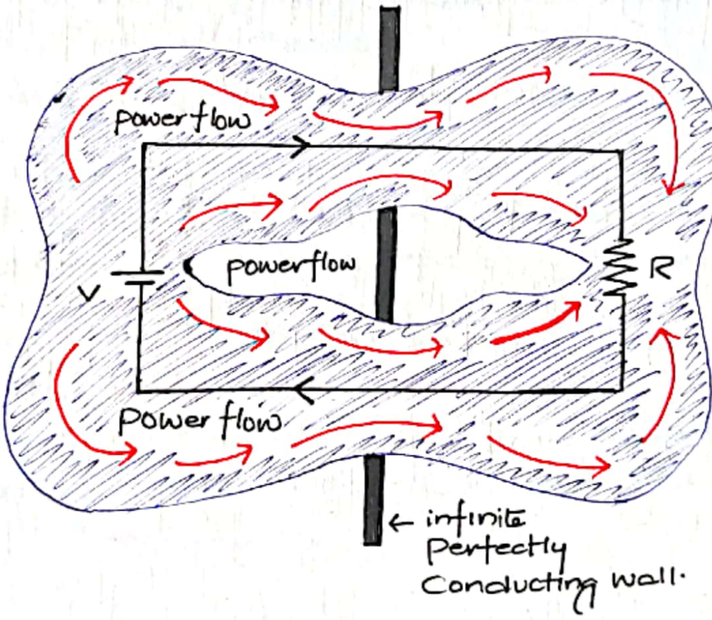
ELECTROMAGNETICS : ITS IMPORTANCE

Electromagnetics is important because it provides a real-world, three-dimensional understanding of electricity and magnetism.

By Circuit theory the battery applies a voltage V sending a current I through the wires to the load. This is a simplistic view. The energy is conveyed from the battery to the load almost enti-rely by electromagnetic fields external to the wires, the wires acting as guides for the energy as in the figure.



Simple circuit showing powerflow from generator to load R through holes in a perfectly Conducting walls.

An electric field extends between the wires and a magnetic field surrounds them. With altern
-ating currents some energy is radiated into space.
At high enough frequencies nearly all may be radia
-ted, the circuit acting as an antenna.

The vast grids of the earth's 50 and 60-Hz po-wer transmission lines not only supply the world's elect-rical needs but their "hum" is the most powerful cont-inuous electromagnetic signal sent out from our planet.

Many electromagnetic devices are inadvertently Coupled to other systems. Vedio display Unit (VDUs) of Computers and telension sets may emit sufficient unintentional radiation that it can be picked up, decoded and the Screen displays reproduced at distances of a kilometer. Any device that radiates is Coupled, in principle, to the entire Universe. By reciprocity, the universe is Coupled to it.

This is the real world and field theory is essential to understand it. The purpose of Electromagnetics.

Complete understanding of the behaviour of materials and Components as used in electrical and electronics engineering Such as

ELECTRIC MOTORS — CAPACITORS, INDUCTORS, GENERATORS

ELECTRIC HEATING — TELEPHONE, TELEVISION, TRANSMISSION LINES

ELECTRIC RELAYS — TRANSFORMER, RADIO, RADAR

Satellite Communication etc requires a knowledge of Electro magnetic fields.

Electro magnetic theory deals with electric field intensity and magnetic field intensity.

Electro magnetic theory has more Variables.

In most of EMF problems three Space Variables are involved. Hence the Solution become Complex. Vector algebra is a powerful tool for solving field problems.

Classical electro dynamics was worked out is in bits and pieces by FRANKLIN, COULOMB, AMPERE, FARADAY and others, but the man who put it all together and built it into the Compact and Consistent theory it is today, was "JAMES CLERK MAXWELL"

James Clerk maxwell (1831-1879) giving interdependence of electricity and magnetism. Infact he is Considered as the founder of electro magnetic theory.

Electro magnetics is the Study of the effects of electric charges at rest and in motion.

There are two kinds of charges: positive and negative. Both positive and negative charges are Sources of an electric field.

Radar: System for detecting the direction, range or presence of objects by sending out pulses of high frequency electro magnetic waves which they reflect.

The are four fundamental vector field quantities in electromag -netics

i. Electric field intensity, E
ii. Electric flux density, D
iii. Magnetic field intensity, H
iv. Magnetic flux density, B

The main aim of electromagnetics is to understand the Concept of four Maxwell's equation and their applications.

$$\nabla \cdot \bar{D} = \rho_v$$

$$\nabla \cdot \bar{B} = 0$$

$$\nabla \times \bar{E} = \frac{-\partial B}{\partial t}$$

$$\nabla \times \vec{H} = J + \frac{\partial D}{\partial t}$$

where ∇ is a vector differential Operator
ρ_v is the Volume charge density
J is Current density.

Electromagnetics deals with Space Concepts and requires thinking in the three dimensions of real world Hence, we must understand the three dimensional Coordinate Systems (rectangular - Cartesian Cylindrical and Spherical)

ELECTROMAGNETIC fields

Introduction:

Electromagnetics is a branch of physics or Electrical Engineering in which the Electric and magnetic phenomenon are studied.

