

# QUICK STUDY ACADEMIC

# DYNAMICS

## NOTATIONS

- A. All scalar quantities are denoted by normal print, e.g., time,  $t$ . Also, the magnitude of vector quantities is denoted by normal print, e.g., velocity magnitude,  $v = |\mathbf{v}|$ .
- B. All vectors quantities are denoted by **italic bold print**, e.g., velocity vector,  $\mathbf{v}$ ; acceleration vector,  $\mathbf{a}$ .

## DEFINITIONS

- A. **Vector Components.** Any vector can be decomposed to a certain number of components based on the reference coordinate system.

### 1. Cartesian (Orthogonal) Coordinate System, $x$ - $y$ - $z$ :

$\mathbf{a} = a_x \mathbf{i} + a_y \mathbf{j} + a_z \mathbf{k} = a_x \mathbf{i} + a_y \mathbf{j} + a_z \mathbf{k} = a(\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z)$ , where  $\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z$  are the vector components and  $\mathbf{i}, \mathbf{j}, \mathbf{k}$  are the unit vectors along the axes  $x, y, z$  respectively.

### 2. Polar Coordinate System, $r$ - $\theta$ :

$\mathbf{a} = a_r \mathbf{e}_r + a_\theta \mathbf{e}_\theta = a(\mathbf{e}_r, \mathbf{e}_\theta)$ , where  $\mathbf{e}_r, \mathbf{e}_\theta$  are the vector components and  $\mathbf{e}_r$  and  $\mathbf{e}_\theta$  are the radial and transverse unit vectors respectively.



### 3. Spherical Coordinates System, $(r, \theta, \phi)$ :

$a_r = a \cos \theta \sin \phi$   
 $a_\theta = a \sin \theta \sin \phi$   
 $a_\phi = a \cos \phi$



### 4. Cylindrical Coordinate System, $(r, \theta, z)$ :

$a_r = a \cos \theta$   
 $a_\theta = a \sin \theta$   
 $a_z = a$



- B. **Scalar product** between two vectors  $\mathbf{a}$  and  $\mathbf{b}$  is defined as:

$\mathbf{a} \cdot \mathbf{b} = |\mathbf{a}||\mathbf{b}| \cos \phi = ab \cos \phi$  where  $\phi$  is the angle formed by the two vectors.

- C. **Vector product** between two vectors  $\mathbf{a}$  and  $\mathbf{b}$  is defined as:

$\mathbf{c} = \mathbf{a} \times \mathbf{b} = |\mathbf{a}||\mathbf{b}| \sin \phi \mathbf{e}_\phi = ab \sin \phi \mathbf{e}_\phi$ , where  $\phi$  is the angle formed by the two vectors, and  $\mathbf{e}_\phi$  is the unit vector perpendicular to the plane defined by the vectors  $\mathbf{a}$  and  $\mathbf{b}$ . Using a cartesian coordinate system the vector product can be defined as:  
 $\mathbf{c} = \mathbf{a} \times \mathbf{b} = (a_x \mathbf{i}_x + a_y \mathbf{i}_y + a_z \mathbf{i}_z) \times (b_x \mathbf{i}_x + b_y \mathbf{i}_y + b_z \mathbf{i}_z) = (a_x b_y - a_y b_x) \mathbf{i}_z + (a_y b_z - a_z b_y) \mathbf{i}_x + (a_z b_x - a_x b_z) \mathbf{i}_y$

- D. **Particles** are hypothetical bodies that do not possess any rotational characteristics. All points of a particle have the same displacement, velocity, and acceleration.

- E. **Rigid bodies** are objects whose points may have different displacement, velocity, and acceleration.
- F. **Kinematics** is the study of motion without considering the forces that cause the motion. Kinematics involve displacement, velocity, acceleration, and time.

- G. **Kinetics** is the study of motion as related to the forces causing the motion. Kinetics involve force, mass, and acceleration.

- H. **Path** is the curve that a particle follows as it moves through the space. The path can be a space curve called trajectory or a plane curve called plane path.

## KINEMATICS PARTICLE MOTION

### RECTILINEAR MOTION

**Rectilinear motion** is whenever particles move along a straight line. The governing equations regarding acceleration,  $\mathbf{a}$ , velocity,  $\mathbf{v}$ , and displacement (position coordinates),  $\mathbf{x}$ , for rectilinear motion are:

$$\mathbf{a} = dv/dt = d^2x/dt^2 = v(dv/dx); \quad \mathbf{v} = dx/dt \Rightarrow \int \mathbf{a} dt; \quad \mathbf{x} = \int \mathbf{v} dt \Rightarrow \int \int \mathbf{a} dt^2$$

Generally, all these variables,  $\mathbf{a}$ ,  $\mathbf{v}$ , and  $\mathbf{x}$ , are vectors. However, in the above equations these variables are treated as scalars, since the motion is rectilinear and their direction can be defined only by their sign (positive or negative).

