General Physics

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Lectures - 1st Level Chemical Sciences

2st Course 2023-2024

Chapter 1 – Physics and Measurements

Fundamental of Physical Science

- Concerned with the fundamental principles of the Universe
- Foundation of other physical sciences
- Has simplicity of fundamental concepts

Divided into six major fields:

- Classical Mechanics
- Relativity
- Thermodynamics
- Electromagnetism
- Optics
- Quantum Mechanics

Objectives of Physics

1- To find fundamental laws that govern natural phenomena

2- To use these laws to develop theories that can predict the results of future experiments Express the laws in the language of mathematics

3- Mathematics provides the bridge between theory and experiment.

Theory and Experiments

- Should complement each other when a discrepancy occurs, theory may be modified or new theories formulated.
- A theory may apply to limited conditions.

Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of ligh

Measurements

Used to describe natural phenomena. Each measurement is associated with a physical quantity

Characteristics of standards for measurements

- Readily accessible
- Possess some property that can be measured reliably
- Must yield the same results when used by anyone anywhere
- Cannot change with time.

Standards of Fundamental Quantities

- Agreed upon by some authority, usually a governmental body SI – Systéme International (Main system used in this text)
- Agreed to in 1960 by an international committee

Fundamental Quantities and Their Units

Quantity	SI Unit
Length	meter
Mass	kilogram
Time	second
Temperature	Kelvin
Electric Current	Ampere
Luminous Intensity	Candela
Amount of Substance	mole

- In mechanics, three fundamental quantities are used:
- 1) Length, 2) Mass, 3)Time
- All other quantities in mechanics can be expressed in terms of the three fundamental quantities.

Derived quantities can be expressed as a mathematical combination of fundamental quantities.

Examples:

- Area … product of two lengths $\left(A = l \times l \text{ ...... } \mathrm{m}^2\right)$
- Speed … ratio of a length to a time interval $\left(v = \frac{l}{t} \text{ ...... } \frac{\mathrm{m}}{s}\right)$
- Density… ratio of mass to volume $\left(\rho = \frac{m}{V} \text{ ...... } \frac{kg}{m^3}\right)$

Prefixes

Prefixes correspond to powers of 10.

Each prefix has a specific name and has a specific abbreviation.

The prefixes can be used with any basic units.

They are multipliers of the basic unit.

Examples: 1 mm = 10^{-3} m 1 mg = 10^{-3} g

TABLE 1.4 *Prefixes for Powers of Ten*

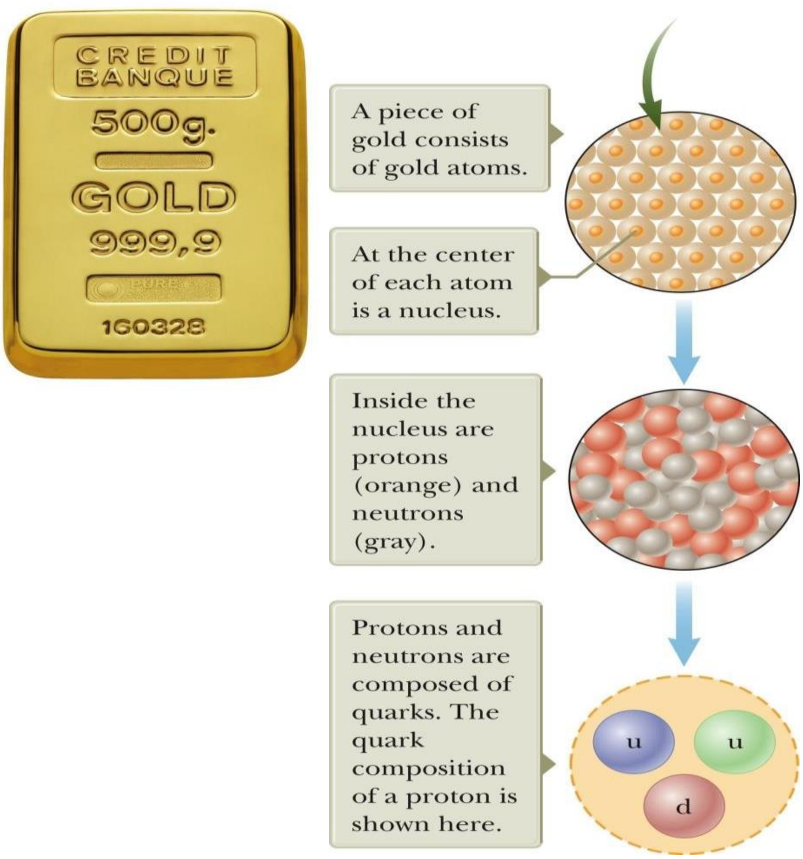
Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{3}	kilo	k
10^{-21}	zepto	z	10^{6}	mega	M
10^{-18}	atto	a	10^{9}	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

Models of Matter

Some Greeks thought matter is made of atoms. No additional structure
JJ Thomson (1897) found electrons and showed atoms had structure.
Rutherford (1911) determined a central nucleus surrounded by electrons.

Nucleus has structure, containing protons and neutrons

- Number of protons gives atomic number
- Number of protons and neutrons gives mass number. Protons and neutrons are made up of quarks.



Note: We infer from the figure above that the atoms of one substance are different from the atoms of other substances in terms of physical and chemical properties.

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Basic Quantities and Their Dimension

Dimension has a specific meaning – it denotes the physical nature of a quantity.

Dimensions are often denoted with square brackets.

- Length [L]
- Mass [M]
- Time [T]

Dimensions and Units

Each dimension can have many actual units.

Table 1.5 for the dimensions and units of some derived quantities

TABLE 1.5 *Dimensions and Units of Four Derived Quantities*

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensions and Units

Quantity	SI Unit		Dimension
velocity	m/s	ms^{-1}	LT^{-1}
acceleration	m/s^2	ms^{-2}	LT^{-2}
force	N $kg\ m/s^2$	$kg\ ms^{-2}$	$M\ LT^{-2}$
energy (or work)	Joule J N m, $kg\ m^2/s^2$	$kg\ m^2s^{-2}$	ML^2T^{-2}
power	Watt W N m/s $kg\ m^2/s^3$	Nms^{-1} $kg\ m^2s^{-3}$	ML^2T^{-3}
pressure (or stress)	Pascal P, N/m^2, $kg/m/s^2$	Nm^{-2} $kg\ m^{-1}s^{-2}$	$ML^{-1}T^{-2}$
density	kg/m^3	$kg\ m^{-3}$	ML^{-3}

Dimensional Analysis

Technique to check the correctness of an equation or to assist in deriving an equation

Dimensions (length, mass, time, combinations) can be treated as algebraic quantities.