A field is a function that specifies the particular quantity every where in a region.

Electro magnetic devices includes Transformers, Transmi-ssion lines, Electric relays, radio/T.V, Electric motors and radars

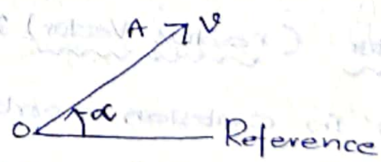
Any physical quantity may be represented either as a Scalar (or) as a Vector.

Scalar: Scalar is a quantity that has only magnitude.

for Eg: Time, mass, area, Speed, distance, temperature etc length, electric potential, Current & energy.

Vector: It is a quantity that has both magnitude and direction.

for Eg: Velocity, acceleration, force, displacement, force, Electric field intensity etc.



The line 'OA' represents a velocity v, the length OA denoting the numerical Value of velocity i.e; in m/Sec and 'α' be the orientation of the vector with reference.
The arrow suggests that the velocity of motion is directed away from the origin 'O' along OA.

Scalar field: If the quantity is Scalar, the field is Said to be Scalar field.

Eg: Temperature of hot Water in a Container.
Sound intensity in a theater.
Electric potential in a region.
Temp distribution in a building.

Vector field: If the (vector) quantity is vector, the field is said to be vector field.

Eg: Gravitational force on a body in space.
Velocity of rain drops in the atmosphere.
Earth's magnetic field, but its magnitude is not same every where.

Unit Vector: A vector 'A' has both magnitude and direction.

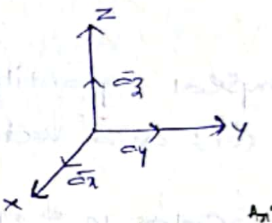
A unit vector 'a_A' along 'A' is defined as a vector whose magnitude is unity and its direction is along 'A'.

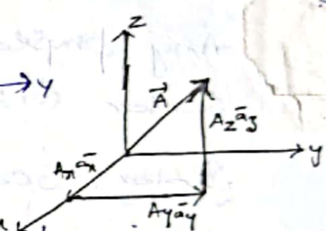
i.e; $$a_A = \frac{A}{|A|} = \frac{A}{A}$$

$$A = |A| a_A = A a_A$$

where A is magnitude of 'A' and its (A) direction a_n

In Cartesian Coordinate System, a vector A may be represented as





$$A = A_x a_x + A_y a_y + A_z a_z$$

where A_x, A_y, A_z are the components of A along x, y, z directions.

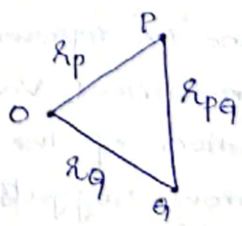
a_x, a_y, a_z are unit vectors along x, y, z directions.

where $$A = |A| = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

$$a_A = \frac{A_x a_x + A_y a_y + A_z a_z}{\sqrt{A_x^2 + A_y^2 + A_z^2}}$$

Position Vector (radius Vector):

A point 'P' in cartesian coordinates may be represented by (x, y, z)



A position vector r_p of point 'P' is as the directed distance from the origin to the point 'P'.

i.e; $r_p = OP = x a_x + y a_y + z a_z$.

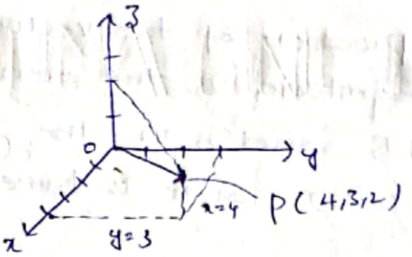
Distance Vector:

The distance vector is the displacement from one point to another point.

i.e; displacement from 'P' to 'Q'

$$r_{PQ} = r_Q - r_P$$

For Eg: Illustration of position vector $r_p = 4a_x + 3a_y + 2a_z$



Problem:

Points P and Q are located at (0,2,4) and (−3,1,5). Calculate a) position vector 'P'. b) distance vector from P to Q c) distance between P and Q.

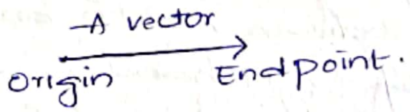
a) $r_p = 0a_x + 2a_y + 4a_z = 2\bar{a_y} + 4\bar{a_z}$

b) $r_{PQ} = r_Q - r_P = (-3a_x + a_y + 5a_z) - (2a_y + 4a_z) = -3a_x - a_y + a_z$

c) distance between P and Q is $|r_{PQ}| = \sqrt{3^2+1^2+1^2} = \sqrt{11}$
$= 3.317$

Vectors:

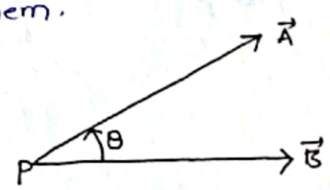
A vector may be represented graphically by a line with an arrow. The line has an origin and an end point. The orientation of the line and the arrow indicates the direction of a vector.



