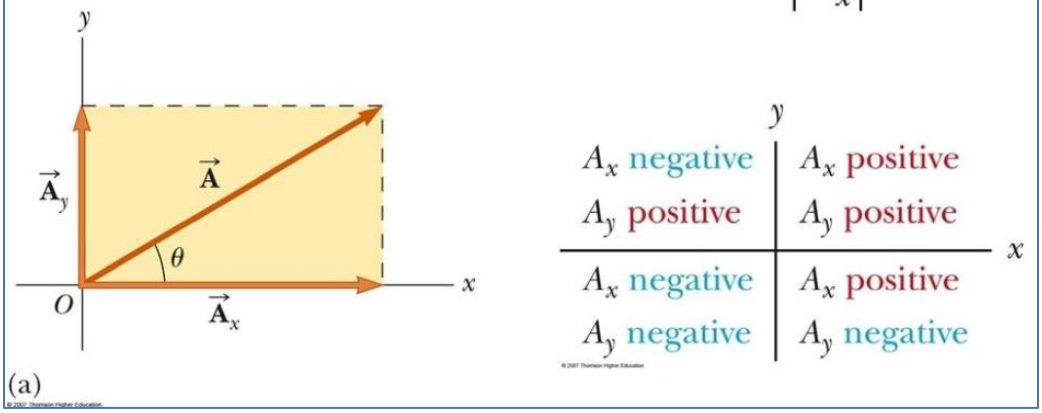
• **Component** of a vector is the projection of the vector on an axis

• To find the projection – drop perpendicular lines to the axis from both ends of the vector – **resolving** the vector



$$|A_x| = |A|\cos\theta \qquad |A_y| = |A|\sin\theta$$

$$|A| = \sqrt{|A_x|^2 + |A_y|^2} \qquad \tan\theta = \frac{|A_y|}{|A_x|}$$



Adding Vectors by Components

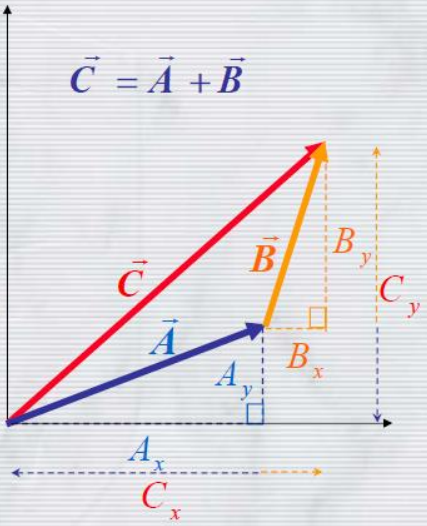
1. The vector in component form:

$$C_x = A_x + B_x$$
$$C_y = A_y + B_y$$

2. The vector in magnitude-angle form:

$$|\vec{C}| = \sqrt{(A_x + B_x)^2 + (A_y + B_y)^2} = \sqrt{C_x^2 + C_y^2}$$

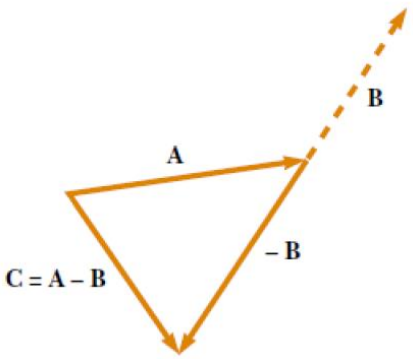
$$\tan\theta = \frac{A_y + B_y}{A_x + B_x} = \frac{C_y}{C_x}$$



Subtracting Vectors by Components

$$\boldsymbol{A} = A_x\boldsymbol{i} + A_y\boldsymbol{j} + A_z\boldsymbol{k}$$
$$\boldsymbol{B} = B_x\boldsymbol{i} + B_y\boldsymbol{j} + B_z\boldsymbol{k}$$

$$\boldsymbol{C} = \boldsymbol{A} - \boldsymbol{B} = \boldsymbol{A} + (-\boldsymbol{B})$$

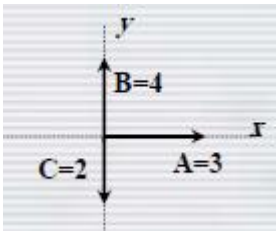


$$\boldsymbol{C} = \boldsymbol{A} - \boldsymbol{B} = \boldsymbol{A} + (-\boldsymbol{B}) = (A_x\boldsymbol{i} + A_y\boldsymbol{j} + A_z\boldsymbol{k}) + (-B_x\boldsymbol{i} - B_y\boldsymbol{j} - B_z\boldsymbol{k})$$

$$\boldsymbol{C} = \boldsymbol{A} - \boldsymbol{B} = (A_x - B_x)\boldsymbol{i} + (A_y - B_y)\boldsymbol{j} + (A_z - B_z)\boldsymbol{k}$$

Examples

Ex.1: Find the magnitude of the vectors shown in the figure:



Solution:

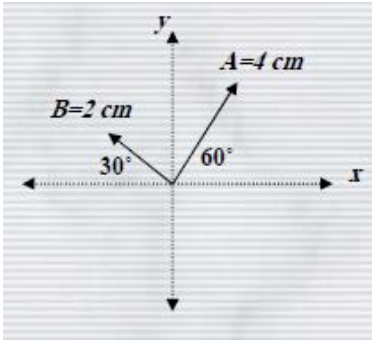
$W_x = A_x + B_x + C_x = 3+0+0= 3$

$W_y = A_y + B_y + C_y = 0+4-2= 2$

$W = (W_x^2 + W_y^2)^{0.5} = (3^2 + 2^2)^{0.5} = 3.6$

Ex.2: Find the direction of the vector **C= A-B** with respect to the +x-axis:

Solution:



Cxi+Cyj = (Axi+Ayj)-(Bxi+Byj)

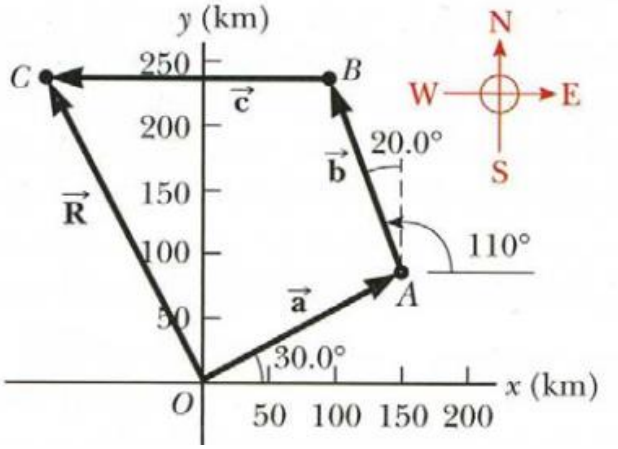
Cx=Ax-Bx = 4cos60-(2cos150) = 3.73

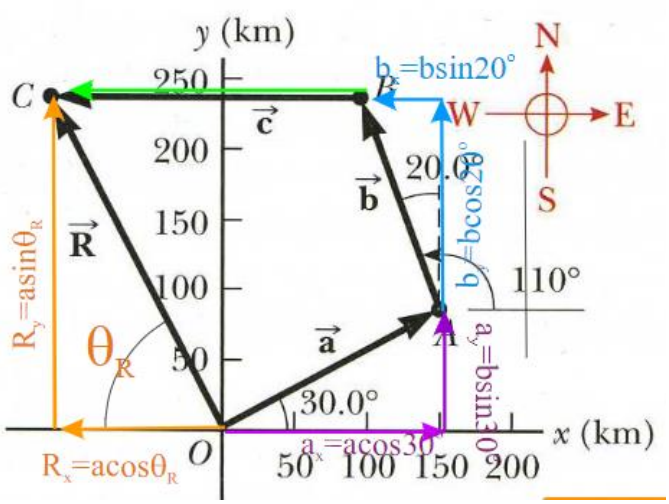
Cy=Ay-By = 4sin60-2sin150=2.46

q=tan-1(Cy/Cx)= 33.4º

Ex.4: A commuter airplane starts from an airport and takes the route shown in Figure below. The plane first flies to city A, located 175 km away in a direction 30.0° north of east. Next, it flies for 150 km 20.0° west of north, to city B. Finally, the plane flies 190 km due west, to city C.
Find the location of city C relative to the location of the starting point.