- Add, subtract, multiply, divide

Both sides of equation must have the same dimensions.

Any relationship can be correct only if the dimensions on both sides of the equation are the same.

Cannot give numerical factors: this is its limitation

Example: Given the equation: $x = \frac{1}{2} a t^2$ Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

The T^2's cancel, leaving L for the dimensions of each side.

- The equation is dimensionally correct.
- There are no dimensions for the constant.

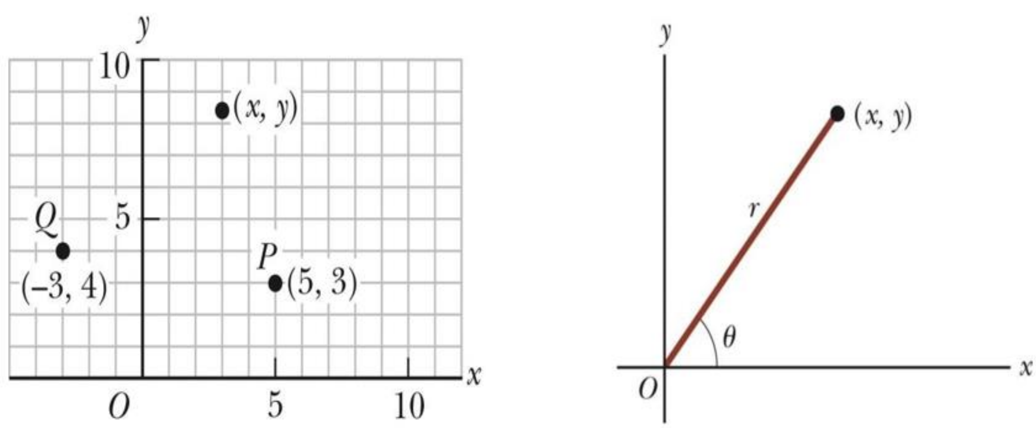
Chapter 2 – Vectors

Coordinate Systems

Used to describe the position of a point in space Common coordinate systems are:

Cartesian Coordinate System

Also called rectangular, in cartesin coordinate system: x- and y- axes intersect at the origin Points are labeled (x,y)



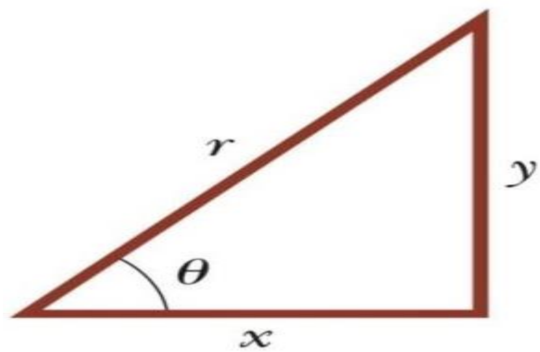
Exp. Find the Cartesian coordinates of a point in the plane (4,1)?.

Polar Coordinate System

Origin and reference line are noted Point is distance *r* from the origin in the direction of angle θ, from reference line. The reference line is often the x-axis. Points are labeled (r,θ). Based on forming a right triangle from *r* and θ

$x = r\cos\theta$ *and* $y = r\sin\theta$

$$r = \sqrt{x^2 + y^2} \qquad (1)$$



$$\sin\theta = \frac{y}{r}$$

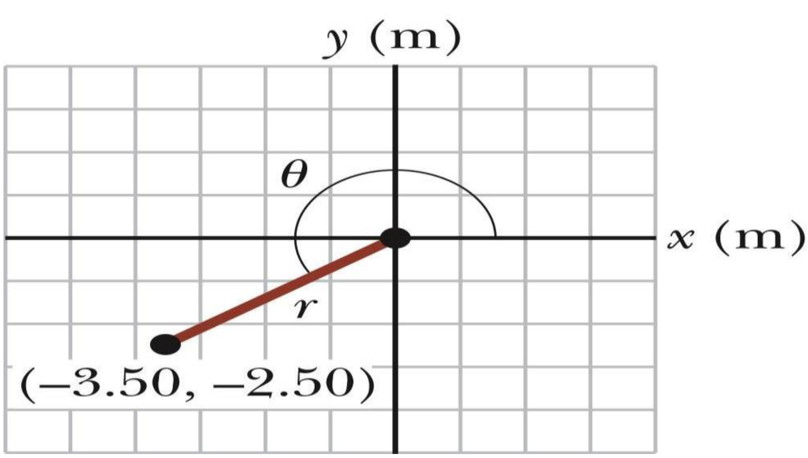
$$\cos\theta = \frac{x}{r}$$

$$\tan\theta = \frac{y}{x}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \qquad (2)$$

Example:

The Cartesian coordinates of a point in the *xy* plane are (x,y)=(-3.5, -2.5) m, as shown in the figure. Find the polar coordinates of this point.



Ans. From Equation (1)

$$r = \sqrt{x^2 + y^2} \qquad (1)$$

$$r = \sqrt{(-3.5)^2 + (-2.5)^2} = 4.3 \text{ m}$$

And from Equ. (2)

$$\tan\theta = \frac{y}{x} = \frac{-2.5}{-3.5} = 0.714$$

$$\theta = \tan^{-1}(0.714)$$

$$\theta = 216^o \quad \text{signs give quadrant}$$

Vectors and Scalars

A ***scalar quantity*** is completely specified by a single value with an appropriate
unit and has no direction.

- Many are always positive
- Some may be positive or negative
- Rules for ordinary arithmetic are used to manipulate scalar quantities.

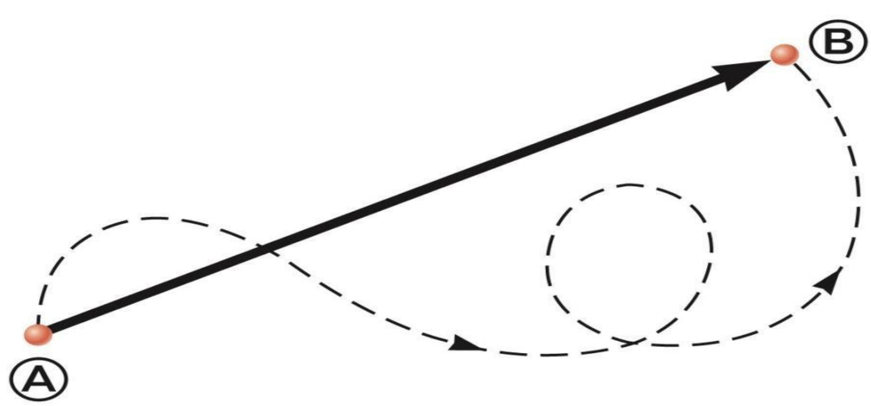
A ***vector quantity*** is completely described by a number and appropriate units plus a direction.