Dot Product: (A·B)

The dot product of two vectors A and B is defined as the product of the magnitudes of A and B and the Cosine of phase angle between them.

$$A \cdot B = AB \cos \theta_{AB}$$



• It is a Scalar product.

If $A = (A_x, A_y, A_z)$ and $B = (B_x, B_y, B_z)$ then

$$A \cdot B = A_x B_x + A_y B_y + A_z B_z$$

Note:

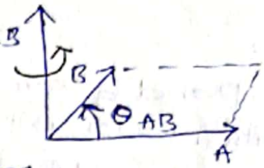
$$a_x \cdot a_x = a_y \cdot a_y = a_z \cdot a_z = 1$$

$$a_x \cdot a_y = a_y \cdot a_z = a_z \cdot a_x = 0.$$

Cross product (A×B)

The cross product of two vectors A and B is a vector quantity whose magnitude is the area of the parallelopiped formed by A and B and is in the direction of advance of right handed screw as A is turned into B.

$$A \times B = AB \sin\theta_{AB}\, \bar{a}_n$$



(i)

where a_n is a unit vector normal to the plane containing A and B.

If $A = (A_x, A_y, A_z)$ and $B = (B_x, B_y, B_z)$

then $A \times B = \begin{vmatrix} a_x & a_y & a_z \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$

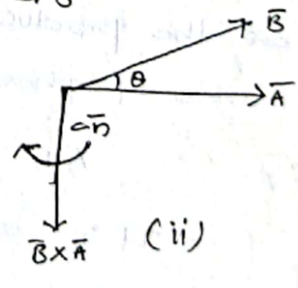
Note: $a_x \times a_y = a_z$, $a_z \times a_x = a_y$, $a_z \times a_y = a_x$.

• Cross product is a vector product

The cross product of two vectors $\bar{A}$ and $\bar{B}$ is another vector whose magnitude is the product of magnitude of $\bar{A}$ and $\bar{B}$ and the sine of angle θ between $\bar{A}$ and $\bar{B}$ and whose direction is the direction of a right hand screw as it is turned from $\vec{A}$ towards $\bar{B}$ through angle θ as shown in figure.

$$\bar{A} \times \bar{B} = |\bar{A}||\bar{B}| \sin\theta_{AB}\, \bar{a}_n$$

where $\bar{a}_n$ is a unit vector (vector of length 1) pointing perpendicular to the plane of $\bar{A}$ and $\bar{B}$

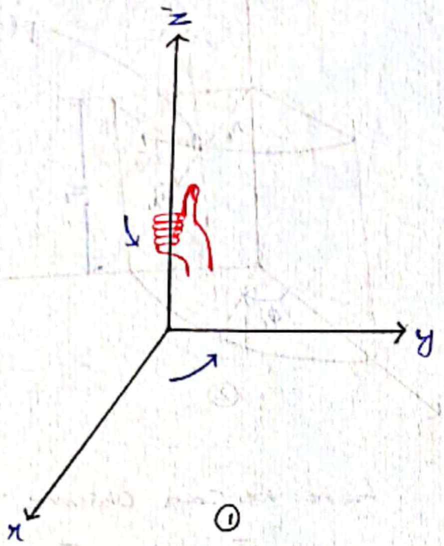


(ii)

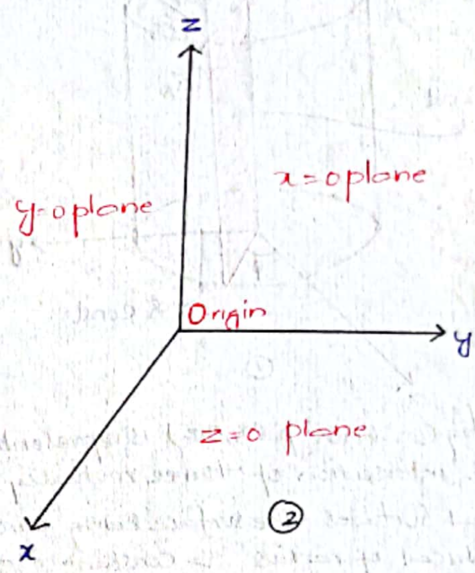
Introduction to Coordinate Systems:

i) Rectangular (or) Cartesian Coordinates:
ii) Cylindrical Coordinates
iii) Spherical Coordinates.