Solution:





$$R_x = (A+B+C+)_x = A_x + B_x + C_x$$

$$R_y = (A+B+C+)_y = A_y + B_y + C_y$$

The magnitude of the resultant, R, is given by the Pythagorean Theorem as

$$R = \text{sqrt}(R_x^2 + R_y^2)$$

The angle of the resultant vector is

$$\theta_R = \tan^{-1}(R_y/R_x)$$

$a_x = a\cos\theta_x = 175\text{km}\cos30^\circ = 175\text{km}\ 0.866 = 152\ \text{km}$

$a_y = a\sin\theta_y = 175\text{km}\sin30^\circ = 175\text{km}\ 0.500 = 87.5\ \text{km}$

$b_x = b\sin\theta_x = -150\text{km}\sin20^\circ = -150\text{km}\ 0.342 = -51.3\ \text{km}$

$b_y = b\cos\theta_y = 150\text{km}\cos20^\circ = 150\text{km}\ 0.940 = 141\ \text{km}$

$c_x = c\cos\theta_x = 190\text{km}\cos180^\circ = 190\text{km}\ (-1) = -\ 190\ \text{km}$

$c_y = c\sin\theta_y = 190\text{km}\sin180^\circ = 0$

$R_x = a_x + b_x + c_x = 152 - 51.3 - 190\ \text{km} = -89.3.\ \text{km}$

$R_y = a_y + b_y + c_y = 87.5 + 141 + 0 = 229.\ \text{km}.$

$R = \text{sqrt}(R_x^2 + R_y^2) = \text{sqrt}(89.3^2 + 229^2) = \text{sqrt}(7974.5+52441) = \text{sqrt}(60415)\ \ 246\ \text{km}.$

$\theta_R = \tan^{-1}(R_y/R_x) = \tan^{-1}(229\text{km}/-89.3\text{km}) = \tan^{-1}(-2.564)$

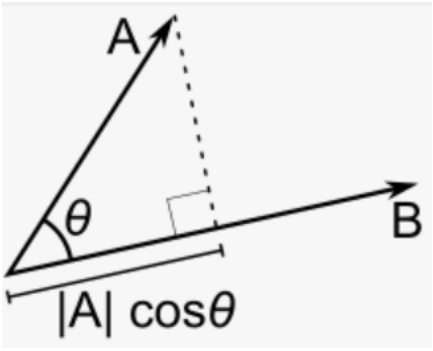
$= -\ 68.7^o$
$= 90 - 68.7$
$=$ **21.3º West of North**

Scalar Product (Dot Product)

The product of the magnitudes of the two vectors and the cosine of the angles between them.

One example of a scalar product is **the work done by a Force (which is a vector) in displacing (a vector) an object is given by the scalar product of Force and Displacement vectors** (**F**.**d**=W).

$\mathbf{A.B} = |A|\,|B|\,cos\,\theta$



General properties of Scalar Product

$\mathbf{A.B} = \mathbf{B.A} = |A|\,|B|\,cos\,\theta$ التبديل

$\boldsymbol{i}.\boldsymbol{i}=\boldsymbol{j}.\boldsymbol{j}=\boldsymbol{k}.\boldsymbol{k}=\mathbf{1}$ (of Unit Vector)

$\boldsymbol{i}.\ \boldsymbol{j}=\boldsymbol{i}.\ \boldsymbol{k}=\boldsymbol{j}.\ \boldsymbol{k}=\mathbf{0}$ (of Unit Vector)

Find the angle between two vectors **A** & **B** using Scalar Product

Let

$$\boldsymbol{A} = a_x\boldsymbol{i} + a_y\boldsymbol{j} + a_z\boldsymbol{k}, \qquad \boldsymbol{B} = b_x\boldsymbol{i} + b_y\boldsymbol{j} + b_z\boldsymbol{k}$$

$$\boldsymbol{A}.\boldsymbol{B} = a_x b_x + a_y b_y + a_z b_z$$

$$B = \sqrt{b_x^2 + b_y^2 + b_z^2} \quad , \quad A = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Then use the formula of scalar product

$$\boldsymbol{A}.\boldsymbol{B} = AB\cos\varphi$$

$$\varphi = \cos^{-1}\frac{\boldsymbol{A}.\boldsymbol{B}}{AB} = \frac{\left(a_x b_x + a_y b_y + a_z b_z\right)}{\sqrt{a_x^2 + a_y^2 + a_z^2}\ \sqrt{b_x^2 + b_y^2 + b_z^2}}$$

Ex. Find the angle between two vectors A & B
$\boldsymbol{A}=2\boldsymbol{i}+3\boldsymbol{j}-\boldsymbol{k}$, $\boldsymbol{B}=3\boldsymbol{i}+4\boldsymbol{j}-5\boldsymbol{k}$

Solution

$$\boldsymbol{A}.\boldsymbol{B} = 2\times 3 + 3\times 4 - 1\times(-5) = 23$$

$A = \sqrt{2^2 + 3^2 + 1^2} = \sqrt{14} = 3.74$ The magnitude of Vector **A**

$B = \sqrt{3^2 + 4^2 + 5^2} = \sqrt{50} = 7.07$ The magnitude of Vector **B**

$$\cos\varphi = \frac{\boldsymbol{A}.\boldsymbol{B}}{AB} = \frac{23}{3.74 \times 7.07} = \frac{23}{26.44} = 0.8699$$

$$\varphi = \cos^{-1} 0.8699 = 29.56^{\circ}$$

Vector Product or (Cross Product)

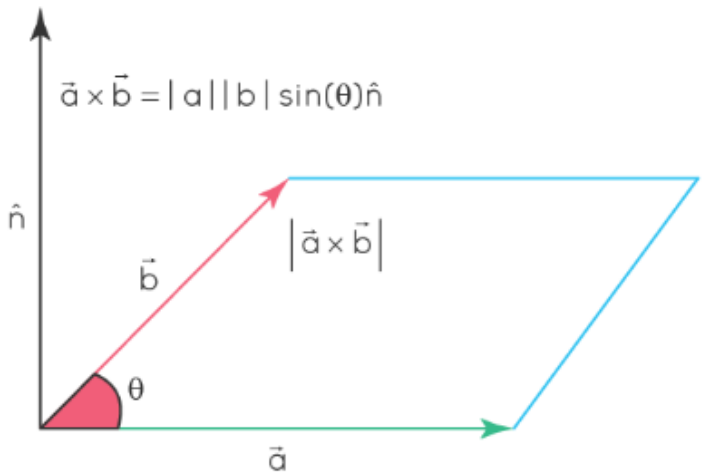
The cross product of two vectors is the third vector that is perpendicular to the two original vectors.
Its magnitude is given by the area of the parallelogram between them and its direction can be determined by the right-hand thumb rule.

The vector product or the cross product of two vectors is shown as:

$$\vec{a} \times \vec{b} = \vec{c}$$

Where

- $\vec{a}$ and $\vec{b}$ are two vectors.
- $\vec{c}$ is the resultant vector.



Where

- $|\vec{a}|$ is the magnitude of the vector a or the length of $\vec{a}$,
- $|\vec{b}|$ is the magnitude of the vector b or the length of $\vec{b}$.

اعادة شرح الموضوع (الضرب الاتجاهي) برموز جديدة شائعة ايضا

The Vector product of two vectors, **A** and **B**, is denoted by **A** × **B**.
Its resultant vector is perpendicular to **A** and **B**.

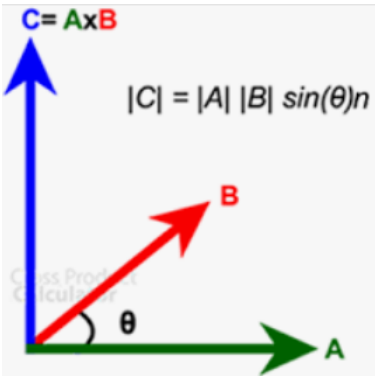
The Cross product of two vectors is also known as a vector product as the resultant of the cross product of vectors is a vector quantity.

