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CHAPTER NOTES

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CHAPTER SUMMARY

Motion in a Plane extends one-dimensional kinematics to two dimensions using vectors, covering vector addition, dot and cross products, and motion under constant acceleration. It builds up to the chapter's most tested ideas, projectile motion, relative velocity, and uniform circular motion. For...

... see more

CHAPTER NOTES

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Key Concepts

1. Scalars and Vectors

A **scalar** is a quantity that has only magnitude — like mass, time, speed, distance, energy, or temperature. You can add scalars with ordinary arithmetic.

A **vector** has both magnitude and direction, and it follows the triangle (or parallelogram) law of addition. Displacement, velocity, acceleration, force, and momentum are vectors. A vector is written in bold (**A**) or with an arrow, and its magnitude is written |**A**| or simply A.

Types of Vectors

- **Equal vectors:** same magnitude and same direction.
- **Unit vector:** a vector of magnitude 1 used to show direction; Â = **A**/|**A**|.
- **Zero (null) vector:** magnitude zero, arbitrary direction; result of adding a vector to its negative.
- **Negative vector:** same magnitude, opposite direction (−**A**).
- **Collinear vectors:** act along the same or parallel lines.

2. Unit Vectors

A **unit vector** has a magnitude of exactly one and only specifies direction. The standard unit vectors along the x, y and z axes are **î, ĵ, k̂** respectively.

Any vector can be written in terms of unit vectors: **A = A_x î + A_y ĵ + A_z k̂**

- î, ĵ, k̂ are mutually perpendicular (orthogonal).
- Each has magnitude 1 and no units.
- The unit vector of any vector is Â = **A**/|**A**|.

3. Addition of Vectors — Triangle Law

The **triangle law** states that if two vectors are represented by two sides of a triangle taken in order, their resultant is given by the third side taken in the opposite order.

[DIAGRAM: Vector A drawn head-to-tail with vector B; the closing side from the tail of A to the head of B is the resultant R = A + B.]

Vector addition is **commutative** (A + B = B + A) and **associative** (A + (B + C) = (A + B) + C).

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4. Addition of Vectors — Parallelogram Law

The **parallelogram law** states that if two vectors acting at a point are represented by two adjacent sides of a parallelogram, their resultant is represented by the diagonal passing through that point.

For two vectors A and B with angle θ between them, the magnitude of the resultant R is:

$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$

The direction of the resultant (angle β with A) is given by:

$\tan\beta = (B\sin\theta)/(A + B\cos\theta)$

- When $\theta = 0°$: $R = A + B$ (maximum).
- When $\theta = 180°$: $R = |A - B|$ (minimum).
- When $\theta = 90°$: $R = \sqrt{A^2 + B^2}$.

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5. Subtraction of Vectors

Subtracting a vector means adding its negative: **A − B = A + (−B)**. So to subtract B, reverse its direction and add it to A using the triangle law.

Magnitude: **$|A - B| = \sqrt{A^2 + B^2 - 2AB\cos\theta}$**

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6. Resolution of Vectors

Splitting a vector into two or more components is called **resolution**. The most useful is resolving a vector into two mutually perpendicular components (rectangular components).

If a vector A makes an angle θ with the x-axis:

- **x-component:** $A_x = A\cos\theta$
- **y-component:** $A_y = A\sin\theta$

Then **$A = A_x\,\hat{i} + A_y\,\hat{j}$**, with magnitude $A = \sqrt{A_x^2 + A_y^2}$ and direction $\tan\theta = A_y/A_x$.

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7. Analytical Method of Vector Addition

To add several vectors accurately, resolve each into components, add the components separately, then recombine.

If R = A + B, then:

- **$R_x = A_x + B_x$**
- **$R_y = A_y + B_y$**

Magnitude: **$R = \sqrt{R_x^2 + R_y^2}$**, and direction $\tan\alpha = R_y/R_x$. This method extends easily to any number of vectors and to three dimensions.

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8. Motion in a Plane with Constant Acceleration

In two dimensions, position, velocity and acceleration are all vectors, and motion along x and y is independent. The equations of motion apply separately to each axis.

- **$v = u + at$** → $v_x = u_x + a_x t$, $v_y = u_y + a_y t$
- **$r = r_0 + ut + \frac{1}{2}at^2$**
- **$v^2 = u^2 + 2a\cdot s$** (along each axis)

Key idea: The horizontal and vertical motions are independent — this is exactly what makes projectile motion solvable.