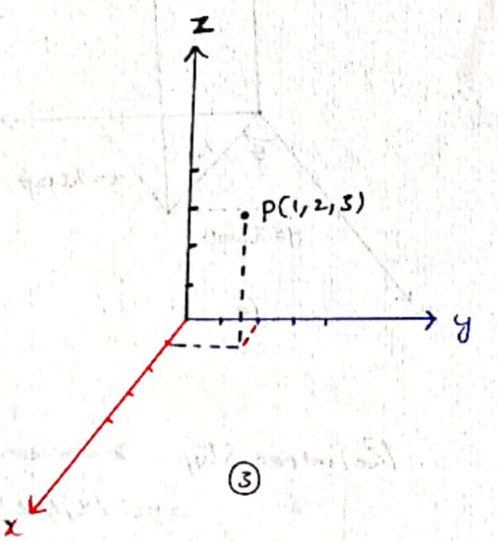
The Cartesian Coordinate System (rectangular) (x,y,z)



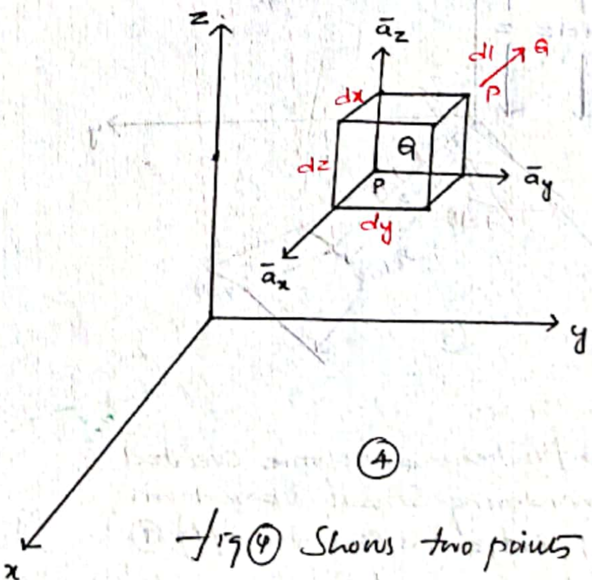
The thumb pointing the direction of positive z-axis, ~~x-axis & y-axis~~
In this System we set up three coordi-nates axes mutually at right angles to each other. It is Customary to choose a right handed Coordinate System in which the rotation from +ve axis towards +ve y axis. (in the direction of fingers of right hand), as thumb poiinting in the direction of +ve z axis



The planes x = Constant, y = Constant and z = Constant, the Constants being Coordinate values of the point.
figure② Shows the three orthogonal planes.

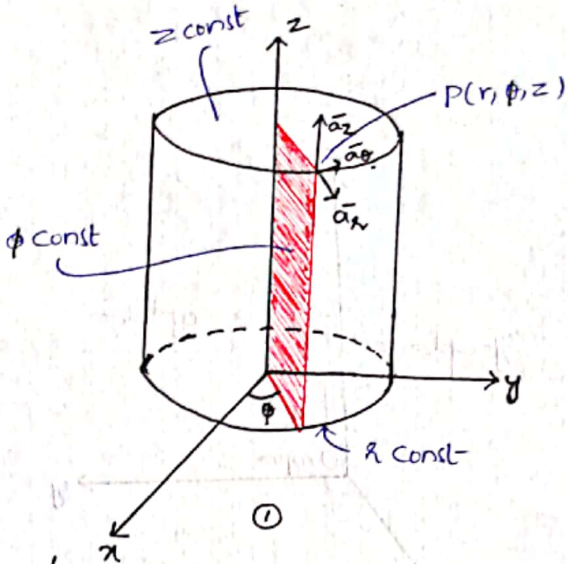


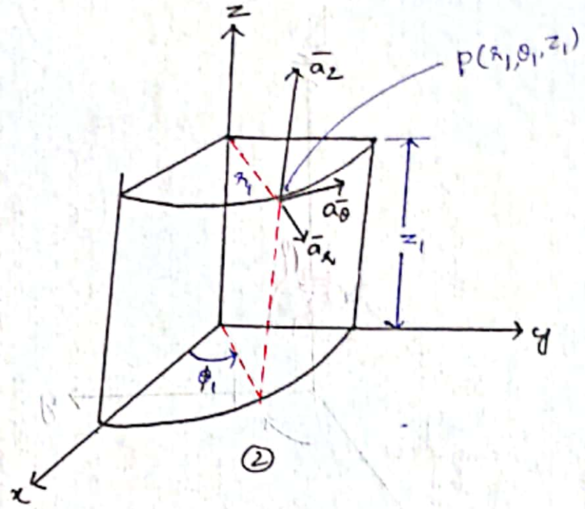
fig③ shows the location of point p whose Coordinates are (1,2,3)
point p is therefore located at the Common point of intersection of the planes x=1, y = 2 & z=3



fig④ Shows two points P(x,y,z) and Q(x+dx, y+dy, z+dz), where Q is obtained by incrementing infi-nitesimally each coordinate from its unit at p.
The increments are Shown as dx, dy and dz in the form of a small box of volume dx, dy, dz.