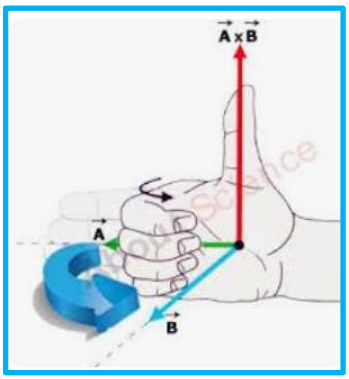
C = **A**×**B** (C is the resulting vector)

The magnitude of this vector is:

$C = |\mathbf{C}| = |\mathbf{A}\times\mathbf{B}| = |A|\,|B|\,\sin\theta$

A×**B** = −(**B**×**A**)





A × **A** = 0
B × **B** = 0

The Cross Product of Unit Vector are

$$i \times j = k \quad , \quad j \times k = i \quad , \quad k \times i = j$$

$$\boldsymbol{j \times i = -k} \quad , \quad \boldsymbol{k \times j = -i} \quad , \quad \boldsymbol{i \times k = -j}$$

$$\boldsymbol{i \times i = j \times j = k \times k = 0}$$

Express the Cross Product of two arbitrary Vectors (**A** & **B**) in terms of their components:

$$\boldsymbol{A} = a_x\boldsymbol{i} + a_y\boldsymbol{j} + a_z\boldsymbol{k} \qquad , \qquad \boldsymbol{B} = b_x\boldsymbol{i} + b_y\boldsymbol{j} + b_z\boldsymbol{k}$$

$$\boldsymbol{A \times B} = \left(a_x\boldsymbol{i} + a_y\boldsymbol{j} + a_z\boldsymbol{k}\right) \times \left(b_x\boldsymbol{i} + b_y\boldsymbol{j} + b_z\boldsymbol{k}\right)$$

$$\boldsymbol{A \times B} = a_xb_y(\boldsymbol{i \times j}) + a_xb_z(\boldsymbol{i \times k}) + a_yb_x(\boldsymbol{j \times i}) + a_yb_z(\boldsymbol{j \times k}) + a_zb_x(\boldsymbol{k \times i}) + a_zb_y(\boldsymbol{k \times j})$$

$$\therefore \boldsymbol{A \times B} = a_xb_y(\boldsymbol{k}) + a_xb_z(-\boldsymbol{j}) + a_yb_x(-\boldsymbol{k}) + a_yb_z(\boldsymbol{i}) + a_zb_x(\boldsymbol{j}) + a_zb_y(-\boldsymbol{i})$$

$$\boldsymbol{A \times B} = \left(a_yb_z - a_zb_y\right)\boldsymbol{i} + (a_zb_x - a_xb_z)\boldsymbol{j} + (a_xb_y - a_yb_x)\boldsymbol{k}$$

$$\boldsymbol{A \times B} = \left(a_yb_z - a_zb_y\right)\boldsymbol{i} - (a_xb_z - a_zb_x)\boldsymbol{j} + (a_xb_y - a_yb_x)\boldsymbol{k}$$

This result can be compactly written as a determinate as below

$$\boldsymbol{A \times B} = \begin{vmatrix} \boldsymbol{i} & \boldsymbol{j} & \boldsymbol{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$\boldsymbol{A} \times \boldsymbol{B} = (a_y b_z - a_z b_y)\boldsymbol{i} - (a_x b_z - a_z b_x)\boldsymbol{j} + (a_x b_y - a_y b_x)\boldsymbol{k}$$

Magnitude of a Vector Formula

$$|A| = \sqrt{x_1^2 + y_1^2 + z_1^2}$$

$$|\vec{v}| = \sqrt{x^2 + y^2}$$

$$|\vec{v}| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Magnitude of a Vector Formula

- For a vector **A** = x_1 **i** + y_1 **j** + z_1 **k**, its magnitude is: $|A| = \sqrt{(x_1^2 + y_1^2 + z_1^2)}$
- For a vector **v** when one of its endpoints is at origin (0,0) and the other end point is at (x, y), its magnitude is: $|\mathbf{v}| = \sqrt{(x^2 + y^2)}$
- For a vector **v** with endpoints at (x_1, y_1) and (x_2, y_2), its magnitude is: $|\mathbf{v}| = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$

Cross Product Example

Example:

Find the cross product of the given two vectors:

$\vec{X} = 5\vec{i} + 6\vec{j} + 2\vec{k}\ and\ \vec{Y} = \vec{i} + \vec{j} + \vec{k}$

Solution:

Given:

$\vec{X} = 5\vec{i} + 6\vec{j} + 2\vec{k}$

$\vec{Y} = \vec{i} + \vec{j} + \vec{k}$

To find the cross product of two vectors, we have to write the given vectors in determinant form. Using the determinant form, we can find the cross product of two vectors as:

$$\vec{X} \times \vec{Y} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 5 & 6 & 2 \\ 1 & 1 & 1 \end{vmatrix}$$

By expanding,

$\vec{X} \times \vec{Y} = (6-2)\vec{i} - (5-2)\vec{j} + (5-6)\vec{k}$

Therefore,

$\vec{X} \times \vec{Y} = 4\vec{i} - 3\vec{j} - \vec{k}$

Example 3: If $\vec{a}$ = (2, -4, 4) and $\vec{b}$ = (4, 0,3), find the angle between them.

Solution

$\vec{a} = 2i - 4j + 4k$

$\vec{b} = 4i + 0j + 3k$

The magnitude of $\vec{a}$ is

$|a| = \sqrt{(2^2+4^2+4^2)} = \sqrt{36} = 6$

The magnitude of $\vec{b}$ is

$|b| = \sqrt{(4^2+0^2+3^2)} = \sqrt{25} = 5$

As per the cross product formula, we have

$$\vec{a} \times \vec{b} = \begin{matrix} \hat{i} & \hat{j} & \hat{k} \\ 2 & -4 & 4 \\ 4 & 0 & 3 \end{matrix}$$

$$= [(-4 \times 3) - (4 \times 0)]\hat{i}$$
$$-[(3 \times 2) - (4 \times 4)]\hat{j}$$
$$+[(2 \times 0) - (-4 \times 4)]\hat{k}$$
$$= -12\hat{i} + 10\hat{j} + 16\hat{k}$$

$\vec{a} \times \vec{b} = (-12, 10, 16)$

The length of the $\vec{c}$ is

$|c| = \sqrt{(-(12)^2+10^2+16^2)}$

$= \sqrt{(144+100+256)}$

$= \sqrt{500}$

$= 10\sqrt{5}$

$$\vec{a} \times \vec{b} = |a||b| \sin\theta$$

$$\sin\theta = \frac{\vec{a} \times \vec{b}}{|a||b|}$$

$\sin\theta = 10\sqrt{5}/(5\times6)$

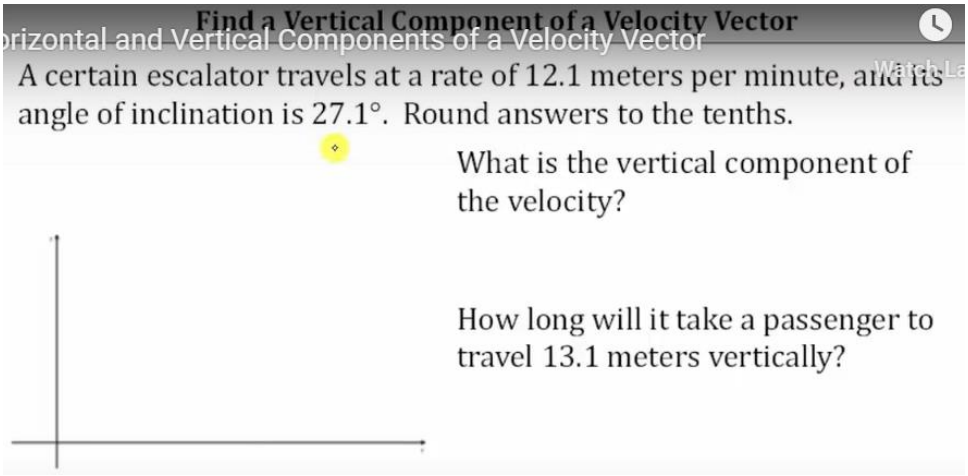
$\sin\theta = \sqrt{5}/3$

$\theta = \sin^{-1}(\sqrt{5}/3)$

$\theta = \sin^{-1}(0.74)$

$\theta = 48°$

Answer: The angle between the vectors is 48°.



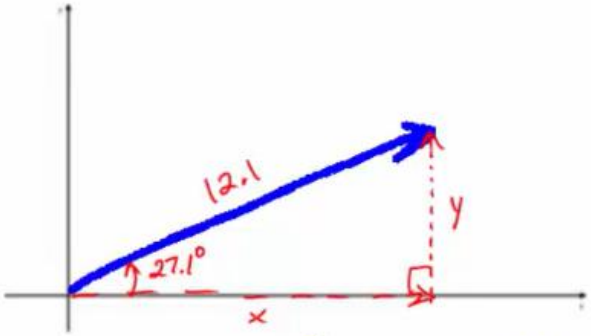
Find a Vertical Component of a Velocity Vector

A certain escalator travels at a rate of 12.1 meters per minute, and its angle of inclination is 27.1°. Round answers to the tenths.

$\vec{v} = \langle 10.8, 5.5 \rangle$

What is the vertical component of the velocity?

5.5 meters per minute



How long will it take a passenger to travel 13.1 meters vertically?