- A. **Formulas for Uniformly Accelerated Rectilinear Motion.** Denoting the initial conditions ( $t = 0$ ) of the various variables by the subscript (0), the relationships between position coordinate,  $\mathbf{x}$ , velocity,  $\mathbf{v}$ , acceleration,  $\mathbf{a}$ , and time,  $t$ , are given as follows:

Given:	Estimate:
$\mathbf{x}_0, \mathbf{v}_0, \mathbf{a}, t$	$\mathbf{x} = \mathbf{x}_0 + \mathbf{v}_0 t + \frac{1}{2} \mathbf{a} t^2$
$\mathbf{x}_0, \mathbf{v}_0, \mathbf{a}, \mathbf{x}$	$\mathbf{x} = \mathbf{x}_0 + \frac{1}{2} \mathbf{a} (t^2 - t_0^2)$
$\mathbf{x}_0, \mathbf{v}_0, \mathbf{a}, t$	$\mathbf{x} = \mathbf{x}_0 + \frac{1}{2} \mathbf{a} (t^2 - t_0^2)$
$\mathbf{x}_0, \mathbf{a}, t$	$\mathbf{v} = \mathbf{v}_0 + \mathbf{a} t$
$\mathbf{x}_0, \mathbf{a}, \mathbf{v}_0, \mathbf{x}$	$\mathbf{v} = \sqrt{\mathbf{v}_0^2 + 2\mathbf{a}(\mathbf{x} - \mathbf{x}_0)}$
$\mathbf{x}_0, \mathbf{v}_0, t$	$\mathbf{a} = (\mathbf{v} - \mathbf{v}_0)/t$
$\mathbf{x}_0, \mathbf{v}_0, \mathbf{v}$	$\mathbf{a} = 2(\mathbf{x} - \mathbf{x}_0)/t^2$
$\mathbf{x}_0, \mathbf{v}_0, \mathbf{v}$	$\mathbf{a} = \frac{1}{2}(\mathbf{v}^2 - \mathbf{v}_0^2)/(\mathbf{x} - \mathbf{x}_0)$
$\mathbf{x}_0, \mathbf{a}, \mathbf{x}$	$t = (\mathbf{v} - \mathbf{v}_0)/\mathbf{a}$
$\mathbf{x}_0, \mathbf{a}, \mathbf{v}$	$t = [2\mathbf{a}(\mathbf{x} - \mathbf{x}_0) + \mathbf{v}_0^2]^{1/2} - \mathbf{v}_0/\mathbf{a}$
$\mathbf{x}_0, \mathbf{a}, \mathbf{v}$	$t = 2(\mathbf{x} - \mathbf{x}_0)/(\mathbf{v} + \mathbf{v}_0)$

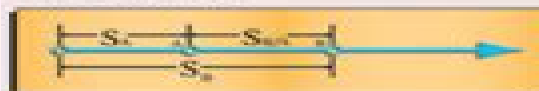


- B. A main example of uniformly accelerated rectilinear motion of free falling particles.

Other types of rectilinear motion include:  
 Non-accelerating motions,  $\mathbf{a} = \mathbf{a}_0 = \mathbf{v}_0/t$ ;  $\mathbf{v} = \mathbf{v}_0$   
 $\mathbf{a} = 0$ , or motions where the displacement decreases exponentially in time at a constant rate,  $-\mathbf{a}_0$ ,  $\mathbf{x} = \mathbf{x}_0 \exp(-\mathbf{a}_0 t)$ ;  $\mathbf{v} = -\mathbf{a}_0 \mathbf{x}_0 \exp(-\mathbf{a}_0 t)$ ; and  $\mathbf{a} = \mathbf{a}_0 \exp(-\mathbf{a}_0 t)$ .

### C. Relative Motion Between Two Particles A and B.

The position coordinate, velocity, and acceleration of particle B as related to particle A are defined as:  
 $\mathbf{r}_{B/A} = \mathbf{r}_B - \mathbf{r}_A$ ;  $\mathbf{v}_{B/A} = \mathbf{v}_B - \mathbf{v}_A$ ;  $\mathbf{a}_{B/A} = \mathbf{a}_B - \mathbf{a}_A$ , where  $\mathbf{r}_{B/A}$  is the distance between the two particles A and B, and  $\mathbf{v}_{B/A}$ ,  $\mathbf{a}_{B/A}$  are respectively the relative velocity and acceleration of particle B with respect to particle A.