Circular Cylindrical Coordinate System (r, ϕ, z)

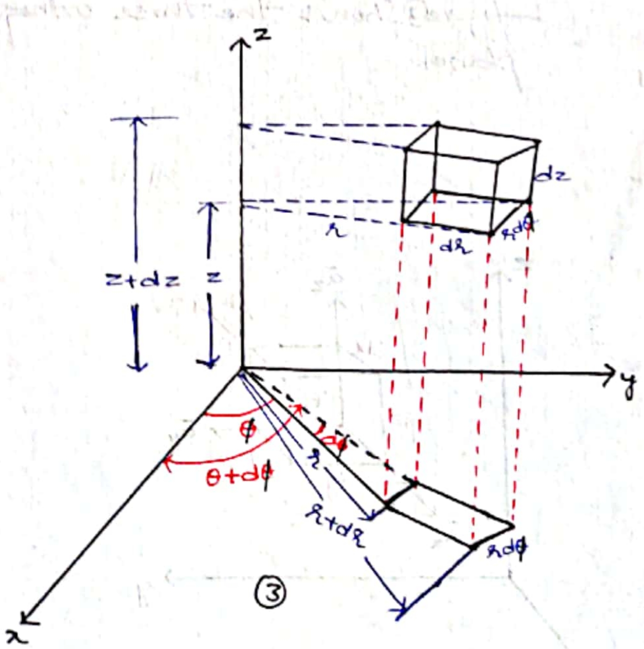


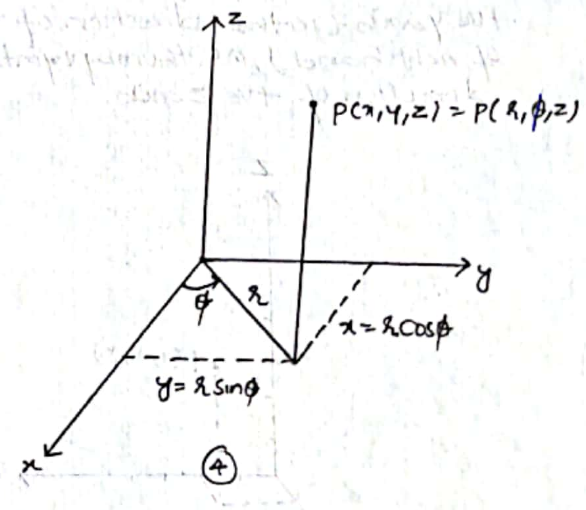


The fig ① shows $p(r, \theta, z)$ is represented by the intersection of three mutually orthogonal surfaces. The surface being circular cylindrical of radius r = constant is a cylinder, ϕ = constant is a plane (made by shifting xz plane by angle θ from $y = 0$ plane) and z = constant plane as shown.

here we can observe that

$$\bar{a}_r \times \bar{a}_\phi = \bar{a}_z$$

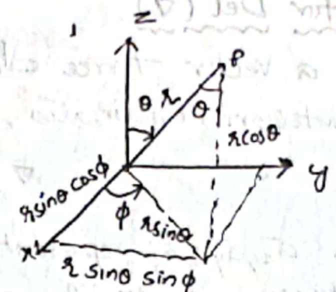


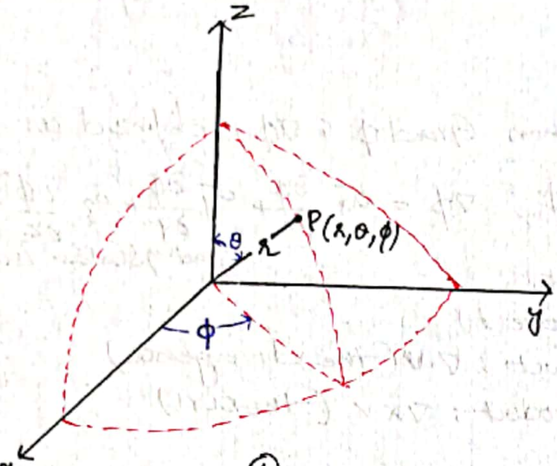


An infintesimal volume created by considering small variations along r, ϕ, z as shown in fig ③. The differential lengths are dr, $r d\theta$ & dz.

Relationship between (x, y, z) and (r, ϕ, z)

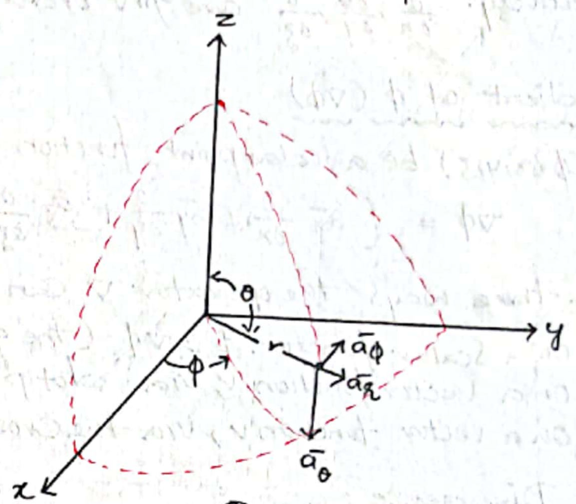
Spherical Coordinate System (r, θ, ϕ)





