

Describing Rotational Motion



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فيزياء:

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التواصل الاجتماعي بحسب الصف الحادي عشر المتقدم



صفحة المناهج
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المزيد من الملفات بحسب الصف الحادي عشر المتقدم والمادة فيزياء في الفصل الأول

انسباير Rotational Dynamics

1

الحركة الدائرية

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اختبار مطابق لمخرجات الهيكل الوزاري منهج انسباير

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حل مراجعة شاملة وفق الهيكل الوزاري منهج انسباير

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مراجعة نهائية وفق الهيكل الوزاري الجديد منهج بريدج

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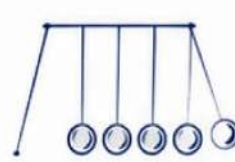
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Einstein of the Arabs

مصدرك الأول

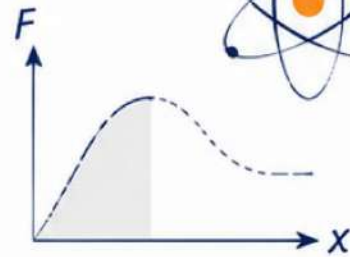
— للعلامة —

الكاملة ✓

في الفيزياء



$$E = mc^2$$



استاذ

عبدالرحمن عصام عيد



معك خطوة بخطوة
نحو التفوق والتميز



0509886279



Einsteinabdo

Einstein_AE



LESSON 1: DESCRIBING ROTATIONAL MOTION



LEARNING OBJECTIVES

By the end of this lesson, students will be able to:

- ✓ Define angular position, angular displacement, and the radian.
- ✓ Convert angles between degrees and radians.
- ✓ Apply the sign convention: counterclockwise positive, clockwise negative.
- ✓ Relate arc length to angular displacement and radius ($x = r\theta$).
- ✓ Define and calculate angular velocity and angular acceleration.
- ✓ Relate tangential (linear) velocity and acceleration to their angular counterparts.
- ✓ Explain why every point on a rigid rotating object shares the same angular quantities but different linear quantities.
- ✓ Relate frequency, period, and angular frequency.
- ✓ Interpret data and graphs from an experiment testing $v = r\omega$.
- ✓ Solve single-step and multi-step examination problems on rotational variables.

Introduction

A bicycle wheel spinning down a street, a car tire gripping the road, an electric fan cooling a room, a turbine spinning inside a power plant, and the Earth turning once a day — all of these are examples of the same kind of motion: **rotation about an axis**. Every point on the object stays the **same distance from that axis** and sweeps through the **same angle in the same time**, even though points at different distances from the axis cover different amounts of ground.

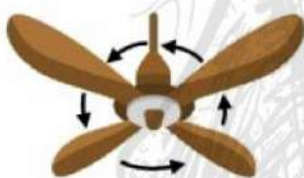


So far, motion has been described using **linear quantities** — **position**, **velocity**, and **acceleration** measured in meters and seconds. **Rotational motion** needs its own set of quantities — **angular position**, **angular velocity**, and **angular acceleration** — which behave in a directly parallel way to their **linear counterparts**. This lesson builds that parallel system from the ground up and connects it back to the linear quantities already familiar from earlier chapters.

Translational vs. Rotational Motion

Translational motion occurs when every point of an object moves the **same distance**, in the **same direction**, over the **same time interval** — such as a car travelling straight down a road.

Rotational motion occurs when an object **spins or turns about a fixed axis**, so that different points on the object move along **circular paths of different radii**, even though they all sweep the same angle.



(a) Motion of a ceiling fan



(b) Motion of Earth about its axis



(c) Motion of a spinning top

Examples of rotational motion

Aspect	Translational Motion	Rotational Motion
Type of path	Straight or curved line	Circular path about a fixed axis
Position variable	Linear position, x (m)	Angular position, θ (rad)
Core variables	x, v, a	θ, ω, α
Typical example	A car driving down a road	A wheel spinning on its axle

1. Angular Position

Angular position (θ) is the **rotational analogue of linear position** — it tells you how far a rotating line has turned from a **fixed reference direction**, usually the **positive x-axis**, measured **counterclockwise by convention**. It can be expressed in **degrees, radians, or revolutions**.

θ = **angle measured from the positive x – axis ($^\circ$, rad, or rev)** *Exam*

connection: *Exam questions rarely ask for angular position alone — it is almost always the starting point for calculating angular displacement.*

Radian–Degree Conversion

To convert from rad $\rightarrow$ degree

$$\text{degree} = \text{radian} \times \frac{180^\circ}{\pi}$$

To convert from degree $\rightarrow$ rad

$$\text{radian} = \text{degree} \times \frac{\pi}{180^\circ}$$

Revolution (rev)

A revolution (rev) represents one complete rotation around a circle. Because one full rotation corresponds to an angle of:

$$360^\circ = 2\pi \text{ rad} = 1 \text{ rev}$$

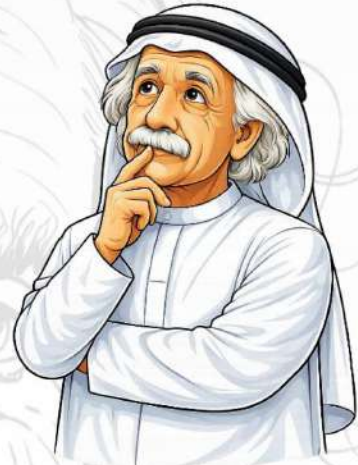
Conversion Between rev and rad

1. From Revolution to Radians

$$\text{Radians} = \text{rev} \times 2\pi$$

2. From Radians to Revolutions

$$\text{rev} = \frac{\text{radians}}{2\pi}$$



2. Angular Displacement

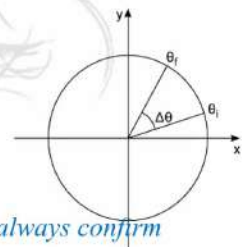
Angular displacement ($\Delta\theta$) is the **change in angular position** of a rotating line as an object turns — the **rotational analogue of linear displacement**. It is a **vector quantity**, so **direction** matters as much as **size** (magnitude).

$$\Delta\theta = \theta_f - \theta_i$$

Sign Convention

- Counterclockwise (CCW) rotation $\rightarrow$ positive angular displacement
- Clockwise (CW) rotation $\rightarrow$ negative angular displacement

Exam connection: *The sign convention is one of the most heavily tested ideas in this lesson — always confirm the direction of rotation before assigning a sign to θ , ω , or α .*



The Physics of a Clock

A standard clock has three hands. To solve rotational motion problems, you must know how long it takes each hand to complete **one full revolution** (1 rev = 2π rad). This time is called the **Period (T)**.

1. The Second Hand:

Completes 1 full revolution every **60 seconds** (1 minute).

2. The Minute Hand:

Completes 1 full revolution every **60 minutes** (1 hour).