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9. Projectile Motion

A **projectile** is any object thrown into the air that moves under gravity alone (air resistance neglected). Its path is a **parabola**. The horizontal velocity stays constant; the vertical velocity changes due to g.

For a projectile launched with speed u at angle θ to the horizontal:

- **Horizontal velocity:** $u_x = u \cos \theta$ (constant)
- **Vertical velocity:** $u_y = u \sin \theta$ (decreases, then increases)

Key Projectile Equations

Quantity	Formula
Time of flight (T)	$T = (2u \sin \theta)/g$
Maximum height (H)	$H = (u^2 \sin^2\theta)/(2g)$
Horizontal range (R)	$R = (u^2 \sin 2\theta)/g$
Equation of path	$y = x \tan \theta - (gx^2)/(2u^2\cos^2\theta)$

Maximum range occurs at $\theta = 45°$, giving $R_{max} = u^2/g$. Two complementary angles (θ and $90° - \theta$) give the same range.

Horizontal Projectile

For a body projected horizontally with speed u from height h: time of fall $t = \sqrt{(2h/g)}$, and horizontal range $= u\sqrt{(2h/g)}$.

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10. Uniform Circular Motion

When a body moves along a circle at constant speed, it is in **uniform circular motion**. The speed is constant, but the velocity keeps changing direction, so the body is accelerating.

Angular Velocity

Angular velocity (ω) is the rate of change of angular displacement. It links to linear speed by $v = \omega r$.

- $\boldsymbol{\omega = \theta/t = 2\pi/T = 2\pi n}$, where T is the time period and n is frequency.
- **SI unit:** radian per second (rad/s).
- Linear speed: $\boldsymbol{v = \omega r}$

Centripetal Acceleration

The acceleration in uniform circular motion always points towards the centre and is called **centripetal acceleration**.

$$a_c = v^2/r = \omega^2 r = (4\pi^2 r)/T^2$$

Important: In uniform circular motion the speed is constant, so there is no tangential acceleration — only the centre-directed centripetal acceleration that changes direction.

Read the rest of the chapter →

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Vectors and Components

A vector has both magnitude and direction, so it adds tip-to-tail, never by plain arithmetic.

$$A_x = A\cos\theta \cdot A_y = A\sin\theta \cdot A = \sqrt{(A_x^2 + A_y^2)}$$

Resolve into ⊥ components first, add component-wise, then recombine.

- ✓ Scalar = size only (mass, speed); vector = size + direction (velocity, force)
- ✓ A component can never exceed the vector (cos, sin ≤ 1)
- ✓ Unit vector $\hat{n}$ has magnitude 1 — direction only, no size

Core law 2/9

Resultant of Two Vectors

Combine two vectors at angle θ using the parallelogram law.

$$R = \sqrt{(A^2 + B^2 + 2AB\cos\theta)} \cdot \tan\alpha = (B\sin\theta)/(A + B\cos\theta)$$

α is the direction of R measured from vector A.

- ✓ Max resultant = A + B at θ = 0° (parallel)
- ✓ Min resultant = |A − B| at θ = 180° (antiparallel)
- ✓ At θ = 90°: R = $\sqrt{(A^2 + B^2)}$

Key tool

Dot and Cross

Two ways to multiply v… number, cross gives a…

$$A \cdot B = AB\cos\theta$$

Dot ⊥ → 0 (work F·d);

- ✓ Dot = 'how para… perpendicular' (
- ✓ Components: A·
- ✓ |A×B| = area of p… (B×A)

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Q1 NEET 2021

A particle moving in a circle of radius R with a uniform speed takes a time T to complete one revolution. If this particle were projected with the same speed at an angle θ to the horizontal, the maximum height attained by it equals 4R. The angle of projection θ is then given by

- A $\theta = \cos^{-1}[(gT^2)/(\pi^2R)]^{(1/2)}$
- B $\theta = \cos^{-1}[(\pi^2R)/(gT^2)]^{(1/2)}$
- C $\theta = \sin^{-1}[(\pi^2R)/(gT^2)]^{(1/2)}$
- D $\theta = \sin^{-1}[(2gT^2)/(\pi^2R)]^{(1/2)}$