2.4 minutes

$\cos(27.1°) = \frac{x}{12.1} \rightarrow x = 12.1\cos(27.1°) \approx 10.8$

$\sin(27.1°) = \frac{y}{12.1} \rightarrow y = 12.1\sin(27.1°) \approx 5.5$

$d = r \cdot t$

$\frac{13.1}{5.5} = \frac{5.5t}{5.5}$

$2.4 \approx t$

If a vector $\vec{v}$ with a magnitude of $\|\vec{v}\|$ makes an angle θ with the positive x-axis, then

$$\vec{v} = \langle \|\vec{v}\|\cos\theta, \|\vec{v}\|\sin\theta \rangle = \|\vec{v}\|\langle \cos\theta, \sin\theta \rangle$$

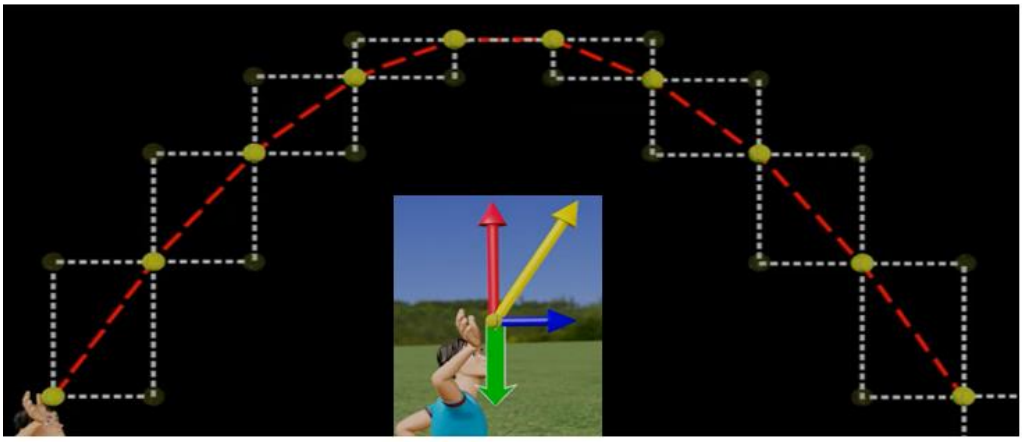
The Motion of Projectiles

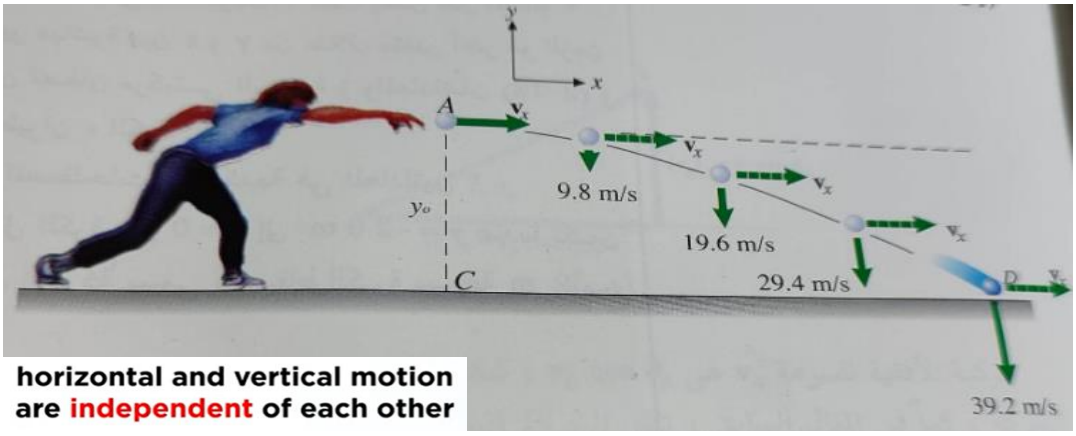
Thrown body = **Projectile**
Thrown body path = **Trajectory**.

Independence of Motion

The horizontal and vertical components of two-dimensional motion are independent of each other. Any motion in the horizontal direction does not affect motion in the vertical direction, and vice versa.

المقذوفة تتحرك حركتين متعامدتين مستقلتين احداهما عن الاخرى.





$v_t = v_i + at$ x-direction $v_t = v_i + at$ y-direction

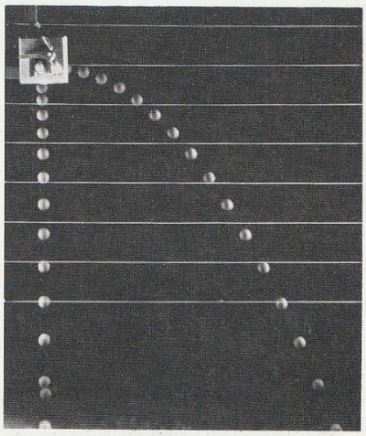
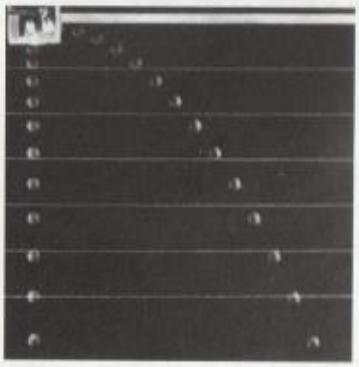
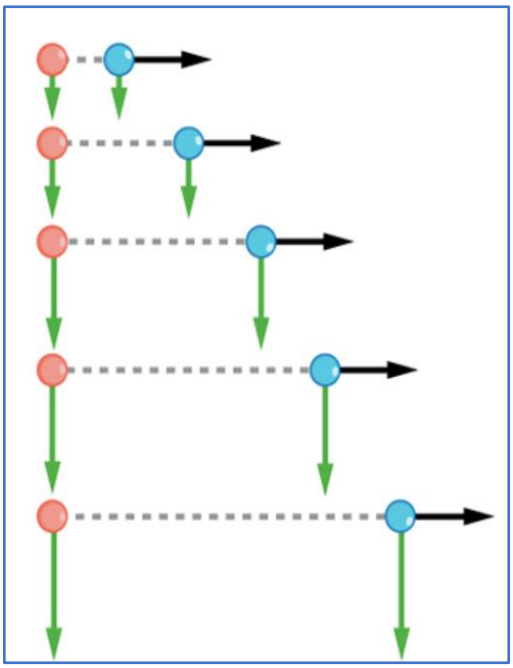


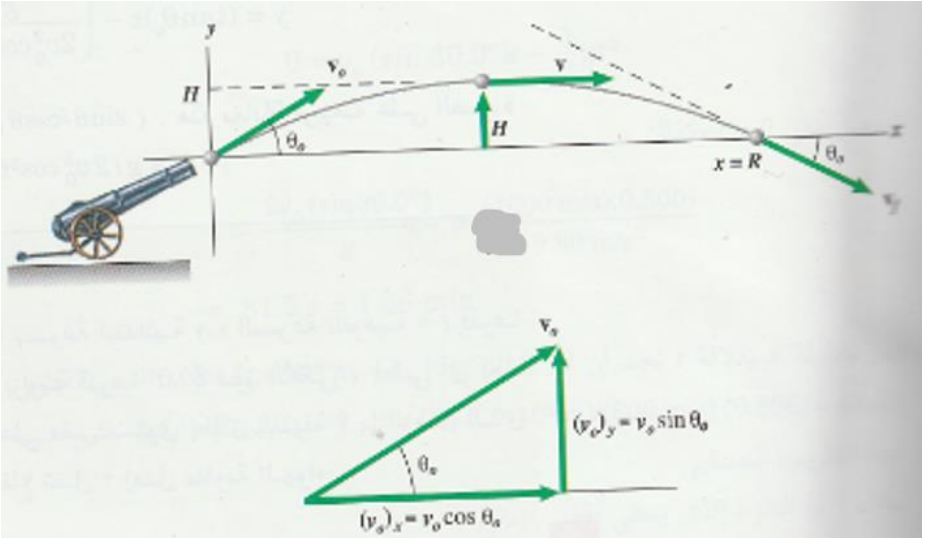
Fig. 4.5 Stroboscopic photograph of two balls that have been released simultaneously from a platform; one ball has horizontal velocity, the other does not.