3. The Hour Hand:

Completes 1 full revolution every **12 hours**.



Einstein_AE Quick Formula: $\Delta\theta = -\left(\frac{\text{Given Time}}{\text{Hand's Period}}\right) \times 2\pi \text{ rad}$

Viewing Direction and the Sign of Rotation

Viewed from above the **North Pole**, Earth rotates **counterclockwise** (west to east) its rotation is **positive**.

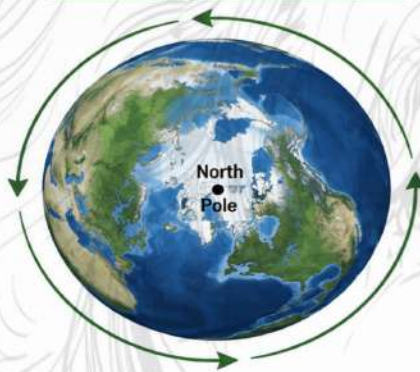
Viewed from above the **South Pole**, that same rotation appears **clockwise** it is **negative** — identical physical motion, opposite sign.



EARTH'S ROTATION: DIRECTION AND SIGN

i Earth rotates on its axis from **west to east**. The appearance of this motion depends on the viewpoint.

VIEW FROM ABOVE THE NORTH POLE

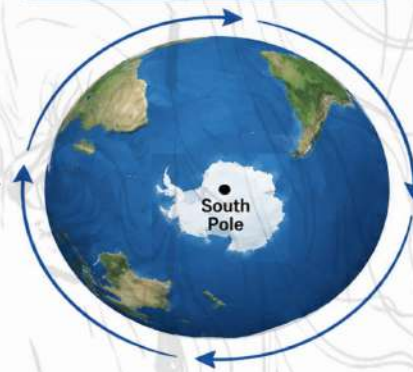


1 DIRECTION: When viewed from above the North Pole, Earth rotates **counter-clockwise** from west to east.



SIGN: In physics and mathematics, counter-clockwise is the **positive** direction (+).

VIEW FROM ABOVE THE SOUTH POLE



2 DIRECTION: When viewed from above the South Pole, the rotation appears **clockwise**.



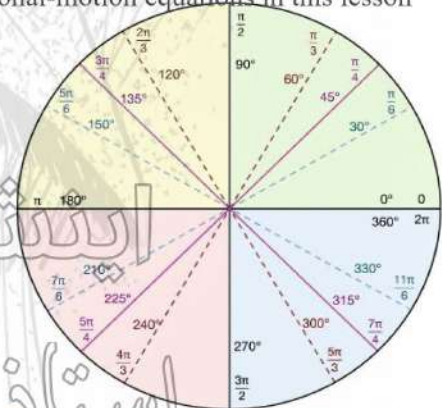
SIGN: Clockwise is the **negative** direction (-).

Exam connection: Before assigning a sign to θ , ω , or α , always confirm which side the rotation is being viewed from — a rotation isn't inherently positive or negative; its sign is only fixed once the observer's vantage point is specified.

3. Radians and Angular Measurement

One radian is the angle subtended at the center of a circle by an arc whose length equals the radius of that circle. Because the radian ties an angle directly to a ratio of two lengths (arc length ÷ radius), it is a "natural," unit-free measure of angle — which is exactly why the rotational-motion equations in this lesson require θ to be in radians, not degrees.

Conversion	Formula
Degrees → Radians	$\text{radians} = \text{degrees} \times (\pi / 180^\circ)$
Radians → Degrees	$\text{degrees} = \text{radians} \times (180^\circ / \pi)$
Reference	$360^\circ = 2\pi \text{ rad} = 1 \text{ revolution}$



Exam connection: A missed degree-to-radian conversion is the single most common source of wrong answers in rotational-motion problems — always check the unit of θ before substituting into an equation.

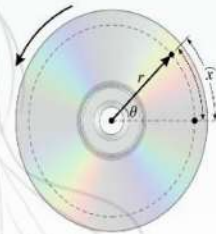
LESSON 1 DESCRIBING ROTATIONAL MOTION

Fill in the missing values. Convert each angle from degrees to radians and from radians to degrees.

Degrees (°)	32°	95°	217°	—	—	12°	—	—
Radians (rad)	—	—	—	π	$\pi/5$	—	3 rad	2.4 rad

3. Arc Length

When an object rotates through an angle θ , a point located a distance r from the axis traces out an arc. The length of that arc, x , depends on both the radius and the angle swept — but only when θ is expressed in radians.



$$x = r\theta \quad (\theta \text{ must be in radians}) \quad \theta = \frac{x}{r}$$

Exam connection: Arc-length problems frequently hide a degree-to-radian conversion inside the question — read the given angle's unit carefully before applying $x = r\theta$.

4. Angular Velocity

Angular velocity (ω) describes how fast an object's angular position changes with time — the rotational analogue of linear velocity. The average angular velocity over a time interval is the angular displacement divided by the time taken; the instantaneous angular velocity is the value at one particular moment (found from the slope of a θ - t graph at that instant).

Where:

✓ ω = angular velocity

✓ $\Delta\theta = \theta_f - \theta_i$

✓ $\Delta t = t_f - t_i$

$$\omega = \frac{\Delta\theta}{\Delta t} \quad [\text{rad/s}]$$

Units of Angular Velocity

1. The SI Base Unit

The standard unit for angular velocity (ω) is **radians per second (rad/s)**.

2. Important Conversions

In exam problems, angular velocity is often given in other practical units. You must convert them to **rad/s** using the following rules:

- **Revolutions per minute (rpm):**

To convert from rpm to rad/s, multiply by $\frac{2\pi}{60}$.

$$\omega = \text{rpm} \times \frac{2\pi}{60}$$

- **Revolutions per second (rev/s or Hz):**

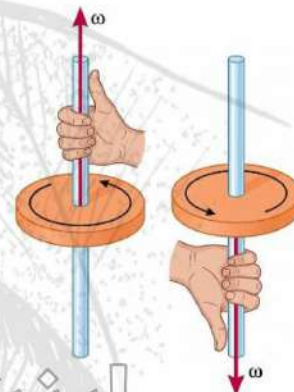
To convert from rev/s to rad/s, multiply by 2π .

$$\omega = \text{rev/s} \times 2\pi$$

- **Degrees per second (deg/s):**

To convert from degrees to radians, multiply by $\frac{\pi}{180}$.

$$\omega = \text{deg/s} \times \frac{\pi}{180}$$



Sign Conventions

- **Counterclockwise (CCW)** → Positive angular velocity
- **Clockwise (CW)** → Negative angular velocity

Exam connection: Distinguish "average angular velocity" (uses total $\Delta\theta$ and Δt) from "instantaneous angular velocity" (a single point on a θ - t graph).