Q2 NEET 2019

The speed of a swimmer in still water is 20 m/s. The speed of river water is 10 m/s and is flowing due east. If he is standing on the south bank and wishes to cross the river along the shortest path the angle at which he should make his strokes w.r.t. north is given by

- A 0°
- B 60° west
- C 45° west
- D 30° west

Q3 NEET 2019

Two bullets are fired horizontally and simultaneously towards each other from roof tops of two buildings 100 m apart and of same height of 200 m with the same velocity of 25 m/s. When and where will the two bullets collide? ($g = 10\ m/s^2$)

A After 2 s at a height 180 m

B After 2 s at a height of 20 m

C After 4 s at a height of 120 m

D They will not collide

Q4 NEET 2017

The x and y coordinates of the particle at any time are $x = 5t - 2t^2$ and $y = 10t$ respectively, where x and y are in metres and t in seconds. The acceleration of the particle at t = 2 s is

A 0

B $5\ m/s^2$

C $-4\ m/s^2$

D $-8\ m/s^2$

Q5 NEET 2016

If the magnitude of the sum of two vectors is equal to the magnitude of the difference of the two vectors, the angle between these vectors is

A 90°

B 45°

C 180°

D 0°

Q6 NEET 2016

In the figure, $a = 15\ m/s^2$ represents the total acceleration of a particle moving in the clockwise direction in a circle of radius R = 2.5 m at a given instant of time. The speed of the particle is

A 4.5 m/s

B 5.0 m/s

C 5.7 m/s

D 6.2 m/s

Q7 NEET 2015

If vectors $A = \cos\omega t\,\hat{i} + \sin\omega t\,\hat{j}$ and $B = \cos(\omega t/2)\,\hat{i} + \sin(\omega t/2)\,\hat{j}$ are functions of time, then the value of t at which they are orthogonal to each other is

A $t = \pi/(4\omega)$

B t = π/(2ω)

C t = π/ω

D t = 0

Q8 NEET 2014

A particle is moving such that its position coordinates (x, y) are (2 m, 3 m) at time t = 0, (6 m, 7 m) at time t = 2 s and (13 m, 14 m) at time t = 5 s. The average velocity vector v(avg) from t = 0 to t = 5 s is

A (1/5)(13î + 14ĵ)

B (7/3)(î + ĵ)

C 2(î + ĵ)

D (11/5)(î + ĵ)

Q9 NEET 2007

A and B are two vectors and θ is the angle between them. If $|A \times B| = \sqrt{3}(A \cdot B)$, the value of θ is

A 60°

B 45°

C 30°

D 90°

Q10 NEET 2005

If a vector 2î + 3ĵ + 8k̂ is perpendicular to the vector 4ĵ − 4î + αk̂, then the value of α is

A −1

B 1/2

C −1/2

D 1

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Frequently Asked Questions

What is the difference between a scalar and a vector?

A scalar has only magnitude, such as mass, speed or distance, while a vector has both magnitude and direction, such as displacement, velocity or force. Vectors must be added tip-to-tail or by components, never by simple arithmetic.

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What are the key projectile motion formulas?

For a projectile launched at speed u and angle theta, the time of flight is T = 2u sin(theta)/g, the maximum height is H = u squared sin squared(theta)/2g, and the horizontal range is R = u squared sin(2 theta)/g. The horizontal velocity u cos(theta) stays constant while the vertical velocity changes...

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Why does an object in uniform circular motion accelerate if its speed is constant?

Even at constant speed the direction of the velocity keeps changing, and any change in velocity is an acceleration. This centripetal acceleration, a = v squared/r = omega squared r, always points toward the centre, perpendicular to the velocity.

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Is Motion in a Plane important for NEET?

Yes, it is a high-weightage Class 11 mechanics chapter and questions on projectile motion, vectors and circular motion appear almost every year. Its vector methods are also reused in later chapters like Laws of Motion and Work, Energy and Power.

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What is the difference between the dot product and the cross product of two vectors?

The dot product A.B = AB cos(theta) gives a scalar and is zero when the vectors are perpendicular, as in work F.d. The cross product has magnitude AB sin(theta), gives a vector perpendicular to both, and is zero when the vectors are parallel, as in torque r cross F.

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