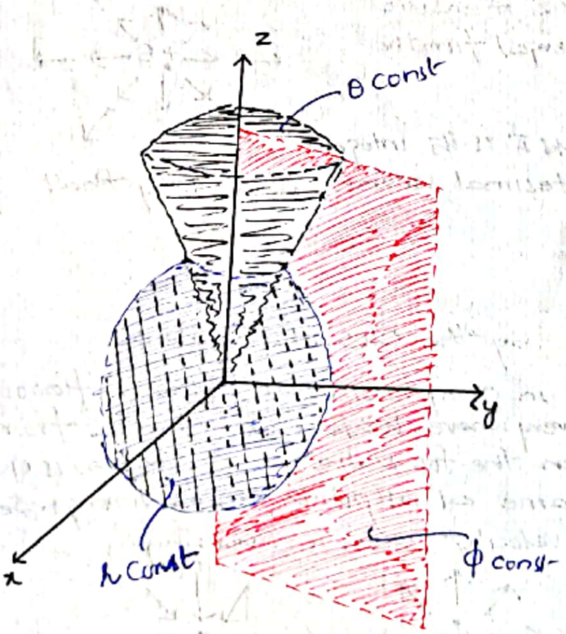
①

Spherical Coordinates
$P(r,\theta,\phi)$



②

Unit vectors in Spherical System



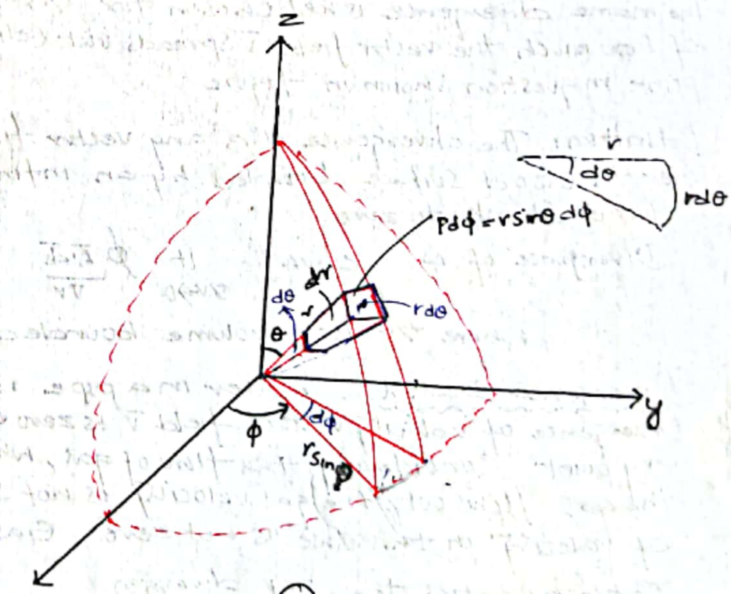
③

Constant r, θ and ϕ Surfaces

r = Constant is a sphere

θ = Constant in a cone

ϕ = Constant in a plane



④

The differential volume formed by considering small variation along r, θ and ϕ is shown in fig ④

The differential lengths are : dr, $rd\theta$ and $r\sin\theta d\phi$

Operator Del (∇)

Del is a vector three dimensional partial differential operator or gradient. In Cartesian Coordinates, it is defined as follows

$$\nabla = \frac{\partial}{\partial x}\bar{a}_x + \frac{\partial}{\partial y}\bar{a}_y + \frac{\partial}{\partial z}\bar{a}_z$$

where $\bar{a}_x, \bar{a}_y$ & $\bar{a}_z$ represent the unit vectors along the x-axis, y-axis and z-axis respectively. $\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}$ are first order partial differentiation operators.

Gradient of ϕ ($\nabla\phi$)

let $\phi(x,y,z)$ be a scalar point function, then Grad ϕ & $\nabla\phi$ is defined as

$$\nabla\phi = \left(\bar{a}_x\frac{\partial}{\partial x} + \bar{a}_y\frac{\partial}{\partial y} + \bar{a}_z\frac{\partial}{\partial z}\right)\phi; \quad \nabla\phi = \bar{a}_x\frac{\partial\phi}{\partial x} + \bar{a}_y\frac{\partial\phi}{\partial y} + \bar{a}_z\frac{\partial\phi}{\partial z}$$

grad of scalar is a vector

The three ways the operator ∇ can act

1. On a Scalar function ϕ : $\nabla\phi$ (the gradient)
2. On a Vector function v, via dot product : $\nabla \cdot V$ (the divergence)
3. On a vector function v, via the cross product : $\nabla \times V$ (the curl)

The Divergence:

let $\bar{V} = V_x\bar{a}_x + V_y\bar{a}_y + V_z\bar{a}_z$ where V_x, V_y & V_z are function of x, y & z by vector-point function.