Example: A particle travels from A to B along the path shown by the broken line.

- This is the ***distance*** traveled and is a scalar.

The ***displacement*** is the solid line from A to B

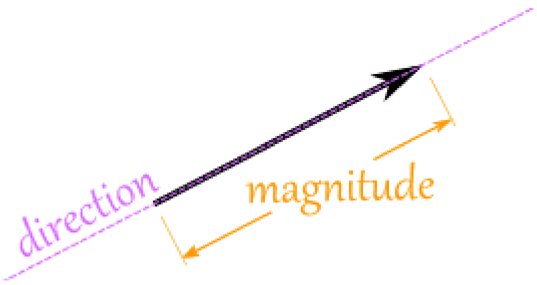
- The displacement is independent of the path taken between the two points.
- Displacement is a vector.



Vectors

In physics, a vector is typically regarded as a geometric entity characterized by amagnitude and a direction , This is a vector:

A vector has magnitude (how long it is) and direction:

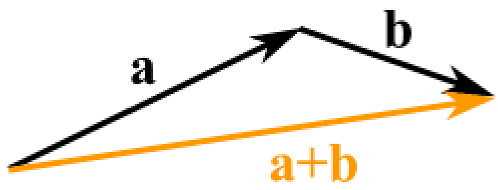


The length of the line shows its magnitude and the arrowhead points in thedirection.

Unit Vector A unit vector is a vector of length 1, sometimes also called a direction vector. The unit vector $\hat{\mathbf{v}}$having the same direction as a given (nonzero) vector $\mathbf{v}$ is defined by

$$\hat{\mathbf{v}} \equiv \frac{\mathbf{v}}{|\mathbf{v}|},$$

Addition: - You can add two vectors by simply joining them, head-to-tail:



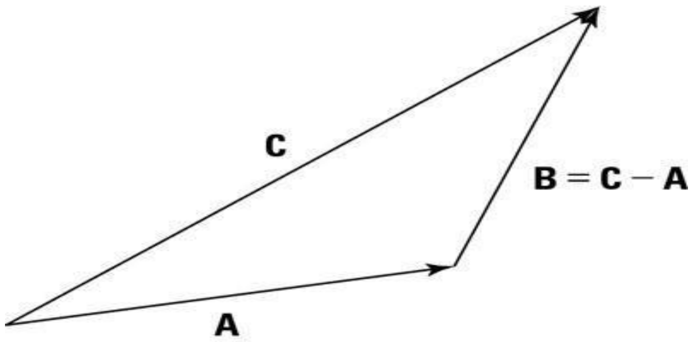
$$\vec{A} = A_x i + A_y j$$

$$\vec{B} = B_x i + B_y j$$

$$\vec{R} = \vec{A} + \vec{B} = (A_x + B_x)i + (A_y + B_y)j$$

<u>Subtraction:</u>

To subtract two vectors, you put their tails, (the non-pointy parts) together; then draw the resultant vector, which is the difference of the two vectors, from the head of the vector you're subtracting to the head of the vector you're subtractingit from.



$$\vec{A} = A_x i + A_y j$$

$$\vec{B} = B_x i + B_y j$$

$$\vec{R} = \vec{A} - \vec{B} = \left(A_x i + A_y j\right) - \left(B_y i + B_y j\right)$$

$$\vec{R} = \vec{A} - \vec{B} = A_x i + A_y j - B_y i - B_y j$$

Example

Two vectors are given by $\vec{A} = 3i - 2j$ and $\vec{B} = -i - 4j$. Calculate (a) $\vec{A} + \vec{B}$, (b) $\vec{A} - \vec{B}$, (c) $\left|\vec{A} + \vec{B}\right|$, (d) $\left|\vec{A} - \vec{B}\right|$, and (e) the direction of $\vec{A} + \vec{B}$ and $\left|\vec{A} - \vec{B}\right|$.

Solution

(a) $\vec{A} + \vec{B} = (3i - 2j) + (-i - 4j) = 2i - 6j$

(b) $\vec{A} - \vec{B} = (3i - 2j) - (-i - 4j) = 4i + 2j$

(c) $\left|\vec{A} + \vec{B}\right| = \sqrt{2^2 + (-6)^2} = 6.32$

(d) $\left|\vec{A} - \vec{B}\right| = \sqrt{4^2 + 2^2} = 4.47$

(e) For $\vec{A} + \vec{B}$, $\theta = \tan^{-1}(-6/2) = -71.6^{\circ} = 288^{\circ}$

For $\vec{A} - \vec{B}$, $\theta = \tan^{-1}(2/4) = 26.6^{\circ}$

Example:

Find **(a)** $\boldsymbol{A} + \mathbf{B}$ and **(b)** $\boldsymbol{A} - \mathrm{B}$ if $= \langle 3,4\rangle$ and $\mathrm{B} = \langle 5,-1\rangle$.

a- $\boldsymbol{A} + \mathbf{B} = \langle A_1 + B_1, A_2 + B_2\rangle$

$= \langle 3 + 5, 4 + (-1)\rangle$

$= \langle 8,3\rangle$

b- $\boldsymbol{A} - \mathrm{B} = \langle A_1 - B_1, A_2 - B_2\rangle$

$= \langle 3 - 5, 4 - (-1)\rangle$

$= \langle -2,5\rangle$

Dot product:

The dot product or scalar product is often defined in one of two ways:algebraically or geometrically.

Algebraic definition

The dot product of two vectors a = [a1, a2, ..., an] and b = [b1, b2, ..., bn] is defined as:

$$\mathbf{a}\cdot\mathbf{b}=\sum_{i=1}^{n}a_ib_i=a_1b_1+a_2b_2+\cdots+a_nb_n$$

When working with vectors represented in a rectangular coordinate system by thecomponents

$$\mathbf{A}=A_x\hat{\mathbf{i}}+A_y\hat{\mathbf{j}}+A_z\hat{\mathbf{k}}$$

$$\mathbf{B}=B_x\hat{\mathbf{i}}+B_y\hat{\mathbf{j}}+B_z\hat{\mathbf{k}}$$

then the dot product can be evaluated from the relation

$$\mathbf{A}\circ\mathbf{B}=A_xB_x+A_yB_y+A_zB_z$$

Notes:

$$\hat{i}.\hat{j}=0$$

$$\hat{i}.\hat{k}=0$$

$$\hat{j}.\hat{k}=0$$

$$\hat{i}.\hat{i}=\hat{j}.\hat{j}=\hat{k}.\hat{k}=1$$

Geometric definition

The dot product of two Euclidean vectors A and B is defined by

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

where θ is the angle between A and B.