5. Tangential Velocity

Every point on a **rotating rigid object** shares the **same angular velocity**, but points **do not all move at the same linear speed**. The **tangential (linear) speed** of a point depends on **how far that point sits from the axis of rotation**: points **farther from the axis** sweep out a **longer arc in the same time**, so they **move faster** along their circular path.

$$v = r\omega$$

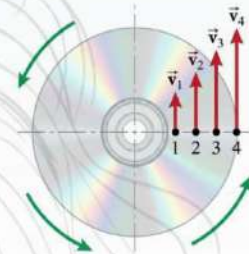
Where:

- v = linear (tangential) speed
- r = distance from the center (radius)
- ω = angular velocity (rad/s)

Note: *Linear Speed is Directly Proportional to Radius*

Near the Axis vs. Far from the Axis

- A point **close to the axis** (small r) has a **small tangential speed**,
- even though ω is the same as every other point.
- A point **far from the axis** (large r) has a **larger tangential speed**, for that same ω .



Tangential (Linear) Speed vs. Angular Speed

The diagram shows two points on the same **rigid rotating disk**:

- **Point A** is at **radius (r_A)** from the center **farther from the axis**.
- **Point B** is at **radius (r_B)** from the center **closer to the axis**, where ($r_A > r_B$).

Both points belong to the **same rigid body**, which rotates with a **single angular velocity (ω)**.

1. Angular Speed — Same for Both Points

Because **A** and **B** are part of the same rigid disk, they sweep through the same angular displacement in the same amount of time.

$$\omega_A = \omega_B = \omega$$

Therefore, all points on a rigid rotating body have the same **angular speed**.

2. Tangential (Linear) Speed — Different for Each Point

Tangential speed depends on the point's distance from the axis of rotation:

$$v = r\omega$$

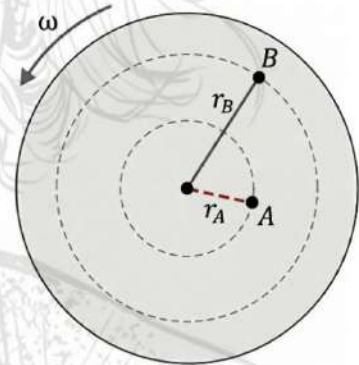
- **For Point A:**

$$v_A = r_A \omega$$

- **For Point B:**

$$v_B = r_B \omega$$

Since $r_A < r_B$ and both points have the same ω , then: $v_A < v_B$



Note 1 — Meshed Gears

Two touching gears are **separate bodies** linked only at the **contact point**. • That point moves **without slipping**, so **linear speed is equal there** ($v_1 = v_2$). • Since $v = r\omega$, **different radii** → **different angular speeds** ($r_1\omega_1 = r_2\omega_2$).

Note 2 — Minute Hand

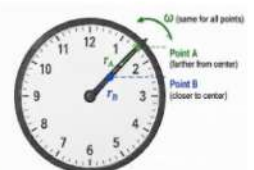
The hand is **one rigid body**, so **every point** shares the **same angular speed** (and $\Delta\theta, \alpha$). **Linear speed differs**, since $v = r\omega$ and r differs along the hand.

Rule: Two bodies touching → shared **linear** speed at contact.

One rigid body → shared **angular** quantities throughout.

Exam connection:

This radius-dependence of tangential speed while angular velocity stays the same for every point



Earth's Angular Velocity — A Rigid-Body Case Study

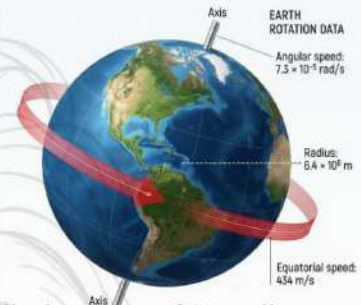
The Earth completes one full rotation on its axis every 24 hours.

In physics, this defines the **Period** (T) of the Earth's rotation: $T = 24$ hours

1. Converting the Time

To work in rad/s, the rotation period must be in seconds.

$$T = 24 \text{ h} \left(\frac{60 \text{ min}}{1 \text{ h}} \right) \left(\frac{60 \text{ s}}{1 \text{ min}} \right) = 86,400 \text{ s}$$



Note: One full rotation (one complete revolution) is equivalent to an angular displacement of 2π radians.

Mathematical Relationship: 1 rotation = 2π radians

2. Calculating Angular Velocity

Using the standard formula for angular velocity ($\omega = \frac{\Delta\theta}{\Delta t}$):

$$\omega_E = \frac{2\pi \text{ rad}}{86,400 \text{ s}} = 7.27 \times 10^{-5} \text{ rad/s}$$

3. Direction of Rotation

Earth spins on an axis through the North and South Poles, turning from **west to east**. That's why the Sun appears to rise in the east: the ground beneath an observer moves eastward, toward the sunrise.

- **Viewed from above the North Pole:** This motion looks counterclockwise → **Positive**.
- **Viewed from above the South Pole:** The same motion looks clockwise → **Negative**.

Conclusion: Using the standard North-Pole viewpoint, ω_E is considered positive.

4. Linear Speed at the Equator

To find how fast a point on the equator is moving through space, we use the linear speed formula: $v = r\omega$

Given Earth's radius $r = 6.38 \times 10^6 \text{ m}$:

$$v_{\text{equator}} = (6.38 \times 10^6 \text{ m})(7.27 \times 10^{-5} \text{ rad/s}) \approx 464 \text{ m/s}$$

5. Earth as a Rigid Body

- **Distance varies:** A point near the poles barely moves in one rotation, while a point at the equator sweeps a huge distance.
- **Angle is constant:** But every point — whether near the poles or at the equator — sweeps through the exact **same angle** in the exact **same time**.
- **Constant Angular Velocity:** Because of this, every part of Earth shares the same angular velocity: $\omega_E = 7.27 \times 10^{-5} \text{ rad/s}$.

Exam connection: This example beautifully combines time-unit conversion, sign convention, the $v = r\omega$ relationship, and rigid-body reasoning.

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6. Angular Acceleration

Angular acceleration (α) describes how quickly angular velocity changes with time — it tells you whether a rotating object is **speeding up**, **slowing down**, or **reversing its spin**.

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{(\omega_f - \omega_i)}{(t_f - t_i)} \quad [\text{rad/s}^2]$$

Sign Convention

- **Positive α :** angular velocity is **increasing in the counterclockwise direction** (or **decreasing in the clockwise direction**).
- **Negative α :** angular velocity is **decreasing in the counterclockwise direction** (or **increasing in the clockwise direction** — i.e. **speeding up while spinning clockwise**).

Example: A fan speeds up from 2.0 rad/s to 8.0 rad/s in 3.0 s: $\alpha = \frac{8.0 - 2.0}{3.0} = 2.0 \text{ rad/s}^2$.