### CURVILINEAR MOTION

**Curvilinear motion** is the motion where particles move along a curved path. The position of a particle is given by the position vector  $\mathbf{r}$ . The velocity,  $\mathbf{v}$ , and the acceleration,  $\mathbf{a}$ , for curvilinear motion are defined as:  
 $\mathbf{v} = d\mathbf{r}/dt$ ;  $|\mathbf{v}| = v = ds/dt$  (particle velocity,  $\mathbf{v}$ , is tangent to the particle's path,  $s$ );  $\mathbf{a} = dv/dt$  (particle acceleration,  $\mathbf{a}$ , is not tangent to the particle's path,  $s$ ).



### A. Cartesian Coordinate System (Rectangular Components):

$\mathbf{r} = r(\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z)$ ;  $\mathbf{v} = v(\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z)$ ;  $\mathbf{a} = a(\mathbf{i}_x, \mathbf{i}_y, \mathbf{i}_z)$   
 $\mathbf{v} = dx/dt \mathbf{i}_x + dy/dt \mathbf{i}_y + dz/dt \mathbf{i}_z$ ;  $\mathbf{a} = dv/dt \mathbf{i}_x + dv/dt \mathbf{i}_y + dv/dt \mathbf{i}_z$

### Circular Periodic Motion:

$\mathbf{x} = r \cos \theta(t)$ ;  $\mathbf{y} = r \sin \theta(t)$ ;  $\mathbf{v} = r \dot{\theta}(-\sin \theta, \cos \theta)$ ;  $\mathbf{a} = -r \dot{\theta}^2 \cos \theta \mathbf{i}_x - r \dot{\theta}^2 \sin \theta \mathbf{i}_y$ ;  $\mathbf{v} = r \dot{\theta} \mathbf{e}_\theta$   
 $\mathbf{a} = -r \dot{\theta}^2 \cos \theta \mathbf{i}_x - r \dot{\theta}^2 \sin \theta \mathbf{i}_y$ ;  $\mathbf{a} = -r \dot{\theta}^2 \mathbf{e}_r$

### Relative Motion Between Two Particles A and B:

$\mathbf{r}_{B/A} = \mathbf{r}_B - \mathbf{r}_A$ ;  $\mathbf{v}_{B/A} = \mathbf{v}_B - \mathbf{v}_A$ ;  $\mathbf{a}_{B/A} = \mathbf{a}_B - \mathbf{a}_A$

### B. Tangential and Normal Components:



1. **Two-Dimensional Motion:** For plane motion, the particle acceleration can be separated into two components, one tangential,  $\mathbf{a}_t$ , and one normal,  $\mathbf{a}_n$ .  $\mathbf{v} = v \mathbf{e}_t$ ;  $\mathbf{a} = \mathbf{a}_t + \mathbf{a}_n = (dv/dt) \mathbf{e}_t + (v^2/\rho) \mathbf{e}_n$ , where  $\mathbf{e}_t$  is the tangential acceleration,  $\mathbf{e}_n$  is the normal acceleration,  $\rho$  is the radius of curvature,  $\mathbf{e}_t$  is the tangential unit vector, and  $\mathbf{e}_n$  is the normal unit vector to the curved path of the particle.

2. **Three-Dimensional Motion:** Osculating plane in a three dimensional motion is the plane in the neighborhood of the moving particle that includes the unit vectors,  $\mathbf{e}_t$  (tangency) and  $\mathbf{e}_n$  (principal normal). The binormal unit vector,  $\mathbf{e}_b$ , is perpendicular to the osculating plane.

### C. Polar Coordinates System (Radial and Transverse Components in Plane Motion):

1. **Particle Velocity:**  
 $\mathbf{v} = v_r \mathbf{e}_r + v_\theta \mathbf{e}_\theta = (dr/dt) \mathbf{e}_r + r(d\theta/dt) \mathbf{e}_\theta$
2. **Particle Acceleration:**  
 $\mathbf{a} = a_r \mathbf{e}_r + a_\theta \mathbf{e}_\theta = (d^2r/dt^2 - r\dot{\theta}^2) \mathbf{e}_r + (2r\dot{\theta}d\theta/dt + r\ddot{\theta}) \mathbf{e}_\theta$ , where  $\mathbf{e}_r$  and  $\mathbf{e}_\theta$  are the unit radial and transverse unit vectors respectively.



# Dynamics Study Guide

**Valarie Balakrishnan**



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