شكل 2-10 :
صورة وميضية لحركة كرتى جولف إحداهما ساقطة من السكون والأخرى منطلقة أفقيا . الفترة الزمنية بين الومضات (1/30 s) والخطوط الأفقية تبعد عن بعضها البعض مسافة قدرها 15 cm . (مركز تطوير التعليم) .



y-direction velocities and **time in the air** are identical



- **Time spends in the air <u>ONLY</u> depends on Vertical Motion**
- **Distance to travel horizontally depends on (Horizontal Velocity (Motion) & the Time spends in the air)**
- **Horizontal Velocity will be <u>CONSTANT</u> at every moment in this trajectory**
- **Vertical Velocities will be the <u>Greatest</u> at the instant (initial moment) the object (projectile) is thrown, and <u>Decrease until reaches Zero at maximum height</u>, and become <u>Increasingly in Negative until hits the ground</u>** (because of constant acceleration in a negative direction due to gravity>

Equations for Projectile Motions

(Ignore the air friction)

$a_x = 0$ m^2/s
$a_y = 0$ m^2/s
$a_z = -g = -9.81$ m^2/s

Note that a_z is negative because the z axis points upward and the acceleration of gravity is downward

$$v_x = v_{0x}$$

$$v_y = 0$$

$$v_z = v_{0z} - gt$$

$$x = v_{0x}t$$

$$y = 0$$

$$z = v_{0z}t - \frac{1}{2}gt^2$$

EXAMPLE 1. A gun aimed southward fires a heavy projectile with a muzzle velocity of 90.0 m/s at an angle of 34° with the horizontal. What are the components of the instantaneous velocity of the projectile in the reference frame of the ground? The x, y, and z axes point south, east, and up, respectively.

SOLUTION: According to Figure 4.3, the velocity vector is in the x–z plane; it makes an angle of 34° with the x axis, an angle of 56° with the z axis, and an angle of 90° with the y axis. Hence

$$v_x = v \cos 34° = 90.0 \text{ m/s} \times \cos 34° = 74.6 \text{ m/s}$$

$$v_y = v \cos 90° = 0 \text{ m/s}$$

$$v_z = v \cos 56° = 90.0 \text{ m/s} \times \cos 56° = 50.3 \text{ m/s}$$

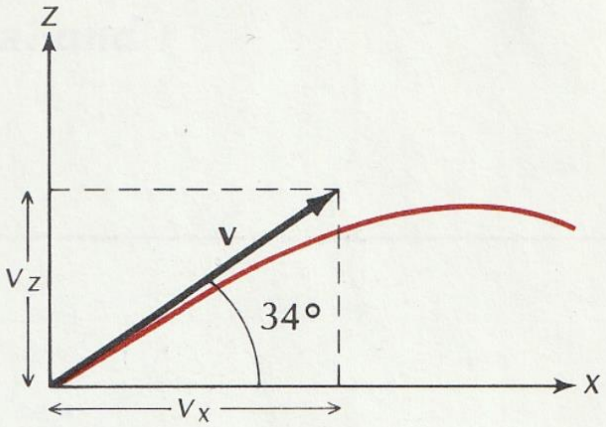


Fig. 4.3 Velocity vector of a projectile.

EXAMPLE 3. Consider the projectile fired from the gun described in Example 1. What is the maximum height reached by the projectile? What is the horizontal distance at this instant?

SOLUTION: The relevant equations are Eqs. (24)–(29). The known quantities are the components of the initial velocity; according to Example 1, these components are $v_{0x} = 74.6$ m/s and $v_{0z} = 50.3$ m/s. Furthermore, we know that the projectile reaches maximum height when $v_z = 0$. In terms of these values of v_{0z} and v_z, Eq. (26) determines the time of maximum height,

$$0 = -gt + 50.3 \text{ m/s}$$

or

$$t = \frac{50.3 \text{ m/s}}{g} = \frac{50.3 \text{ m/s}}{9.81 \text{ m/s}^2} = 5.13 \text{ s}$$

With this value of the time, we can calculate the maximum height,

$$z = v_{0z}t - \tfrac{1}{2}gt^2$$

$$= 50.3 \text{ m/s} \times 5.13 \text{ s} - \tfrac{1}{2} \times 9.81 \text{ m/s}^2 \times (5.13 \text{ s})^2$$

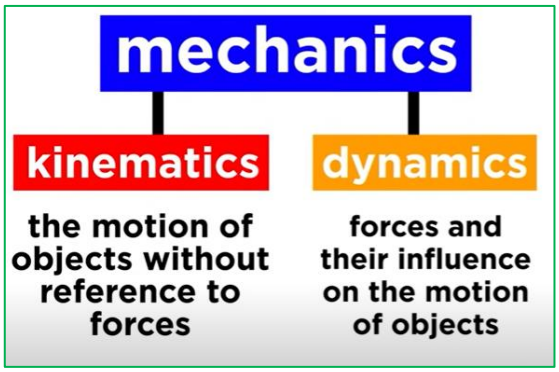
$$= 129 \text{ m}$$

and the horizontal distance,

$$x = v_{0x}t = 74.6 \text{ m/s} \times 5.13 \text{ s} = 383 \text{ m}$$

In our calculation we have ignored the effects of air resistance. For a heavy projectile with such a fairly low velocity, this is a good approximation.

Force



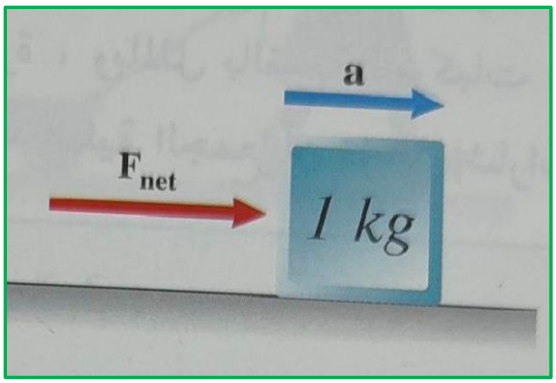
Force …. any interaction that if unopposed will alter the motion of an object

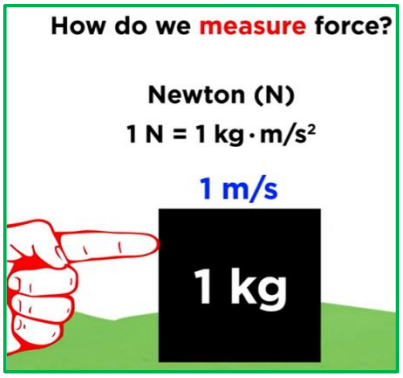
Force …. Must have Magnitude and Direction

A force can cause an object with a mass to start moving, stop moving, moving faster, slower in a different direction.

Object can exert a force by falling or rolling.

Gravity force between planets and stars, ets.





The four fundamental forces of nature are:

1. **The strong nuclear force**
2. **The weak force**
3. **Electromagnetic force**
4. **Gravity**

contact forces

arise when objects touch or collide



noncontact forces

motion induced by action at a distance

also called "field forces"



Newton's First Law of Motion (or Law of Inertia)

"A body at rest remains at rest and a body in motion continues to move at constant velocity unless acted upon by an external force."

This require constant force.
Constant force must be applied to maintain motion against friction (and against gravity)



The ice has very little friction, let's pretend the ice has zero friction



there is no friction in space,

the rocket is moving with roughly constant velocity and never stop moving

- **Inertia is the capacity of an object to resist changes in motion**
- **Force is required to initiate or terminate motion.**
- **In absence of force constant velocity is maintained** (Only motion with constant velocity including zero velocity, requires no application of force).

inertia

proportional to the mass of the object





more mass

= more inertia

= more resistance to motion

more mass = more Force is required to start or stop moving





mass is a measurement of an object's inertia

whether at rest or in motion

Newton's First Law = Law of Inertia

In absence of a net force an object will preserve its state of motion, whether at rest or moving with constant velocity.

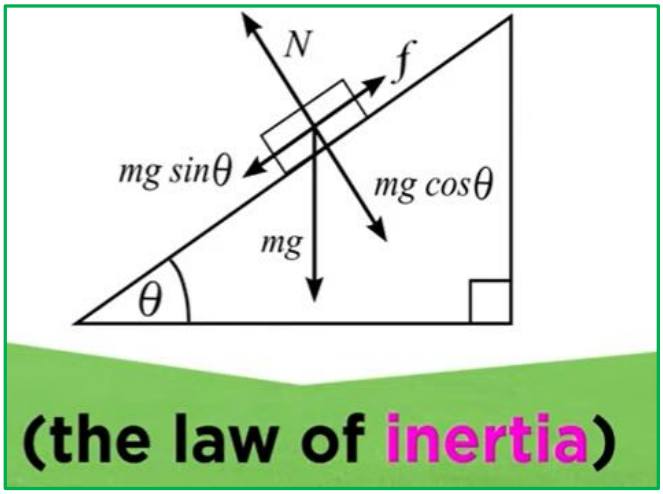
Sum of vectors that representing these forces is called the net force.

If the net force is Not zero, there will some acceleration.

If the net force is zero, there will be No acceleration.

Newton's First Law of Motion

an object will preserve its state of motion unless acted upon by some external net force



Newton's Second Law of Motion:

A force acting on a body gives it an **acceleration** which is in the **direction of the force** and has a magnitude **inversely proportional to the mass** of the body.