Exam connection: A negative α does not always mean "slowing down" — it means the angular velocity is changing in the clockwise (negative) sense, which could mean speeding up if the object is already rotating clockwise.

7. Tangential Acceleration

Just as **tangential velocity depends on radius**, so does **tangential acceleration** — the **rate of change of a point's tangential speed**. Two points on the **same rotating rigid object** share the **same angular acceleration (α)**, but the point **farther from the axis** experiences a **larger tangential acceleration (a_t)**.

$$a = r\alpha$$

Example: A gear has **angular acceleration $\alpha = 4.0 \text{ rad/s}^2$** . A tooth at **$r = 0.02 \text{ m}$** has **$a_t = 0.08 \text{ m/s}^2$** ; a tooth at **$r = 0.06 \text{ m}$** (three times farther out) has **$a_t = 0.24 \text{ m/s}^2$** — **three times larger**.

Principle: Since both teeth are on the **same rigid gear**, the angular acceleration is constant ($\alpha = \text{constant}$).

Relation: From $a_t = r\alpha$, the tangential acceleration is **directly proportional** to the radius: $a_t \propto r$

Ratio Formula:

$$\frac{a_2}{a_1} = \frac{r_2}{r_1} \Rightarrow \frac{a_2}{0.08} = \frac{0.06}{0.02}$$

$$a_2 = 0.24 \text{ m/s}^2$$

Exam connection: Comparison questions between two radii on the same object are common — remember that α is identical for both points, but $a = r\alpha$ is not.

8. Linear–Angular Relationships

The **three pairs of linear and angular quantities** introduced so far are summarized below. In every case, the **linear quantity equals the angular quantity multiplied by the radius r** — provided the angular quantity is **expressed in radians** (or rad/s, or rad/s²).

$$\text{Linear Quantity} = \text{Angular Quantity} \times r$$

Quantity	Linear	Angular	Relationship
Displacement	$x \text{ (m)}$	$\theta \text{ (rad)}$	$x = r\theta$
Velocity	$v \text{ (m/s)}$	$\omega \text{ (rad/s)}$	$v = r\omega$
Acceleration	$a \text{ (m/s}^2\text{)}$	$\alpha \text{ (rad/s}^2\text{)}$	$a = r\alpha$

Exam connection: Mixed problems often give a linear quantity and ask for the corresponding angular quantity (or vice-versa) — identify r first, then choose the matching row of this table.

9. Frequency, Period & Angular Frequency

Frequency (f) is the number of complete revolutions an object makes per second. Period (T) is the time needed for one complete revolution. Angular frequency — which, for a steadily rotating object, is numerically the same as its angular velocity (ω) — expresses that same rotation rate in radians per second.

$$f = \frac{\omega}{2\pi} \quad \omega = 2\pi f \quad T = \frac{1}{f}$$

Quantity	Symbol	Meaning	SI Unit
Frequency	f	Revolutions per second	Hz (s^{-1})
Period	T	Time for one revolution	s
Angular frequency	ω	Radians swept per second	rad/s

Exam connection: Students often confuse f (Hz) with ω (rad/s) — remember the factor of 2π that converts one into the other.

10. Rigid Body Rotation

A rigid body is a solid object in which deformation can be neglected — the distance between any two points on the object stays constant as it moves. Because of this, every point on a rotating rigid body sweeps through the same angle in the same time, so all points share identical angular quantities (θ , ω , α). However, points at different distances from the axis trace different-length paths, so their linear (tangential) quantities differ (x , v , a_t).

Same for every point on the object	Different at each point (depends on r)
Angular displacement, $\Delta\theta$	Arc length, $x = r\theta$
Angular velocity, ω	Tangential velocity, $v = r\omega$
Angular acceleration, α	Tangential acceleration, $a = r\alpha$

This is because θ , ω , and α describe how much angle is swept — a property of the whole rigid object — while x , v , and a describe actual distance travelled, which naturally depends on how far a given point sits from the axis.

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Experimental Investigation: $v = r\omega$

Aim: To verify the relationship between the tangential speed of a point on a rotating disk and its distance from the axis of rotation (r).

Equipment: • A motorized turntable (or rotating disk) with adjustable, controllable speed • A meter rule • Marker points fixed at several radii • A stopwatch or photogate timer



Independent variable: the radius, r , of each marked point (distance from the center).

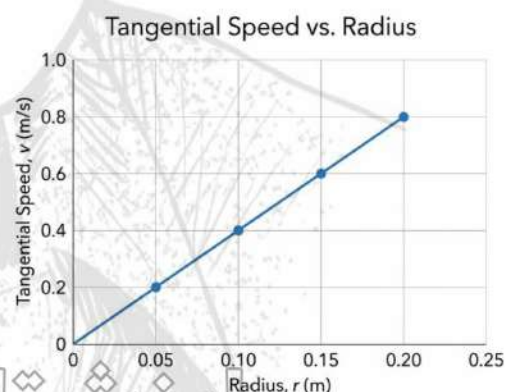
Dependent variable: the tangential speed, v , of each marked point.

Controlled variables: the disk's angular velocity, ω (held constant for the whole set of trials); the disk surface and marker method; the timing technique used for every trial.

Procedure

- Mark four or five points on the disk at different, known radii from the center.
- Set the disk to rotate at a fixed, constant angular velocity.
- For each marked point, measure the time for one complete revolution and calculate its tangential speed, $v = \frac{2\pi r}{T}$ (or use a photogate for direct speed readings).
- Repeat each measurement three times and record the average.
- Tabulate r and the corresponding average v for every marked point.

Radius, r (m)	Time for 1 rev, T (s)	Tangential speed, $v = 2\pi r/T$ (m/s)
0.05	1.57	0.20
0.10	1.57	0.40
0.15	1.57	0.60
0.20	1.57	0.80



Expected relationship: a graph of v (y-axis) against r (x-axis) should be a straight line through the origin, since $v = r\omega$ with ω held constant — the slope of that line equals ω .

Conclusion: the data confirm $v = r\omega$: tangential speed increases in direct proportion to radius, for a fixed angular velocity.

Sources of error: human reaction-time error when starting/stopping a stopwatch, slipping of the marked point on the disk surface, parallax error when measuring radius, and small fluctuations in motor speed.

Worked Examples

WE1: Angle Conversions

Problem: Convert (a) 45° to radians and (b) $\frac{3\pi}{4}$ rad to degrees.

RELATIONSHIP:

$$\begin{aligned}\text{Radians} &= \text{Degrees} \times \frac{\pi}{180} \\ \text{Degrees} &= \text{Radians} \times \frac{180}{\pi}\end{aligned}$$

ANSWER:

$$(a) 45 \times \frac{\pi}{180} = \frac{\pi}{4} \text{ rad} \approx 0.785 \text{ rad}$$

$$(b) \left(\frac{3\pi}{4}\right) \times \frac{180}{\pi} = 135^\circ$$

WE2: Arc Length

Problem: A roller-coaster car travels around a vertical loop of radius **9.0 m**. Find the arc length for three-quarters of the loop ($\theta = \frac{3\pi}{2}$ rad).