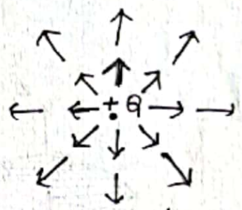
The divergence of $\bar{V}$ is denoted by $\nabla\cdot\bar{V}$ or div $\bar{V}$ is defined as

$$\nabla\cdot\bar{V} = \left(\frac{\partial}{\partial x}\bar{a}_x + \frac{\partial}{\partial y}\bar{a}_y + \frac{\partial}{\partial z}\bar{a}_z\right)\cdot\left(V_x\bar{a}_x + V_y\bar{a}_y + V_z\bar{a}_z\right) = \frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z}$$

Observe that the divergence of a vector function $\bar{V}$ is itself a scalar

Geometrical interpretation:

The name divergence is well chosen for $\nabla\cdot\bar{V}$ is a measure of how much the vector field $\bar{V}$ spreads out (diverges) from the point in question shown in figure



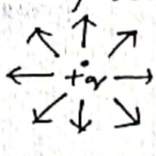
Definition: The divergence of a any vector field $\bar{A}$ is its integral over the closed surface bounded by an infinitesimal volume divided by that volume shrinks to zero.

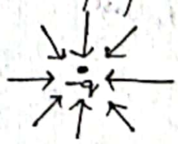
Divergence of A $\quad \text{div}A = \lim_{\Delta v \to 0} \frac{\oint \bar{A}\cdot d\bar{s}}{\Delta v}$

where Δv is the volume bounded by the closed surface S.

Divergence example: water in a pipe is in compressible i.e; flow in = flow out. Divergence of velocity vector field $\bar{V}$ is zero every where. Water can't diverge from any point. Considering the flow of gas, when the top valve of a cylinder is opened the gas flows out, the gas velocity is not same at all points, the divergence of velocity in this case is not zero - Gas velocity vector is diverging.

In electrostatics the EFI diverges (spread out) from positive charge and converges (negative divergence) at a negative charge shown $\longrightarrow$





The Curl

Curl $\vec{V}$ or $\nabla\times\bar{V}$, $\bar{V} = V_x\bar{a}_x + V_y\bar{a}_y + V_z\bar{a}_z$

$$\text{Curl}\bar{V} = \nabla\times V = \begin{vmatrix} \bar{a}_x & \bar{a}_y & \bar{a}_z \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ V_x & V_y & V_z \end{vmatrix}$$

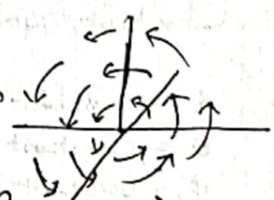
We may describe curl as circulation per unit area

mathematical form of definition

$$\text{Curl}\,\bar{V} = \nabla\times\bar{V} = \lim_{\Delta s \to 0} \frac{\oint \bar{V}\cdot d\bar{l}}{\Delta s}$$

where Δs is planar area enclosed by the closed line integral.

Interpretation



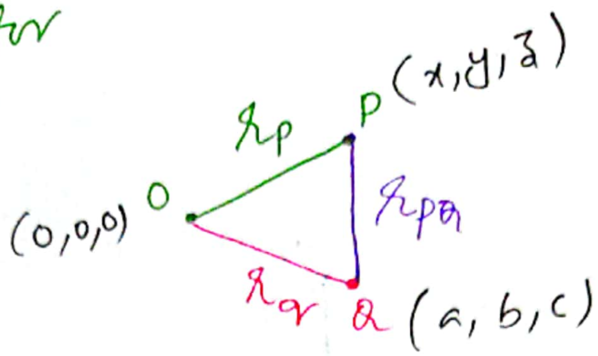
→ Curl deals with rotation.

→ Consider a water whirlpool, which is downwards, If a leaf is thrown into the pool it rotates and moves in downward direction

→ In this case direction of curl of vel vector is downward

→ Consider wind whirlpool, which is upwards. If a piece of paper is released here, it rotates and finally moves upwards

Position vector



position vector r_p

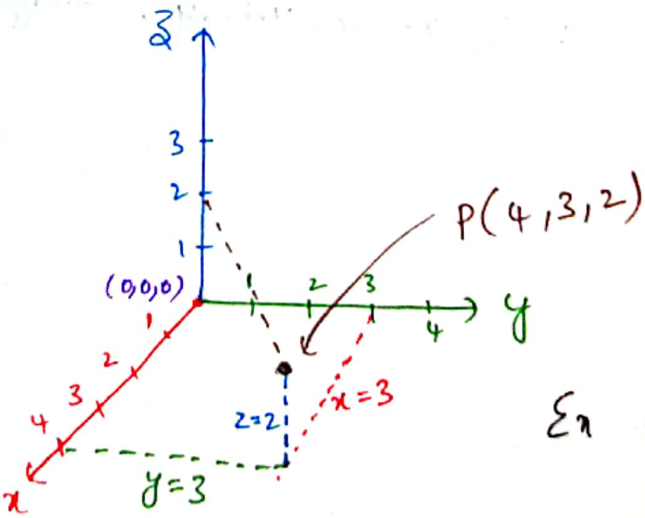
$$r_p = OP = (x-0)\,a_x + (y-0)\,a_y + (z-0)\,a_z$$
$$= x\,a_x + y\,a_y + z\,a_z$$