Newton's First Law of Motion

an object will preserve its state of motion unless acted upon by some external net force

what if there is indeed a net force present?

F_{net}

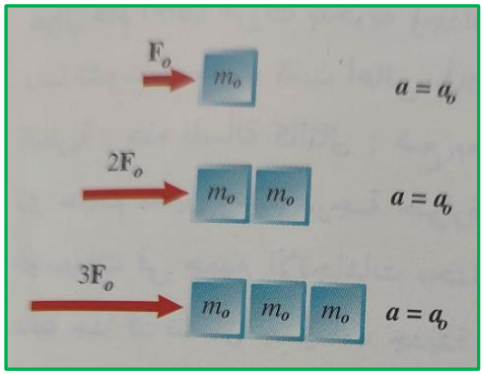
Newton's Second Law of Motion

force = mass x acceleration

$$F = ma$$

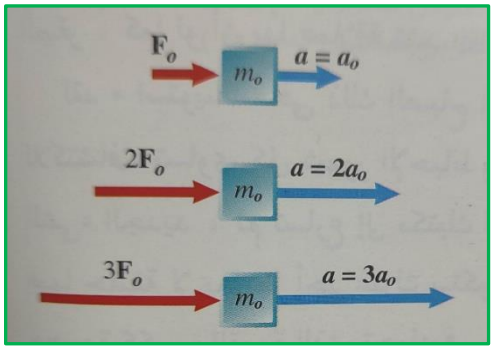
$1\ N = 1\ kg \cdot m/s^2$

the Newton is the SI unit of force



Force is directly proportional to the mass at constant acceleration

$$F \sim m$$



Force directly proportional to the acceleration at constant mass

$$F \sim a$$

$$F = ma$$

Paraphrase of Newton's Second Law

Newton's Second Law of Motion

the acceleration an object experiences is directly proportional to the applied force and inversely proportional to its mass

$$a \propto F$$

$$a \propto \frac{1}{m}$$

F = ma



heavier objects require more force to accelerate



lighter objects require less force to accelerate

a = F/m



$$1\ m/s^2 = \frac{0.00001\ N}{0.00001\ kg}$$



$$1\ m/s^2 = \frac{0.05\ N}{0.05\ kg}$$



$$1\ m/s^2 = \frac{25\ N}{25\ kg}$$

Example

You wish to push a cart across a frictionless surface, so you apply a 20.0 N force for a period of 3.0 seconds. As a result, the cart goes from rest to a velocity of 2.3 m/s. What is the mass of the cart?

$a = (2.3\ m/s)/(3.0\ s) = 0.77\ m/s^2$

$F = ma$

$20.0\ N = m\ (0.77\ m/s^2)$

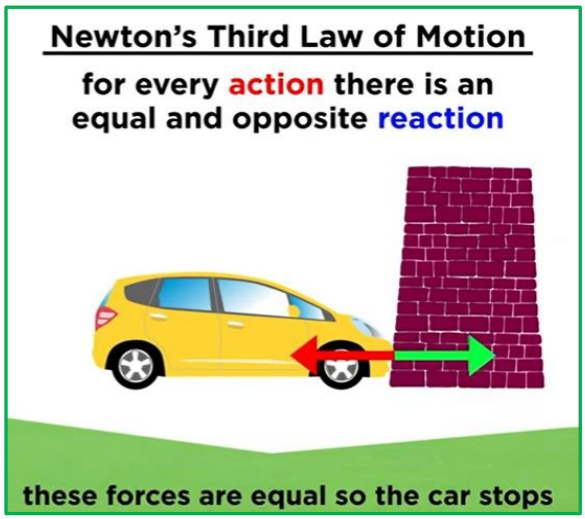
$m = 26\ kg$

Professor Mac Explains Newton's Second Law of Motion

https://www.youtube.com/watch?v=-KxbIIw8hlc

Newton's Third Law of Motion: Action and Reaction

Whenever a **body** **exerts a force on** **another body**, **the latter** **exerts a force of equal magnitude and opposite direction** **on the former**.



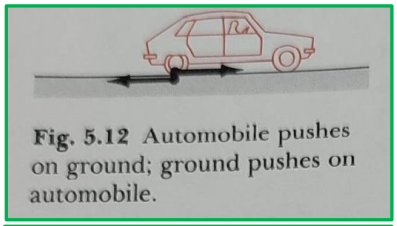


Fig. 5.12 Automobile pushes on ground; ground pushes on automobile.

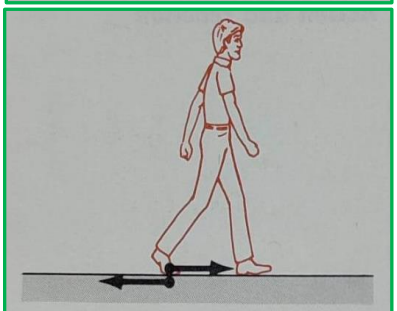


Fig. 5.13 Man pushes on ground; ground pushes on man.



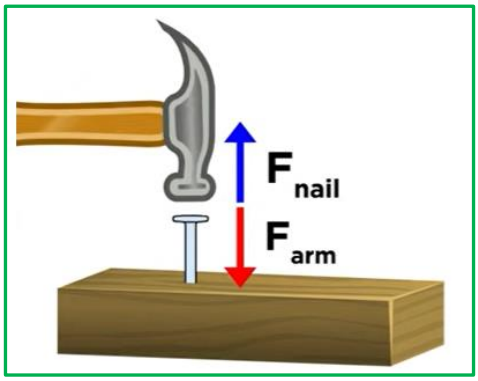
Fig. 5.14 Earth pulls on apple; apple pulls on Earth.

there can never be a single **isolated force**

forces always come in pairs

How can anything move at all?

only the forces acting on an object contribute to the motion of that object



when looking at the hammer we only consider forces acting on the hammer

when looking at the nail we only consider forces acting on the nail

the rock accelerates towards the earth



the earth accelerates towards the rock

(the earth and the rock impart **equal force** upon each other)

we did Not notice this in everyday experience

$$F = ma$$

so

$$a = F/m$$

the force is the same but the **acceleration is not**

$$F = ma$$

so

$$a = F/m$$

10 kg means a large acceleration



$$F = ma$$

so

$$a = F/m$$

6×10^{24} kg means the earth's acceleration is negligible



Mass vs. Weight and the Normal Force

mass
scalar

mass
the amount of matter an object contains

weight
vector

weight
the force exerted on an object by virtue of its position in a gravitational field

gravity pulls objects to earth

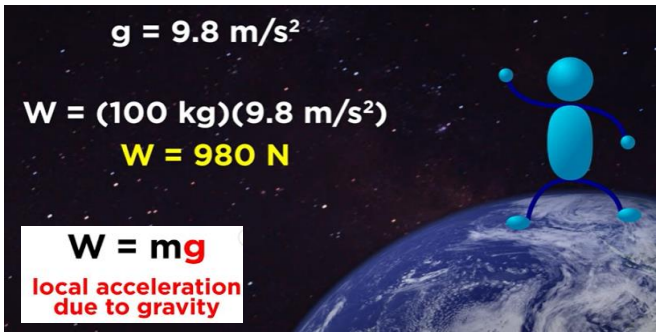
mass ∝ weight

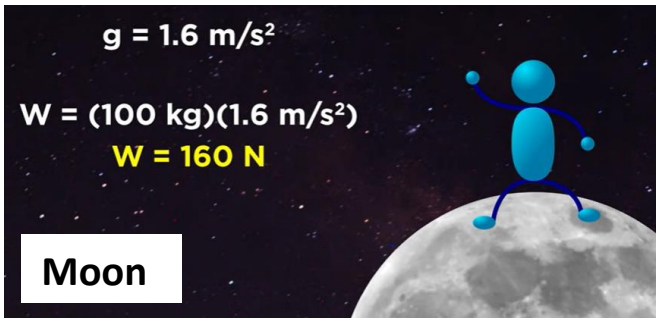
objects with more mass will weigh more

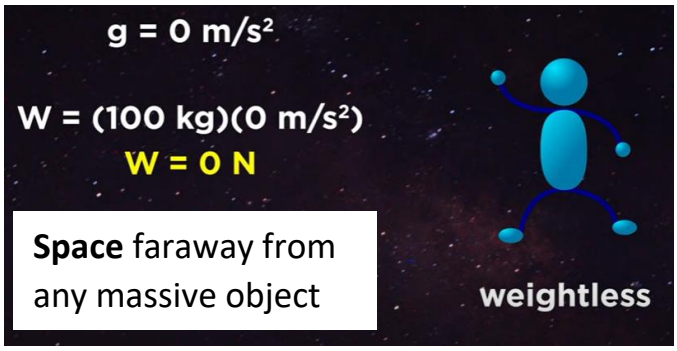


m = 100 kg









W = mg

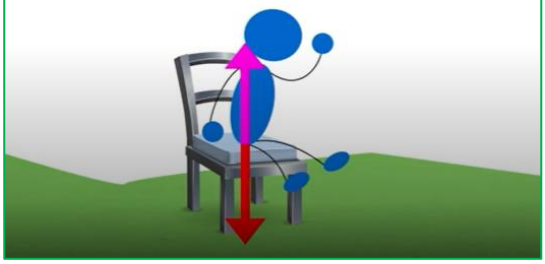
What is the reactionary force for weight?

on a surface parallel to the ground

the normal force

directly opposes

weight



more mass means more weight and a stronger normal force

since these forces are equal in magnitude you remain still

An object on Earth ($g = 9.8\ m/s^2$) has a weight of 62 N.