RELATIONSHIP:

$$x = r\theta \quad (\text{where } \theta \text{ is in radians})$$

ANSWER:

$$x = (9.0) \left(\frac{3\pi}{2}\right) = (9.0)(4.712) = 42.4 \text{ m}$$

WE3: Average Angular Velocity

Problem: A ceiling fan's blades rotate through **15.7 rad** in **2.5 s**, starting from $\theta_i = 0$. Find the average angular velocity.

RELATIONSHIP:

$$\omega = \frac{\Delta\theta}{\Delta t}$$

ANSWER:

$$\omega = \frac{15.7}{2.5} = 6.28 \text{ rad/s} \quad (\approx 1 \text{ rev/s})$$

WE4: Tangential Speed

Problem: A merry-go-round rotates at $\omega = 1.2$ rad/s. Horse A sits **1.5 m** from the center; Horse B sits **3.0 m** from the center. Find each horse's tangential speed, and state which horse experiences the faster ride.

RELATIONSHIP:

$$v = r\omega$$

ANSWER:

$$\begin{aligned}v_A &= (1.5)(1.2) = 1.8 \text{ m/s} \\ v_B &= (3.0)(1.2) = 3.6 \text{ m/s}\end{aligned}$$

Conclusion: Horse B moves faster, since it is located farther from the axis of rotation.

Lesson 1 DESCRIBING ROTATIONAL MOTION

First Choose the correct answer

Every Key Performance Indicator (KPI) for this lesson is assessed at least once below, matching the exact learning outcomes and exam pattern this lesson

1. Angular Measure & Angular Displacement

Section A — Multiple Choice

1 Which of the following is a **unit used to measure an object's rotation**?

- (a) Meter (b) Newton (c) Radian (d) Kilogram

2 **Angular displacement** is the **change in an object's** _____ **as it rotates.**

- (a) orbit (b) angle (c) velocity (d) acceleration

3 **One complete revolution (360°)** is equal to:

- (a) $\pi/4$ rad (b) $\pi/2$ rad (c) π rad (d) 2π rad

4 The radian is a unit of angular measurement and is equal to approximately _____ degrees.

- (a) 30° (b) 57° (c) 60° (d) 180°

5 A degree is equal to:

- (a) $1/360$ of a revolution (b) $1/500$ of a revolution
(c) $1/(2\pi)$ of a revolution (d) $1/4$ of a revolution

6 The Earth rotates a total of **how many radians** in **24 hours**?

- (a) π rad (b) $\pi/2$ rad (c) 2π rad (d) 4π rad



7 For the minute hand of a clock, **what is the angular displacement** in one hour?

- (a) π rad (b) π rad (c) 2π rad (d) 2π rad

8 It is known that the Earth rotates about its axis.

What angle does the Earth rotate through in **6 hours**, as viewed from above the North Pole?

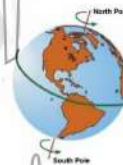
- (a) $-\pi/2$ rad (b) $+\pi/2$ rad (c) $-\pi/6$ rad (d) $+\pi/6$ rad



9 It is known that the Earth rotates about its axis.

What angle does the Earth rotate through in **12 hours**, as viewed from above the South Pole?

- (a) $-\pi$ rad (b) $+\pi$ rad (c) $-\pi/2$ rad (d) $+\pi/2$ rad



10 A wheel with a **radius** of **50 cm** completes two full revolutions.

How many radians has it turned through?

- (a) 4π radians (b) 2π radians (c) π radians (d) 3π radians

11 Convert **90°** to radians.

- (a) π rad (b) $\pi/2$ rad (c) 2π rad (d) $\pi/4$ rad

12 Convert π radians to degrees.

- (a) 90° (b) 180° (c) 270° (d) 360°

13 Which rotation is considered **positive**?

- (a) Clockwise (b) Downward (c) Counterclockwise (d) Horizontal

14 An object rotates **clockwise** through an angle of **90°** . Its **angular displacement** is:

- (a) $+\pi/2$ rad (b) $-\pi/2$ rad (c) $+\pi$ rad (d) $-\pi$ rad

15 How many revolutions are equal to 4π radians?

- (a) 1 rev (b) 2 rev (c) 3 rev (d) 4 rev

16 Convert **270°** to radians.

- (a) $\pi/2$ rad (b) π rad (c) $3\pi/2$ rad (d) 2π rad

17 A wheel rotates **counterclockwise** through **one-quarter revolution**.

The **angular displacement** is:

- (a) $-\pi/2$ rad (b) $+\pi/2$ rad (c) $-\pi$ rad (d) $+\pi$ rad

18 Earth rotates through **how many radians** in **12 h**?

- (a) $\pi/2$ rad (b) π rad (c) 2π rad (d) 3π rad



19 Earth rotates through **how many radians** in **6 h**?

- (a) $\pi/2$ rad (b) π rad (c) 2π rad (d) $\pi/4$ rad



20 Earth rotates through **how many radians** in **1 h**?

- (a) $\pi/24$ rad (b) $\pi/12$ rad (c) $\pi/6$ rad (d) $\pi/2$ rad



21 Earth rotates through **how many radians** in **1.5 h**?

- (a) $\pi/12$ rad (b) $\pi/6$ rad (c) $\pi/8$ rad (d) $\pi/4$ rad



22 Which angle represents **half a revolution**?

- (a) $\pi/2$ rad (b) π rad (c) 2π rad (d) 3π rad

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- 23 What angle does the Earth rotate through in **3 hours** when viewed from the **North Pole**?
 (a) $-\pi/4$ rad (b) $+\pi/8$ rad (c) $+\pi/4$ rad (d) $-\pi/8$ rad



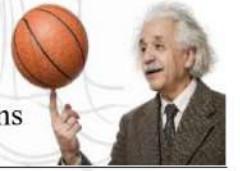
- 24 What is **angular displacement**?
 (a) The rate of change of angular velocity
 (b) The change in the angle for a rotating body
 (c) The change in linear velocity of an object
 (d) The change in the direction of angular velocity

- 25 A bike wheel rotates **4.50 revolutions**. **How many radians** has it rotated?
 (a) 4.5 rad (b) 7.0 rad (c) 0.08 rad (d) 28.3 rad

- 26 A wheel rotated **7.50 revolutions** and then stopped. **How many radians** has it rotated?
 (a) 1.2 rad (b) 7.5 rad (c) 23.6 rad (d) 47.1 rad

- 27 A ball rotated a total of 24.9 radians. **How many revolutions** was that?