In particular, if **A** and **B** are orthogonal, then the angle between them is 90° and

$$\mathbf{A} \cdot \mathbf{B} = 0.$$

Properties

The dot product fulfils the following properties if **a**, **b**, and **c** are real vectors and ris a scalar.

1. **Commutative:** $\mathbf{a} \cdot \mathbf{b} = \mathbf{b} \cdot \mathbf{a}.$

which follows from the definition (θ is the angle between **a** and **b**):

$$\mathbf{a} \cdot \mathbf{b} = \|\mathbf{a}\|\|\mathbf{b}\|\cos\theta = \|\mathbf{b}\|\|\mathbf{a}\|\cos\theta = \mathbf{b} \cdot \mathbf{a}$$

2. **Distributive over vector addition:**

$$\mathbf{a} \cdot (\mathbf{b} + \mathbf{c}) = \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c}.$$

3. **Scalar multiplication:**

$$(c_1\mathbf{a}) \cdot (c_2\mathbf{b}) = c_1 c_2 (\mathbf{a} \cdot \mathbf{b})$$

Cross product:

The cross product of two vectors **a** and **b** is denoted by **a** × **b**. The cross product **a** × **b** is defined as a vector **c** that is perpendicular to both **a** and **b**, with a direction given by the right-hand rule and a magnitude equal to the area of the parallelogram that the vectors span.

Geometric definition

The cross product is defined by the formula

$$\mathbf{a} \times \mathbf{b} = \|\mathbf{a}\| \, \|\mathbf{b}\| \sin\theta \ \mathbf{n}$$

Algebraic definition

$$\mathbf{a} = a_x\hat{\mathbf{i}} + a_y\hat{\mathbf{j}} + a_z\hat{\mathbf{k}}$$

$$\mathbf{b} = b_x\hat{\mathbf{i}} + b_y\hat{\mathbf{j}} + b_z\hat{\mathbf{k}}$$

When working in rectangular coordinate systems, the cross product of vectors **a** and **b** given by

$$\mathbf{a}\times\mathbf{b} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$= (a_y b_z - a_z b_y)\hat{\mathbf{i}} - (a_x b_z - a_z b_x)\hat{\mathbf{j}} + (a_x b_y - a_y b_x)\hat{\mathbf{k}}$$

$$\mathbf{i} = \mathbf{j} \times \mathbf{k} \qquad \mathbf{k} \times \mathbf{j} = -\,\mathbf{i}$$

$$\mathbf{j} = \mathbf{k} \times \mathbf{i} \qquad \mathbf{i} \times \mathbf{k} = -\,\mathbf{j}$$

$$\mathbf{k} = \mathbf{i} \times \mathbf{j}\,, \qquad \mathbf{j} \times \mathbf{i} = -\,\mathbf{k}\,, \ \mathbf{i} \times \mathbf{i} = \mathbf{j} \times \mathbf{j} = \mathbf{k} \times \mathbf{k} = \mathbf{0}$$

Algebraic properties

- The self-cross product of a vector is the zero vector, i.e., **a** ×

$\mathbf{a} \times \mathbf{b} = -\mathbf{b} \times \mathbf{a}$,

a = **0**.

- The cross product is anti-commutative,

- distributive over addition,

$\mathbf{a} \times (\mathbf{b} + \mathbf{c}) = (\mathbf{a} \times \mathbf{b}) + (\mathbf{a} \times \mathbf{c})$,

Area and volume the cross product

The length of the cross product ***a*×*b*** is equal to the area of the parallelogramdetermined by ***a*** and ***b***. The volume of the parallelepiped determined by thevectors ***a***, ***b*** and ***c*** is the absolute value of the scalar triple product:

***V*= |*a*·(*b*×*c*)|.**

Example: Find the angle between the two vectors

Ans. $\vec{A} = 2i + 3j + 4k \quad , \quad \vec{B} = i - 2j + 3k$

$$\vec{A}.\vec{B} = |A||B|\cos\theta$$

$$\cos\theta = \frac{\vec{A}.\vec{B}}{|A||B|}$$

$$\vec{A}.\vec{B} = A.B = A_x B_x + A_y B_y + A_z B_z = (2)(1) + (3)(-2) + (3) = 8$$

$$|A| = \sqrt{(2)^2 + (3)^2 (3)^2} = \sqrt{4 + 9 + 16} = \sqrt{29}$$

$$|B| = \sqrt{(1)^2 + (-2)^2 + (3)^2} = \sqrt{1 + 4 + 9} = \sqrt{14}$$

$$\cos\theta = \frac{8}{\sqrt{29}\sqrt{14}} = 0.397$$

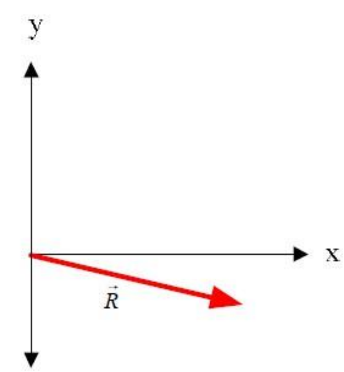
$$\theta = \cos^{-1}(0.397) = 66.6^o$$

Example 1.5

Find the sum of two vectors $\vec{A}$ and $\vec{B}$ given by

$$\vec{A} = 3i + 4j \qquad \text{and} \qquad \vec{B} = 2i - 5j$$

Solution



Note that A_x=3, A_y=4, B_x=2, and B_y=-5

$$\vec{R} = \vec{A} + \vec{B} = (3+2)i + (4-5)j = 5i - j$$

The magnitude of vector $\vec{R}$ is

$$R = \sqrt{R_x^{\ 2} + R_y^{\ 2}} = \sqrt{25+1} = \sqrt{26} = 5.1$$

Example

If $\vec{C} = \vec{A} \times \vec{B}$, where $\vec{A} = 3i - 4j$, and $\vec{B} = -2i + 3k$, what is $\vec{C}$?

Solution

$$\vec{C} = \vec{A} \times \vec{B} = (3i - 4j) \times (-2i + 3k)$$

which, by distributive law, becomes

$$\vec{C} = -(3i \times 2i) + (3i \times 3k) + (4j \times 2i) - (4j \times 3k)$$

Using equation (123) to evaluate each term in the equation above we get

$$\vec{C} = 0 - 9j - 8k - 12i = -12i - 9j - 8k$$

The vector $\vec{C}$ is perpendicular to both vectors $\vec{A}$ and $\vec{B}$.