1) What is the mass of the object on Earth?

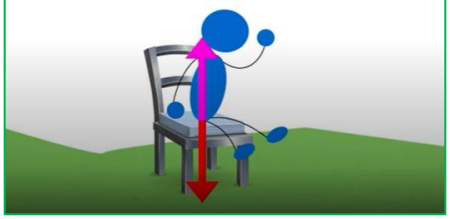
2) What is the mass of the object on Mars?

3) What is the weight of the object on Mars? ($g = 3.7\ m/s^2$)

Applying Newton's Laws

Normal Force

on a surface parallel to the ground
the normal force
directly opposes
weight

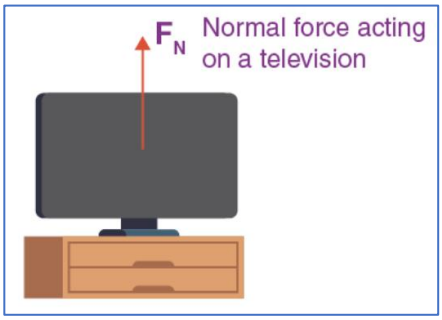


more mass means
more weight and a
stronger normal force

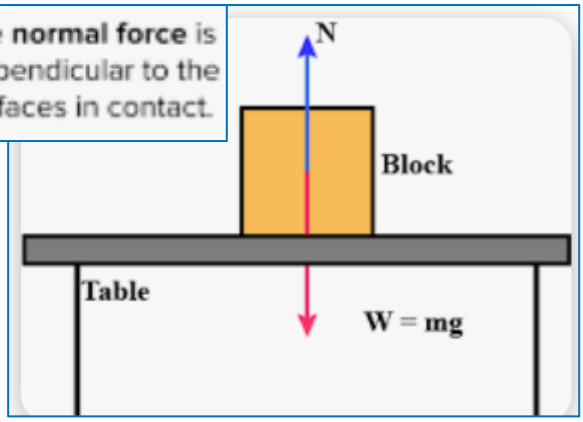
since these forces are
equal in magnitude
you remain still

W = mg

What is the reactionary force for weight?



The **normal force** is perpendicular to the surfaces in contact.



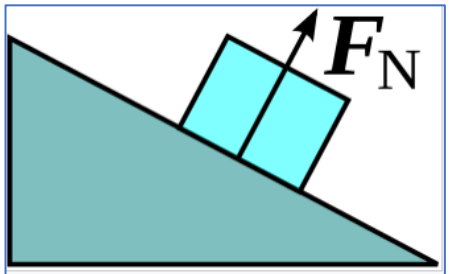
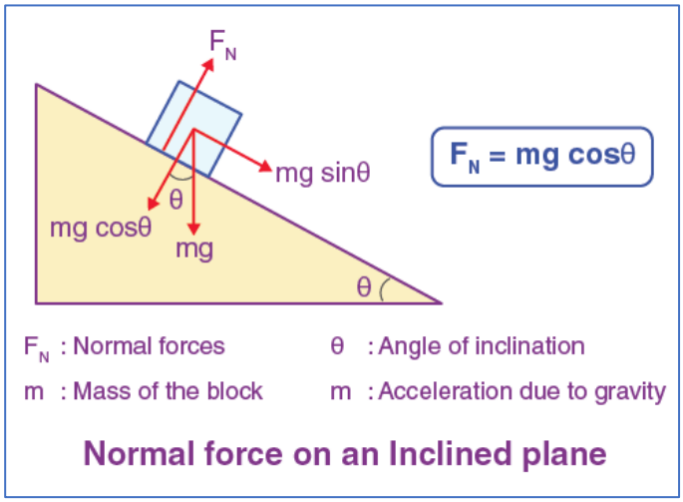


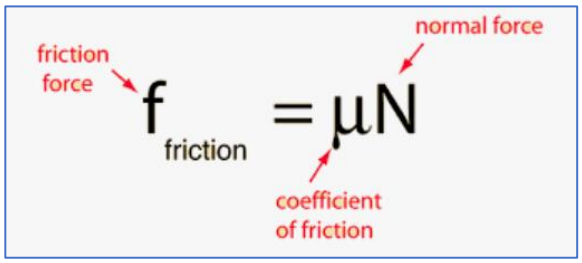
Figure 1: F_N represents the **normal force**



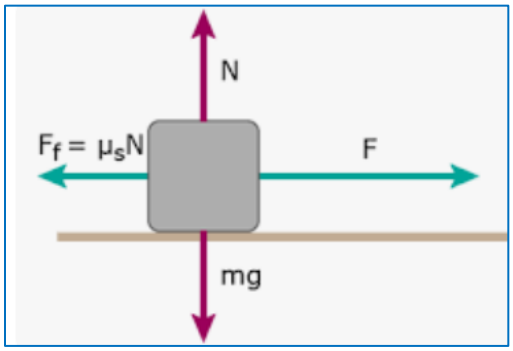
Normal force on an Inclined plane

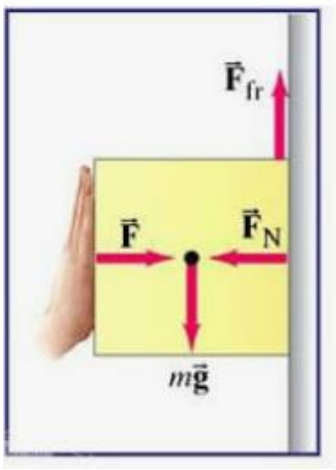
Friction Force

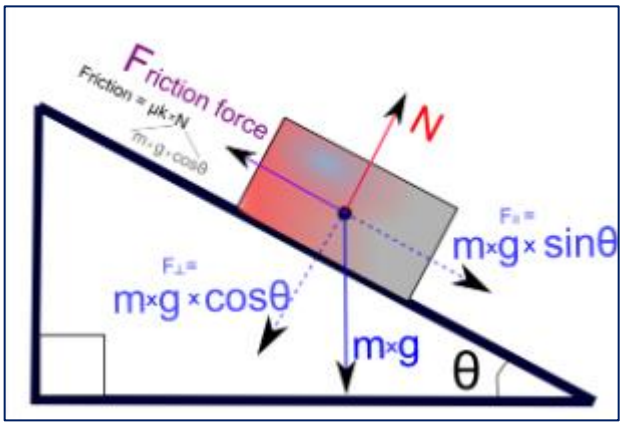
Friction magnitude is directly proportional to the normal force magnitude and the roughness between the sliding surfaces. The coefficient of friction is the ratio of the magnitude of frictional force divided by the normal force magnitude.



N is the Normal force (Also, it is denoted by $\mathbf{F_N}$, or $\mathbf{F_n}$)







Friction Force

The magnitude of the frictional force has two forms: one for static situations (static friction), the other for situations involving motion (kinetic friction). What follows is an approximate empirical (experimentally determined) model only. These equations for static and kinetic friction are not vector equations.

MAGNITUDE OF STATIC FRICTION

The magnitude of static friction f_s is

$$f_s \leq \mu_s N,$$

6.1

where μ_s is the coefficient of static friction and N is the magnitude of the normal force.

The symbol $\leq$ means *less than or equal to*, implying that static friction can have a maximum value of $\mu_s N$. Static friction is a responsive force that increases to be equal and opposite to whatever force is exerted, up to its maximum limit. Once the applied force exceeds

$f_s(\max)$, the object moves. Thus,

$$f_s(\max) = \mu_s N.$$

MAGNITUDE OF KINETIC FRICTION

The magnitude of kinetic friction f_k is given by

$$f_k = \mu_k N,$$

6.2

where μ_k is the coefficient of kinetic friction.