- (a) 15.0 revolutions (b) 5.00 revolutions (c) 2.50 revolutions (d) 4.00 revolutions



- 28 Mr Abdulrahman moves **counterclockwise** through $3\pi/2$ radians and then rotates in the opposite direction through $\pi/2$ radians. What is his final **angular displacement**?

- (a) $-3\pi/2$ rad (b) π rad (c) $\pi/4$ rad (d) $-\pi/2$ rad

- 29 A rotating wheel turns counterclockwise through 300° . It then reverses its direction and rotates clockwise through 120° . What is the resultant angular displacement of the wheel?

- (a) $+\frac{\pi}{3}$ rad (b) $+\pi$ rad (c) $-\pi$ rad (d) $-\frac{7\pi}{3}$ rad

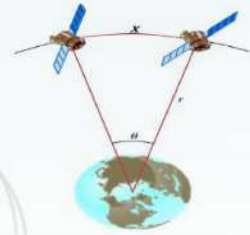
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2. Arc Length & Circular Distance

30

KhalifaSat satellites are in the same orbit of radius $4.25 \times 10^7 \text{ m}$. If their angular separation is **0.04 rad**, which expression represents the **arc length** s separating them?

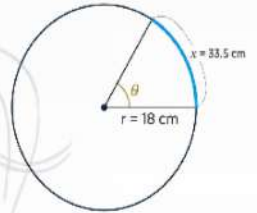
What is the **arc length** along the orbit separating the two satellites?



- (a) $\frac{4.25 \times 10^7 \text{ m} \times 0.04 \text{ rad}}{2}$ (b) $4.25 \times 10^7 \text{ m} \times 0.04 \text{ rad}$
 (c) $\frac{4.25 \times 10^7 \text{ m}}{0.04 \text{ rad}}$ (d) $\frac{4.25 \times 10^7 \text{ m} \times 0.04 \text{ rad}^2}{2}$

31

A car tire rotates counterclockwise. Point A moves along an arc of **33.5 cm** on a tire of radius **18 cm**. Which expression represents the magnitude of the angle θ ?



- (a) $\frac{(33.5 \text{ cm} - 18 \text{ cm})}{18 \text{ cm}}$ (b) $\frac{18 \text{ cm}}{33.5 \text{ cm}}$ (c) $\frac{(33.5 \text{ cm} + 18 \text{ cm})}{33.5 \text{ cm}}$ (d) $\frac{33.5 \text{ cm}}{18 \text{ cm}}$

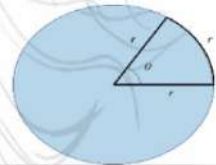
32

What is the **arc length** for an angle of **2 rad**?

- (a) Four times the radius (b) Twice the radius (c) Half the radius (d) Equal to the radius

33

The diagram shows a sector of a circle with **radius** r . The **arc length** of the sector is r . What is the measure of angle θ ?



- (a) 30° (b) 57° (c) 60° (d) 180°

34

A motorbike completes **half a revolution** around a circular racing track. If the **diameter** of the track is **300 m**, what distance does the bike travel?

- (a) 48 m (b) 480 m (c) 47 m (d) 470 m

35

A wheel is rotated so that a point on the edge moves through **1.50 m**. The **radius** of the wheel is **2.50 m**.

What angle, in radians, is the wheel rotated?

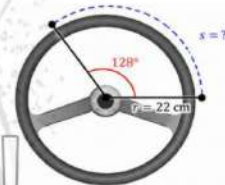


- (a) 0.60 rad (b) 1.50 rad (c) 2.50 rad (d) 4.00 rad

36

A steering wheel is rotated through **128°**. Its **radius** is **22 cm**.

How far would a point on the steering wheel's edge move?



- (a) 24 cm (b) 49 cm (c) 56 cm (d) 128 cm

37

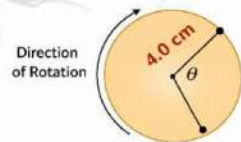
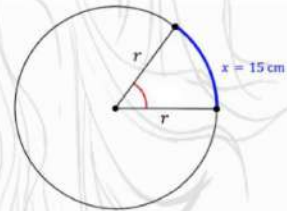
The **radius** of a circle is **10 m** and the **angular displacement** is **3 rad**. Find the arc length.

- (a) 10 m (b) 13 m (c) 30 m (d) 300 m

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LESSON 1 DESCRIBING ROTATIONAL MOTION

- 38 An object moves through an **arc length** of **18 m** around a circle of **radius 6 m**. Find the **angular displacement**.
 (a) 2 rad (b) 3 rad (c) 4 rad (d) 6 rad
- 39 A point moves through an **arc length** equal to πr . The **angular displacement** is:
 (a) $\pi/2$ rad (b) π rad (c) 2π rad (d) 3π rad
- 40 A wheel of **radius 0.5 m** rotates through **4 rad**. What **distance** does a point on the rim travel?
 (a) 1 m (b) 2 m (c) 4 m (d) 8 m
- 41 A circular path has **radius 15 cm** and **arc length 45 cm**. Find the **angle θ** .
 (a) 1 rad (b) 2 rad (c) 3 rad (d) 4 rad
- 42 If the **angular displacement** doubles while the **radius** remains constant, the **arc length** will:
 (a) Remain constant (b) Be halved (c) Double (d) Become zero
- 43 A point travels an **arc length** of 20π cm on a circle of **radius 10 cm**. Find θ .
 (a) π rad (b) 2π rad (c) 3π rad (d) 4π rad
- 44 A steering wheel is rotated through 60° .
 A point on its edge moves through an **arc length** of **15 cm**.
 What is the **radius** of the steering wheel?
 (a) 18 cm (b) 22 cm (c) 26 cm (d) 30 cm
- 45 A point on a CD is located **4.0 cm** from the center.
 If it moves a linear distance of **12 cm**, what is the **angular displacement θ** ?
 (a) 3.0 rad (b) 2.0 rad (c) 1.0 rad (d) 0.3 rad
- 47 A person runs around a circle of **radius 2.00 m** and completes **2.25 revolutions**.
 What is the total distance travelled?
 (a) 34.0 m (b) 15.3 m (c) 25.1 m (d) 28.3 m
- 46 A car completes $3/4$ of a revolution around a roundabout of **radius 12 m**.
 What is the total distance travelled?
 (a) 19 m (b) 75 m (c) 28 m (d) 57 m
- 48 A point on a car tire rotates **half a revolution clockwise**. What is its **angular displacement**?
 (a) $-\pi/2$ rad (b) $\pi/2$ rad (c) π rad (d) $-\pi$ rad