The direction of $\vec{R}$ with respect to x-axis is

$$\theta = \tan^{-1}\frac{R_y}{R_x} = \tan^{-1}\frac{-1}{5} = -11^o$$

Example 1.6

The polar coordinates of a point are r=5.5m and θ=240°. What are the rectangular coordinates of this point?

Solution

$$x = r\cos\theta = 5.5 \times \cos 240 = -2.75 \text{ m}$$

$$y = r\sin\theta = 5.5 \times \sin 240 = -4.76 \text{ m}$$

Example 1.10

A particle moves from a point in the xy plane having rectangular coordinates (-3,-5)m to a point with coordinates (-1,8)m. (a) Write vector expressions for the position vectors in unit vector form for these two points. (b) What is the displacement vector?

Solution

(a) $\vec{R}_1 = x_1 i + y_1 j = (-3i - 5j)m$

$$\vec{R}_2 = x_2 i + y_2 j = (-i + 8j)m$$

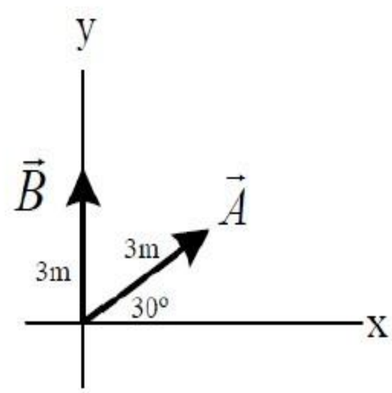
(b) Displacement = $\Delta\vec{R} = \vec{R}_2 - \vec{R}_1$

$$\Delta\vec{R} = (x_2 - x_1)i + (y_2 - y_1)j = -i - (-3i) + 8j - (-5j) = (2i + 13j)m$$

A vector has x component of -25 units and a y component of 40 units. Find the magnitude and direction of this vector.

Find the magnitude and direction of the resultant of three displacements having components (3,2) m, (-5, 3) m and (6, 1) m.

Two vector are given by $\vec{A} = 6i - 4j$ and $\vec{B} = -2i+5j$. Calculate (a) $\vec{A}+\vec{B}$, (b) $\vec{A}-\vec{B}$, $|\vec{A}+\vec{B}|$, (d) $|\vec{A}-\vec{B}|$, (e) the direction of $\vec{A}+\vec{B}$ and $\vec{A}-\vec{B}$.



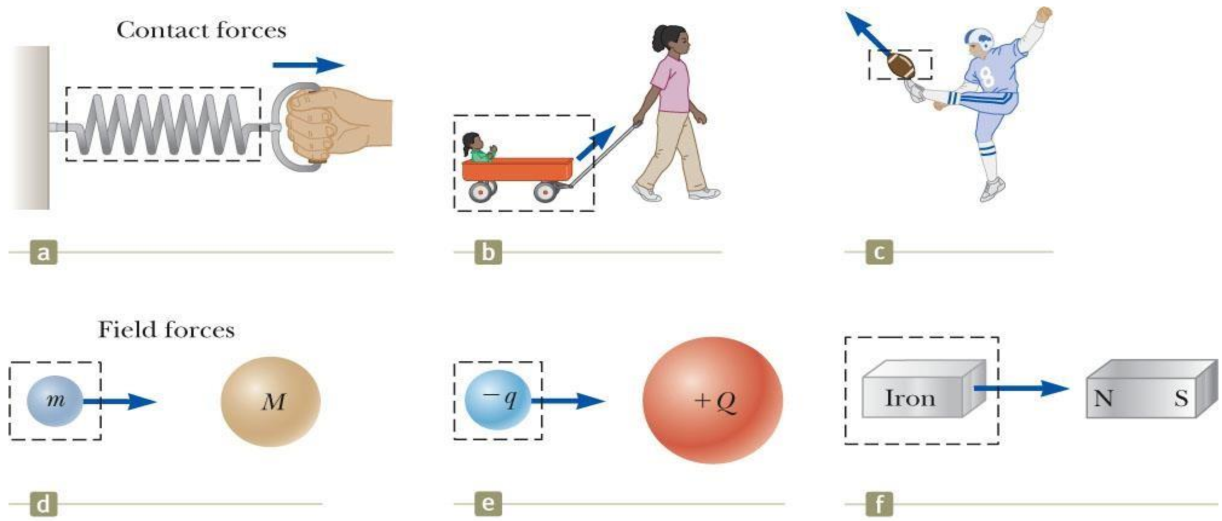
Find the x and y components of the vector $\vec{A}$ and $\vec{B}$ shown in Figure .
Derive an expression for the resultant vector $\vec{A}+\vec{B}$ in unit vector notation.

Chapter 3 - Force and Laws of Motion

Forces

It is the influence that changes or attempts to change the shape of the body or its state of movement

Classes of Forces



1- Gravitational force: Between objects

2- Electromagnetic forces: Between electric charges

3- Nuclear force: Between subatomic particles

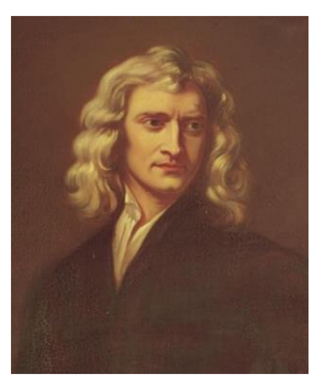
4- Weak forces: Arise in certain radioactive decay processes

Newton Laws of Motion

Newton's laws are classified into three types

Newton's First Law of Motion: states that an object at rest will remain at rest and an object in motion will remain in motion with a constant velocity unless acted on by a net external force.

The first law can be stated mathematically as



$$\sum \mathbf{F} = 0 \Rightarrow \frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = 0.$$

Newton's Second Law of Motion: The acceleration of a body is directly proportionalto, and in the same direction as, the net force acting on the body, and inversely proportional to its mass. Thus, $F = ma$, where F is the net force acting on the object,m is the mass of the object and a is the acceleration of the object.

The second law states that the net force on an object is equal to the rate of change ofits linear momentum p

$$F = \frac{dp}{dt} \qquad (1)$$

Wehere. $$p = mv \qquad (2)$$

نعوض معادلة (2) في معادلة (1)

$$F = \frac{d(mv)}{dt}$$

$$F = m\frac{dv}{dt}$$

$$F = ma \qquad (3)$$

The unit of measurement for force is (kg.m/s^2), but the SI unit of force is the newton (N)

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

Weight and Mass

Q: Whate are the difference between weight and mass?

Weight is the force of the Earth's gravity to a body and is measured in Newton (N).

Mass is the amount of matter that a body contains and is measured in kilograms (kg).