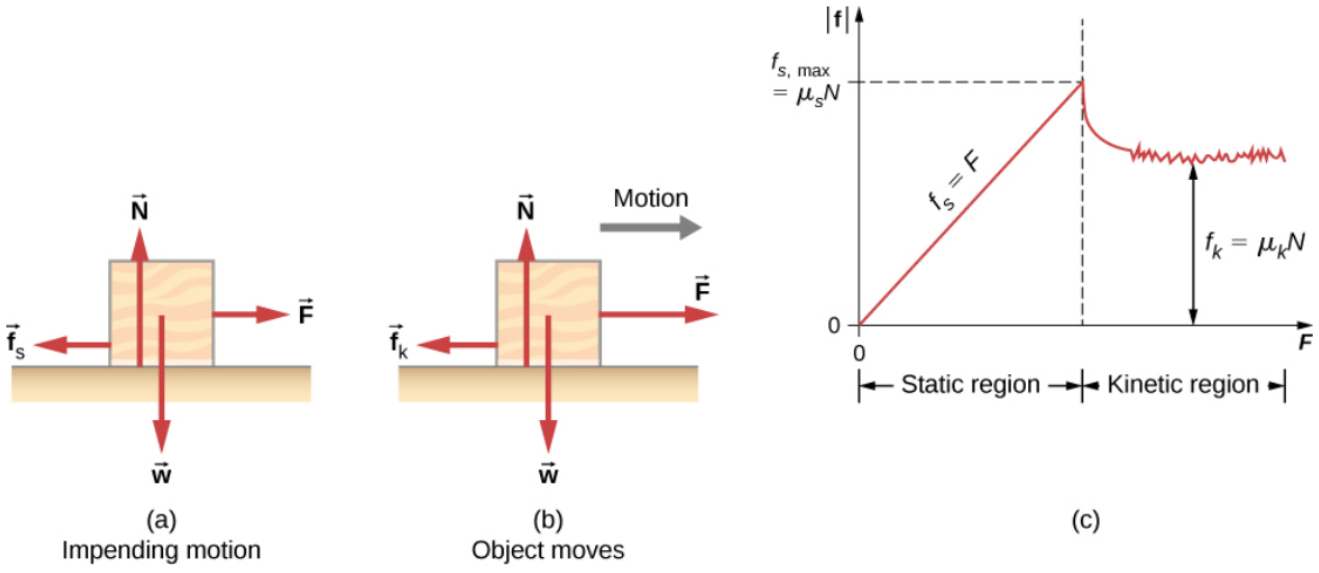


Figure 6.11 (a) The force of friction $\vec{\mathbf{f}}$ between the block and the rough surface opposes the direction of the applied force $\vec{\mathbf{F}}$. The magnitude of the static friction balances that of the applied force. This is shown in the left side of the graph in (c). (b) At some point, the magnitude of the applied force is greater than the force of kinetic friction, and the block moves to the right. This is shown in the right side of the graph. (c) The graph of the frictional force versus the applied force; note that $f_s(\max) > f_k$. This means that $\mu_s > \mu_k$.

System	Static Friction μ_s	Kinetic Friction μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.5-0.7	0.3-0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.4	0.02

Table 6.1 Approximate Coefficients of Static and Kinetic Friction

Summary

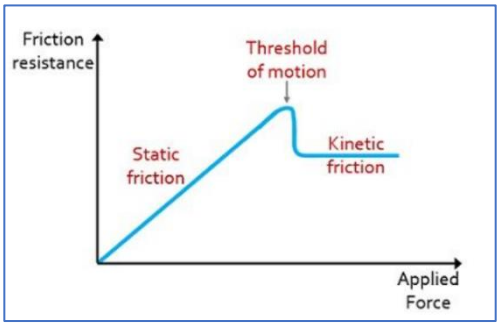
$f_s \le \mu_s F_n$ $f_{s\,max} = \mu_s F_n$ $f_k = \mu_k F_n$ Typically, $\mu_s > \mu_k$

μ_k is the coefficient of kinetic friction

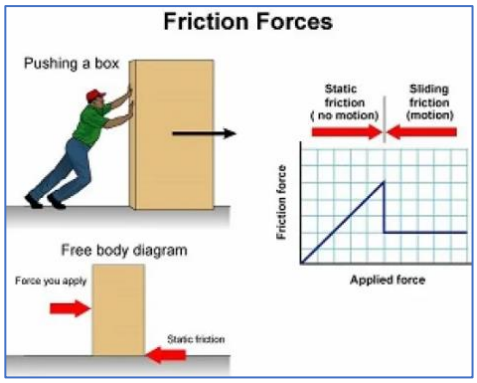
μ_s is the coefficient of static friction

F_n is the Normal force (Also, it is denoted by F_N, or N)

f is the friction force



Basis for Comparison	Static Friction	Kinetic Friction
Basic	It is associated with body at rest.	It is associated with motion of object.
Magnitude	More	Comparatively less
Denoted as	F_s	F_k
Expression	$\mu_s F_N$	$\mu_k F_N$
Magnitude of force	Dependent	Independent
Nature	It is opposition to the beginning of motion.	It is the opposition relative to motion of the body.
Value	Can be zero.	Can never be zero.
Behaviour	Shows linear increase up to a maximum value.	Shows invariable nature and remains constant.
When it acts	In the absence of relative motion.	In the presence of relative motion.
Example	Pen placed on the table.	Moving a pen over a table top.



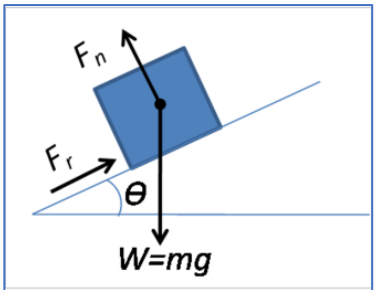


Figure 2: Weight (W), the frictional force (F_r), and the normal force (F_n) acting on a block. Weight is the product of mass (m) and the acceleration of gravity (g).

A hardcover book is resting on a tabletop with its front cover facing upward. You place a coin on the cover and very slowly open the book until the coin starts to slide. The angle θ_{max} is the angle of the cover just before the coin begins to slide. Find the coefficient of static friction μs between the coin and book.

Find the coefficient of static friction μ_s between the coin and book.

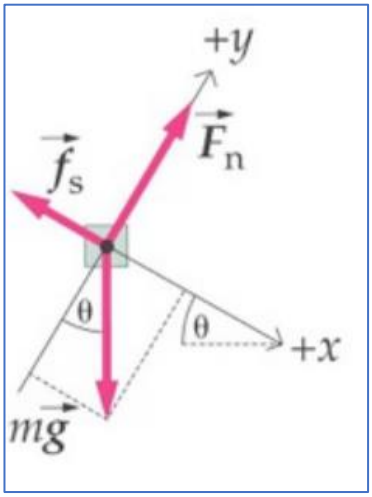


$$\sum F_y = ma_y \quad \Rightarrow \quad F_n - mg\cos\theta = 0 \quad \text{or} \quad F_n = mg\cos\theta$$

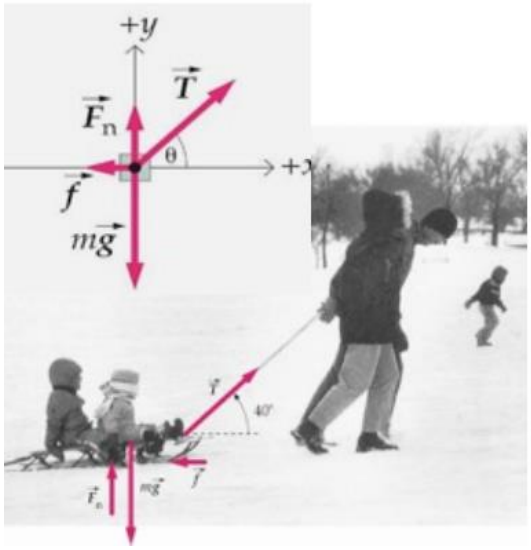
$$f_s = \mu_s F_n \text{ at } \theta_{max}, \text{ so } f_s = \mu_s mg\cos\theta_{max}$$

$$\sum F_x = ma_x \quad \Rightarrow \quad -f_s + mg\sin\theta_{max} = 0 \quad \text{or} \quad f_s = mg\sin\theta_{max}$$

$$\text{Therefore, } \mu_s\cos\theta_{max} = \sin\theta_{max} \quad \text{or} \quad \mu_s = \tan\theta_{max}$$



Pulling A Sled



Elevator or Lift

This is an application of Newton's second law to the forces felt in an elevator (Lift). **If you are accelerating upward you feel heavier, and if you are accelerating downward you feel lighter.** If the elevator cable broke, you would feel weightless since both you and the elevator would be accelerating downward at the same rate.