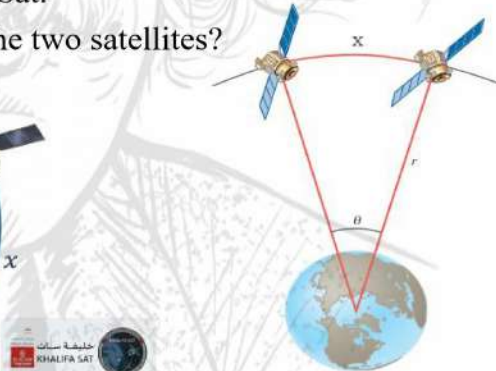
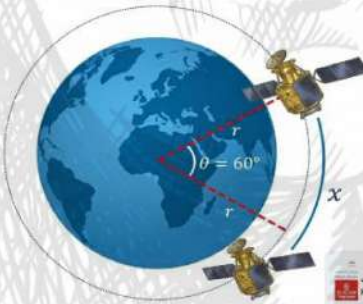
- 49 Ahmed ties a **0.750 m** string to a ball and rotates it through 5.00 complete revolutions. What is the total distance travelled by the ball?
 (a) 50.3 m (b) 23.6 m (c) 4.71 m (d) 7.50 m
- 50 A point on the outer edge of a lucky wheel moves **31.4 m**, and the **diameter** of the wheel is **1.00 m**. How many revolutions does the wheel complete?
 (a) 20.0 revolutions (b) 5.00 revolutions (c) 1.00 revolution (d) 10.0 revolutions
- 51 A group of boys are holding hands in a circle of **radius 1.5 m**. What is the total distance covered by one boy after **5.0 revolutions**?



Section B — Free Response / Practice

- 52 **FR1** A car on a Ferris wheel has an **angular displacement** of **0.34 rad**. If the car moves through an **arc length** of **12 m**, what is the **radius** of the Ferris wheel?

- 53 **FR2** **KhalifaSat** is an Earth-observation satellite orbiting Earth in a circular path. take the orbital radius to be $r = 6.98 \times 10^6$ m. Another satellite is located in the same orbit, with an angular separation of $\theta = 60^\circ$ from KhalifaSat. What is the arc length x along the orbit separating the two satellites?



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LESSON 1 DESCRIBING ROTATIONAL MOTION

3. Angular Speed, Angular Velocity & Frequency

54 A rotating disc has a knob on the edge. The disc completes one rotation every 3.0 s. Using this information, you can calculate the angular _____ of the knob.

- Ⓐ Acceleration Ⓑ Displacement Ⓒ Speed Ⓓ Revolution

55 If an object rotates **counterclockwise**, its **angular velocity** is _____.

- Ⓐ Positive Ⓑ Negative Ⓒ Zero Ⓓ Infinite

56 A car travels around a roundabout in 25 s. Its **angular displacement** is 2.9 rad. What is the car's average **angular velocity**?

- Ⓐ 73 rad/s Ⓑ 0.12 rad/s Ⓒ 3.0 rad/s Ⓓ 8.6 rad/s

57 A record rotates **clockwise** at 33.3 rev/min. What is its **angular speed**?

- Ⓐ 3.49 rad/s Ⓑ 1.75 rad/s Ⓒ 0.29 rad/s Ⓓ 209 rad/s

58 Which of the following is equivalent to 5000 rpm?

- Ⓐ 524 rad/s Ⓑ 420 rad/s Ⓒ 240 rad/s Ⓓ 120 rad/s

59 An object completes one full revolution (360°) in 2 seconds. What is its **angular speed** in rad/s?

- Ⓐ $3\pi/4$ rad/s Ⓑ $\pi/2$ rad/s Ⓒ 2π rad/s Ⓓ π rad/s

60 A rotating toy above a crib makes one complete **counterclockwise** rotation in 1 min. What is its **angular velocity** in rad/min?

- Ⓐ $+2\pi$ rad/min Ⓑ $+4\pi$ rad/min Ⓒ -2π rad/min Ⓓ -4π rad/min



61 The toy completes one **counterclockwise** rotation each minute. What is its **angular displacement** in 3 min?

- Ⓐ $+2\pi$ rad Ⓑ $+4\pi$ rad Ⓒ $+6\pi$ rad Ⓓ $+8\pi$ rad



63 A record rotates **clockwise** at 33.3 rev/min. What is its **angular velocity** in rad/s?

- Ⓐ $+3.49$ rad/s Ⓑ -3.49 rad/s Ⓒ $+0.29$ rad/s Ⓓ -0.29 rad/s

62 An object completes one full revolution in 2 s. What is its **angular velocity**?

- Ⓐ $+\pi$ rad/s Ⓑ $-\pi$ rad/s Ⓒ $+2\pi$ rad/s Ⓓ -2π rad/s

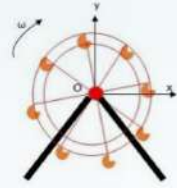
64 The minute hand of a clock completes one full revolution in 1 h.

What is its **angular displacement** after 1 h?

- Ⓐ $+2\pi$ rad Ⓑ -2π rad Ⓒ $+\pi$ rad Ⓓ π rad

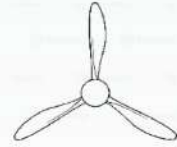
- 65 A Ferris wheel rotates **clockwise** and completes one full revolution every **8.0 s**. What is its **angular velocity**?

(a) $+\pi/4$ rad/s (b) $-\pi/4$ rad/s (c) $+\pi/2$ rad/s (d) $-\pi/2$ rad/s



- 66 A propeller spins at **1880 rev/min**. What is its **angular velocity** in rad/s?

(a) 98.5 rad/s (b) 157 rad/s (c) 197 rad/s (d) 314 rad/s



- 67 A Ferris wheel completes one full revolution every **8 seconds**. What is the magnitude of its **angular velocity**?

(a) $2\pi/3$ rad/s (b) $\pi/8$ rad/s (c) $\pi/4$ rad/s (d) $\pi/2$ rad/s



- 68 A motor has an **angular speed** of **1200 rad/s**. What is its **frequency**?

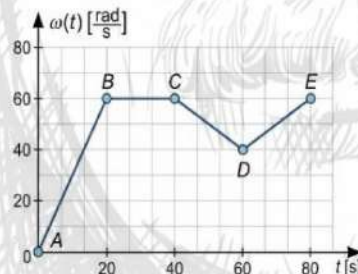
(a) 150 Hz (b) 190 Hz (c) 300 Hz (d) 280 Hz

- 69 A disk rotates with a **frequency** of **1.3 Hz**. What is the **angular velocity** of the disk?

(a) 8.2 rad/s (b) 7.4 rad/s (c) 4.7 rad/s (d) 2.4 rad/s

- 70 The graph shows **angular velocity** $\omega(t)$ for rotating fan blades. The maximum **angular velocity** is **60 rad/s**. During which interval is the constant **angular acceleration** equal to **1 rad/s²**?