Weight and mass are relatedby the equation:

$$W = mg \qquad (4)$$

Newton's Third Law of Motion: For every action there is an equal and opposite reaction, the mathematical formula for this law is:

$$F_1 = -F_2$$

For example, if a ball is placed on the table, the ball will exert a force onthe table. At the same time, however, the table exerts a force on the ball (it is this force that prevents the ball from being sucked into the table!).

This "equal and opposite reaction force" is known as the **normal reaction force**, and the letter ***N*** or ***R*** is commonly used to represent it.

Example

Two forces, $F1$ and $F2$, act on a 5-kg mass. If $F1$ =20 N and $F2$ =15 N,
find the acceleration in (a) and (b) of the Figure

Solution

(a) $\sum F = F1 + F2 = (20i + 15j)$ N
$\sum F = ma \therefore 20i + 15j = 5\ a$
$a = (4i + 3j)$ m/s2 or $a = 5$m/s2
(b) $F2$x = 15 cos 60 = 7.5 N
$F2$y = 15 sin 60 = 13 N
$F2 = (7.5i + 13j)$ N
$\sum F = F1 + F2 = (27.5i + 13j) = ma = 5\ a$
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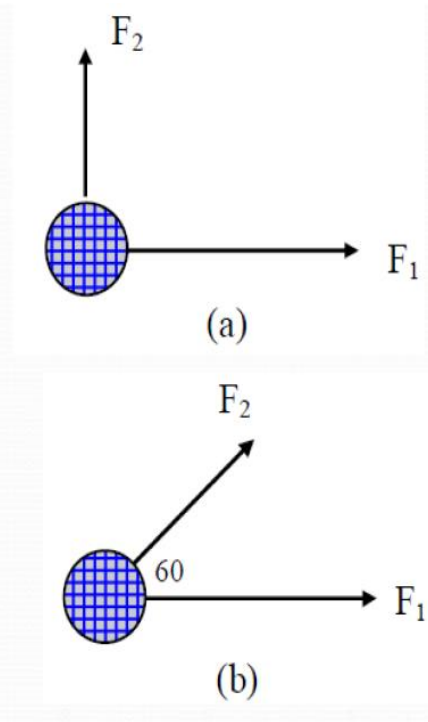

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$$v = \frac{dx}{dt} = 3 + 4t - 19.5t^2$$

$$= 3 + 4(3) - 19.5(3)^2 = -160.5\ m/sec$$

$$a = \frac{dv}{dt} = 4 - 39t = -\frac{113m}{sec^2}$$

Linear motion with constant acceleration: - Linear motion is motion along a straight line, and can therefore be described mathematically using only one dimension.

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where

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The final velocity

$$v^2 = v_o^2 + 2a\Delta x \qquad (3)$$

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Example: Luke drops a pile of roof shingles from the top of a roof located 8.52 m above the ground. Determine the time required for the shingles to reach the ground.

Ans.

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

$$-8.52 = 0 + (0)*(t) + 0.5*(-9.8)*(t)^2$$

$$-8.52 = -4.9*(t)^2$$

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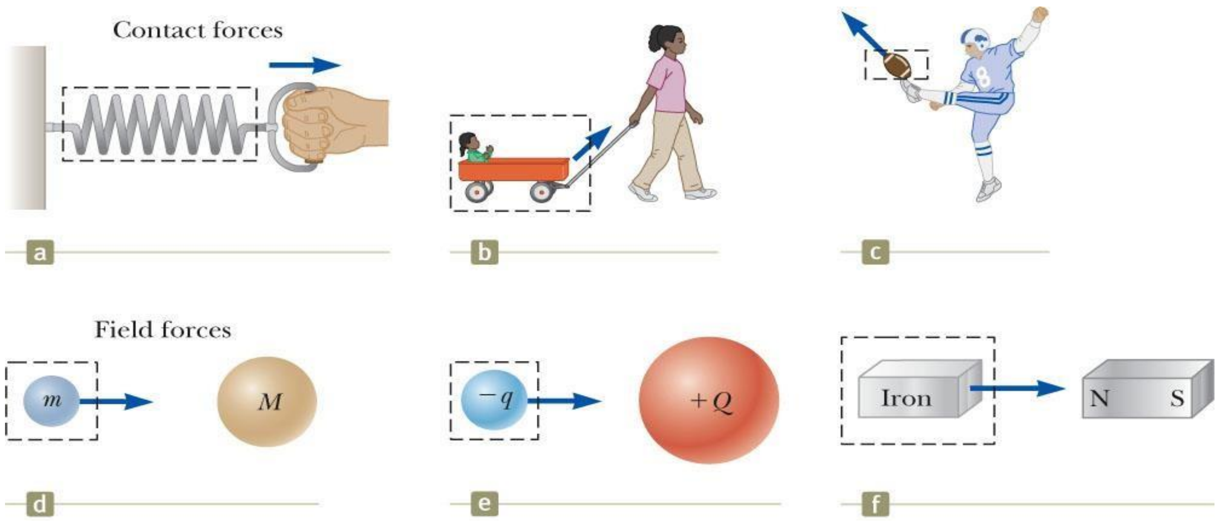
Chapter 3 - Force and Laws of Motion

Forces

It is the influence that changes or attempts to change the shape of the body or its state of movement

Classes of Forces



5- Gravitational force: Between objects

6- Electromagnetic forces: Between electric charges

7- Nuclear force: Between subatomic particles

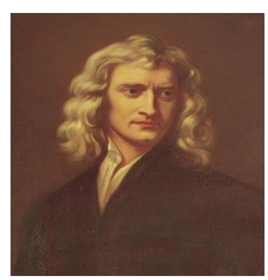
8- Weak forces: Arise in certain radioactive decay processes

Newton Laws of Motion

Newton's laws are classified into three types

Newton's First Law of Motion: states that an object at rest will remain at rest and an object in motion will remain in motion with a constant velocity unless acted on by a net external force.

The first law can be stated mathematically as



$$\sum \mathbf{F} = 0 \Rightarrow \frac{d\mathbf{v}}{dt} = 0.$$

Newton's Second Law of Motion: The acceleration of a body is directly proportionalto, and in the same direction as, the net force acting on the body, and inversely proportional to its mass. Thus, $F = ma$, where F is the net force acting on the object,m is the mass of the object and a is the acceleration of the object.

The second law states that the net force on an object is equal to the rate of change ofits linear momentum p

$$F = \frac{dp}{dt} \qquad (1)$$

Wehere. $$p = mv \qquad (2)$$

نعوض معادلة (2) في معادلة (1)

$$F = \frac{d(mv)}{dt}$$

$$F = m\frac{dv}{dt}$$

$$F = ma \qquad (3)$$

The unit of measurement for force is (kg.m/s^2), but the SI unit of force is the newton (N)

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

Weight and Mass

Q: Whate are the difference between weight and mass?