Distance vector

$$r_{pQ} = r_Q - r_P$$
$$= (a-x)\,\bar{a}_x + (b-y)\,\bar{a}_y + (c-z)\,\bar{a}_z$$

Illustration of position vector

$r_p = 4a_x + 3a_y + 2a_z$



Origin (0,0,0)

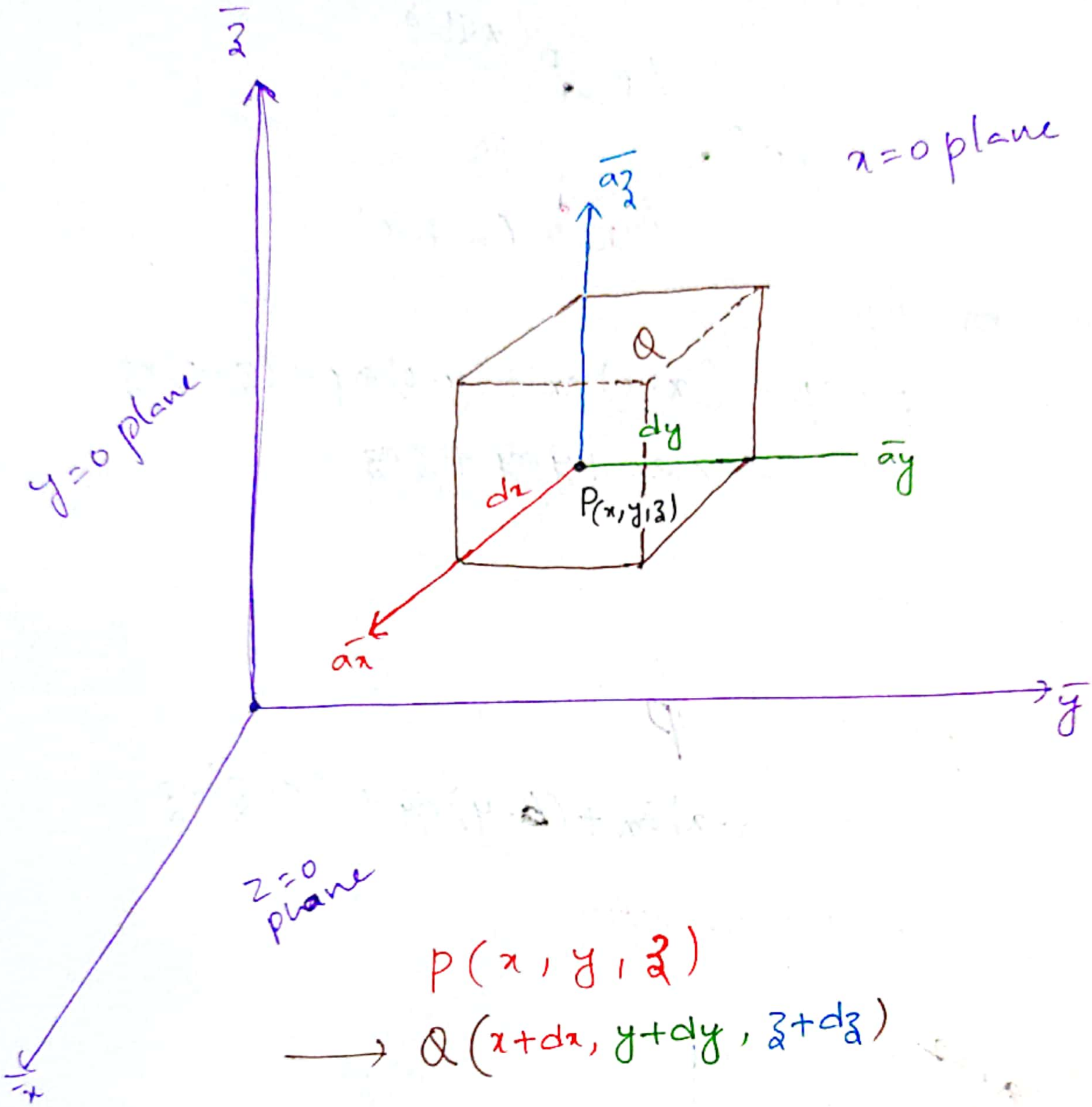
Ex P(0,2,4) Q(-3,1,5)

Ex (0,0,0) – (0,2,4)

$$r_p = (0-0)a_x + (2-0)a_y + (4-0)a_z = 0a_x + 2a_y + 4a_z = 2\bar{a}_y + 4\bar{a}_z$$

$$r_{pq} = r_q - r_p = (-3-0)\bar{a}_x + (1-2)a_y + (5-4)a_z = -3\bar{a}_x + \bar{a}_y + \bar{a}_z$$

$$|r_{pq}| = \sqrt{(-3)^2 + (-1)^2 + 1^2} = \sqrt{11} = 3.317$$



$P(x, y, z)$

$\longrightarrow Q(x+dx, y+dy, z+dz)$