Weight is the force of the Earth's gravity to a body and is measured in Newton (N).

Mass is the amount of matter that a body contains and is measured in kilograms (kg).

Weight and mass are relatedby the equation:

$$W = mg \qquad (4)$$

Newton's Third Law of Motion: For every action there is an equal and opposite reaction, the mathematical formula for this law is:

$$F_1 = -F_2$$

For example, if a ball is placed on the table, the ball will exert a force onthe table. At the same time, however, the table exerts a force on the ball (it is this force that prevents the ball from being sucked into the table!).

This "equal and opposite reaction force" is known as the **normal reaction force**, and the letter ***N*** or ***R*** is commonly used to represent it.

Example

Two forces, $F1$ and $F2$, act on a 5-kg mass. If $F1$ =20 N and $F2$ =15 N,
find the acceleration in (a) and (b) of the Figure

Solution

(a) $\sum F = F1 + F2 = (20i + 15j)$ N
$\sum F = ma \therefore 20i + 15j = 5\ a$
$a = (4i + 3j)$ m/s2 or $a = 5$m/s2
(b) $F2x = 15 \cos 60 = 7.5$ N
$F2y = 15 \sin 60 = 13$ N
$F2 = (7.5i + 13j)$ N
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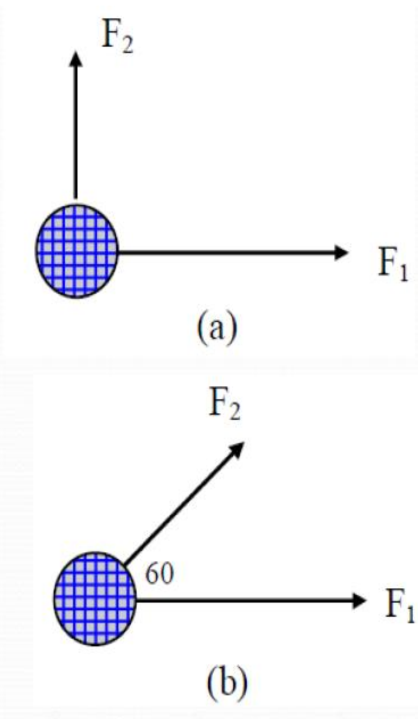

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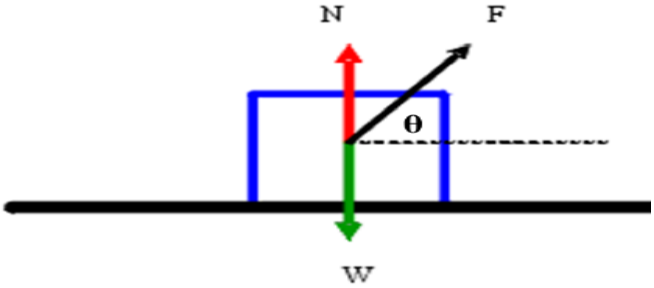
Work

It is a force that affects a body and causes its displacement (or movement), and the equation below shows the mathematical formula for the law of work:

$$Work = Force.\,Displacement.\cos\theta$$

$$\mathrm{W} = F.\,d.\,cos\,\theta$$

From the law of work, we note that there are two basic variables:
1) displacement and 2) the extent of the force that causes or hinders displacement.



Since the unit of force is ***N*** and the unit of displacement is ***m***, then the unit of workis ***N.m***, defined in (SI – System) is Joule (***J)***.

Work has two values: positive or negative depending on the sign of cos(θ).
1) (W+) If the force factor affects the body in the same direction of motion.
1) (W-) If the force factor affects the body in a direction opposite to the direction of motion.

Example:- 55, 000J of work is done to move a rock 25m. How much force was applied?

$$F = \frac{\mathrm{W}}{d} = \frac{55000}{25} = 2200J$$

Work done against gravity – gravitational potential energy

Let's now consider the work done when we lift an object. In order to lift an object that has mass ***m***, we have to apply an upward force ***mg*** to overcome the downward force of gravity. If this force raises the object through a height ***h***, then the work doneis:

$$\mathrm{W} = Fd = mg \times h = mgh$$

Example:- Calculate the work done in lifting a 12 kg suitcase from floor level up toa luggage rack 2.0 m above the floor.

$$W = mgh = 12 \times 9.8 \times 2 = 235.2J$$

Work done by a variable force

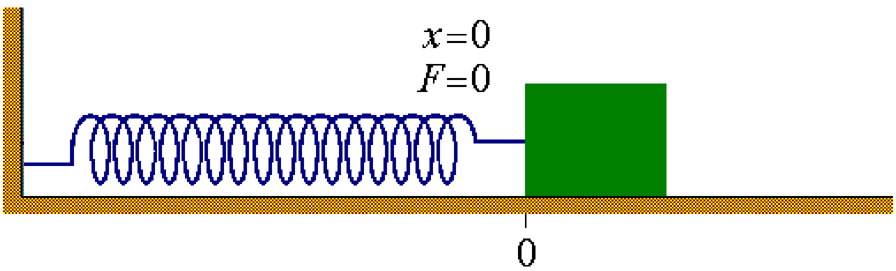
Let us now consider the work done by a force ***F*** that is not constant. We consider first a force that varies in magnitude only. Let the force be given as a function of position ***F(x)*** and assume that the force acts in the ***x***-direction. Suppose that a bodyis moved along the ***x***-direction by this force. The work done by this force in moving the body from ***a*** to ***b*** is

$$W = \int_a^b F_x dx$$

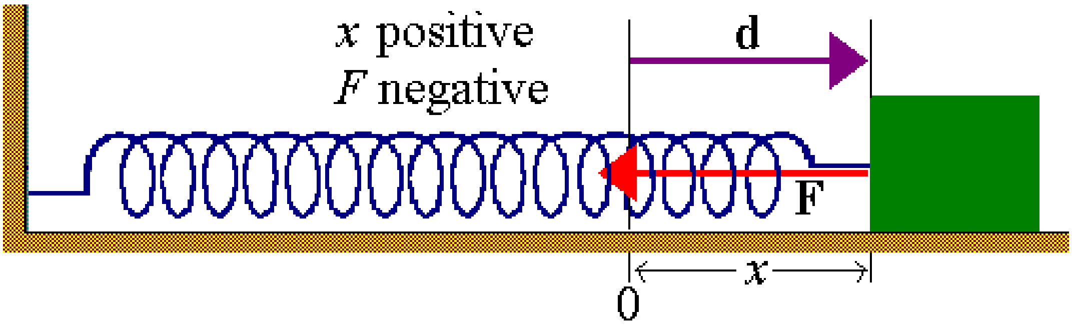
In the more general case of a force which changes with distance, the work may still be calculated as the area under the curve.

Work done by a spring

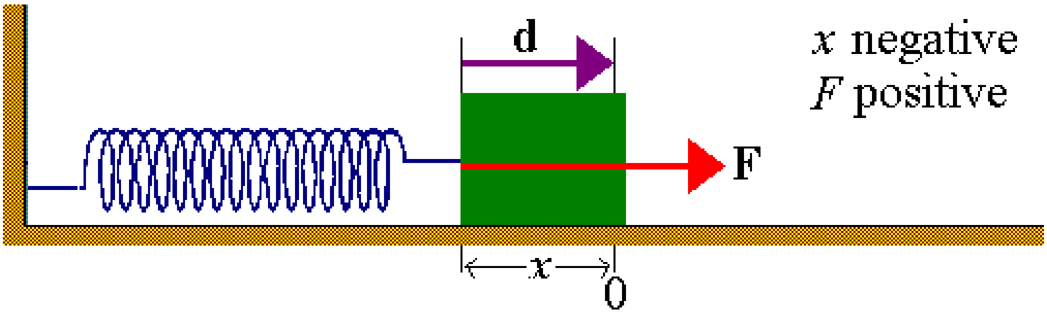
A common physical system for which the force varies with position is shown in figure below. It shows a spring in its relaxed state, that is, it is neither compressed nor extended. One end is fixed, and a particle-like object, say, a block, is attached tothe other, free end.



In figure below, we have stretched the spring by pulling the block to the right. In reaction, the spring pulls on the block toward the left, so as to restore the relaxed state. (The spring's force is sometimes said to be a ***restoring force***.)



In figure below, we have compressed the spring by pushing the block to the left. The spring by pushing the block toward the right, again so as to restore the relaxed state.



The force ***F*** exerted by a spring is

$$F = -kx \qquad \text{(Hooke's law).}$$

Where: k is called the spring constant. The minus sign indicates that the spring force is always opposite in direction from the displacement of its free end.

Work done by an external force on the spring, $W_a = \frac{1}{2}kx^2$, while the work done by the spring is $W_{sp} = -\frac{1}{2}kx^2$.

Example:- A block whose mass *m* is 15 kg slides on a horizontal frictionless surfacewith a constant speed ***v*** of 3.7 m/s. It is brought momentarily to rest as it compressesa spring in its path. By what distance *d* is the spring compressed? The spring constant ***k*** is 1500 N/m.

Solution:

The work done by the spring force on the block as the spring is compressed a distance ***d*** from its rest state is given by

$$W_s = -\frac{1}{2}kd^2 .$$

The change in the kinetic energy of the block as it is stopped is

$$\Delta K = K_f - K_i = 0 - \frac{1}{2}mv^2.$$

The work-energy theorem requires that these two quantities be equal. Setting them so

$$W_{sp} = \Delta K \rightarrow -\frac{1}{2}kd^2 = -\frac{1}{2}mv^2$$

and solving for ***d***

$$d = v\sqrt{\frac{m}{k}} = 3.7 \text{ m/s } (15 \text{ kg} / 1500 \text{ N/m})^{1/2}$$

$d = 0.37$ **m** $= 37$ **cm.**

Energy: -

The energy of a body is a measure of its ability to do work.

Kinetic Energy

The kinetic energy (***K.E.***) of a body is the energy a body has as a result of itsmotion. A body which isn't moving will have zero kinetic energy, therefore.

$$K.E. = \frac{1}{2} mv^2$$

where ***m*** is the mass and ***v*** is the velocity of the body.

Kinetic energy is a scalar quantity; it does not have a direction. The standard metricunit of measurement for kinetic energy is the Joule.

$$1 \text{ Joule} = 1 \text{ kg} * \frac{m^2}{s^2}$$

Let us derive a useful relationship between work and kinetic energy. Say we have atotal force $\vec{F}$acting on an object. Then the work is

$$W = \int_{x_i}^{x_f} F(x)dx \text{........................} 1$$

Using the Newton's 2nd law to replace ***F(X)*** by ***ma***, we get

$$W = \int_{x_i}^{x_f} madx \text{......................} 2$$

We know that

$$madx = m\frac{dv}{dt}dx = mvdv \dots\dots\dots\dots\dots\dots\dots.3$$

Then we get

$$W = \int_{v_i}^{v_f} mvdv = m\int_{v_i}^{v_f} vdv = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \ldots\ldots\ldots\ldots.4$$

$$W = K_f - K_i = \Delta K \ldots\ldots\ldots\ldots\ldots\ldots 5$$

This states that the work done by the total force on an object is the change in kineticenergy of the object.

__Example:-__ Consider a block of mass 4kg moving initially at 2 m/sec on a horizontalfrictionless surface. What is the required work to double speed of the object?

$$W = K_f - K_i$$

$$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W = \frac{1}{2} \times 4 \times (4)^2 - \frac{1}{2} \times 4 \times (2)^2$$

$$W = 24\,J$$

The potential energy

The gravitational potential energy ***U*** of an object of mass ***m*** kilograms placed at aheight ***h*** metres above the ground is given by the formula:

$$U = mgh$$

Potential energy is always associated with change in the configuration of a systemof particles.

$$U = mg(y_2 - y_1)$$

Then the work done is equal the change in the potential energy

$$W = \Delta U = U_2 - U_1 = mg(y_2 - y_1)$$

The unit of the potential energy is Joule (***J***).

Power

In physics, power (***P***) is defined as the amount of energy consumed per unit time. The unit of power is the joule per second (J/s), known as the watt.

$$\bar{P} = \frac{Work}{Time} = \frac{W}{\Delta t}$$

The instantaneous power is the instantaneous rate of doing work, which we canwrite as

$$P = \frac{d\mathrm{W}}{dt}$$

We can also express the power delivered to a body of the force that acts on the bodyand its velocity. Thus, for particle moving in one dimension

$$P = \frac{d\mathrm{W}}{dt} = \frac{d(Fx)}{dt} = \frac{Fdx}{dt}$$

$$P = F.v$$

$$P = Fv\cos(\theta)$$

There is another common unit used by engineers is called ***horsepower*** (***hp***)

1hp=746 w

Example: A loads of bricks whose mass is 420 kg is to be lifted through a height of120m in 5min. What is the minimum power of the winch motor?

$$P = F.v$$

$$v = \frac{y}{t} = \frac{120}{300} = 0.4m/sec$$

$$F = mg = 420 \times 9.8 = 4116N$$

$$P = 4116 \times 0.4 = 1646.4\,w$$