(a) CD (b) AB
(c) DE (d) BC



Section B — Free Response / Practice

- 71 **FR2** Calculate the **angular speed** in the following cases:

a. $\theta_i = 1.0 \text{ rad}, \theta_f = 3.6 \text{ rad}, t_i = 30.0 \text{ s}, t_f = 50.0 \text{ s}$

b. $\theta_i = 0.10 \text{ rad}, \theta_f = 2.0 \text{ rad}, t_i = 0.00 \text{ s}, t_f = 50.0 \text{ s}$

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72 FR3 A kitchen blender rotates at **200 revolutions** per minute (**200 RPM**).

- What is the **angular speed** of the blender in rad/s?
- How many **radians** does the blender rotate in **5 seconds**?
- How many **complete revolutions** does it make in **5 seconds**?



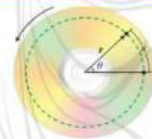
73 FR4 How long does it take the second hand of a clock to move through **4.00 rad**?

4. Linear–Angular Relationships & Rigid Rotation

74 A cylinder of **radius 0.7 m** rotates at **10 rad/s**.

What is the **linear speed** of point P?

- (a) 7π rad/s (b) 14π rad/s (c) 7.0 m/s (d) 0.70 m/s

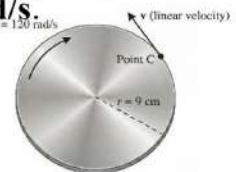


75 A metal disk rotates **counterclockwise** with an angular velocity of **120 rad/s**.

Point C is located **9 cm** from the **center** of the disk.

What is the **linear velocity** of point C?

- (a) 1.08 m/s (b) 10.8 m/s (c) 13.3 m/s (d) 1080 m/s



76 For the same CD, what is the **linear displacement** of a point on its edge in **2.0 s**?

- (a) 0.60 m (b) 0.30 m (c) 3.8 m (d) 60 m

77 Two touching gears are shown, one larger than the other.

Which **quantity** is the **same** for **both** gears at the contact?

- (a) Linear speed (b) Angular speed
(c) Angular displacement (d) Angular acceleration



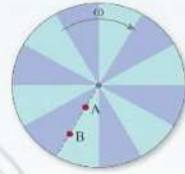
78 In a clock, all parts of the minute hand are **equal** in:

- (a) Linear speed (b) Angular speed
(c) Angular displacement (d) Angular acceleration



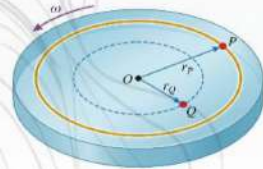
- 79 Two spots A and B lie on the same rotating disk at different distances from the center. How can their angular velocities be compared?

(a) $\omega_B > \omega_A$ (b) $\omega_A > \omega_B$
 (c) Both are zero (d) Both are equal and non – zero



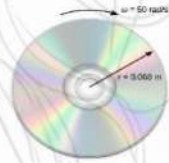
- 80 Two points P and Q are on the same rotating disk, with P farther from the center than Q. Which statement is correct?

(a) $v_P > v_Q$ and $\omega_P > \omega_Q$ (b) $v_P > v_Q$ and $\omega_P = \omega_Q$
 (c) $v_P = v_Q$ and $\omega_P > \omega_Q$ (d) $v_P = v_Q$ and $\omega_P = \omega_Q$



- 81 A CD rotates at **50 rad/s**. A point on its edge is **0.060 m** from the center. What is the linear velocity of the point?

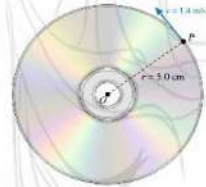
(a) 1.5 m/s (b) 3.0 m/s (c) 6.0 m/s (d) 12.0 m/s



- 82 A CD-ROM track moves with a constant linear velocity of **1.4 m/s**. Point P is **5.0 cm** from the center.

What is the angular velocity of the CD-ROM?

(a) 14 rad/s (b) 28 rad/s (c) 42 rad/s (d) 56 rad/s



- 83 An automobile wheel rotates with an angular velocity of **2.50 rad/s**. Point P is located **7.00 cm** from the center, while point Q is located **9.00 cm** from the center.

What is the ratio of the linear velocity ($\frac{v_Q}{v_P} = ?$)

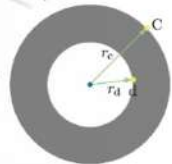
(a) $\frac{7}{9}$ (b) $\frac{9}{7}$ (c) $\frac{2.50}{7}$ (d) $\frac{7}{2.50}$



- 84 A metal disk rotates **counterclockwise**. Point d is located at a distance from the center, while point c is located at a distance, such that $r_d = 0.8r_c$.

If the linear velocity of point d is **12.0 m/s**, what is the linear velocity of point c?

(a) 12.0 m/s (b) 15.0 m/s (c) 24.0 m/s (d) 31.0 m/s

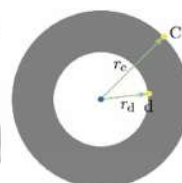


- 85 A metal disk rotates **counterclockwise with a constant angular velocity**.

The linear velocity of point C is **18.0 m/s**, while the linear velocity of point D on the same disk is **15.0 m/s**. If and represent their respective distances from the center,

which equation correctly describes the relationship between them?

(a) $r_C = 0.83r_D$ (b) $r_C = 1.20r_D$ (c) $r_C = 1.44r_D$ (d) $r_C = r_D$



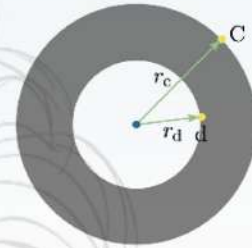
LESSON 1 DESCRIBING ROTATIONAL MOTION

- 86 A metal disk rotates **counterclockwise**. Point c is located at a distance r_c from the center, while point d is located at a distance r_d , such that $r_d = 0.5r_c$.

If the linear velocity of point c is 20.0 m/s,

what is the linear velocity of point d?

- (a) 5.0 m/s (b) 10.0 m/s (c) 20.0 m/s (d) 40.0 m/s



Section B — Free Response / Practice

- 87 **FR5** The outer edge of a truck tire has a **radius** of 45 cm and a **linear velocity** of 23 m/s. What is the **angular velocity** of the tire in rad/s?

- 88 **FR7** Do all parts of the minute hand on a watch have the same **angular displacement**?

Do they have the same **linear displacement**? Explain.



5. Angular Acceleration & Tangential Acceleration

- 89 A clothes washer drum rotates at **635 rev/min**, then comes to rest in **8.0 s**. What is the **angular acceleration** of the drum?

- (a) $+8.3 \text{ rad/s}^2$ (b) 8.3 rad/s^2 (c) $+4.2 \text{ rad/s}^2$ (d) -4.2 rad/s^2



- 90 A centrifuge rotor starts from rest and reaches **20,000 rev/min** in **30 s**. What is its **average angular acceleration**?

- (a) 70 rad/s^2 (b) 111 rad/s^2 (c) 333 rad/s^2 (d) 2100 rad/s^2

- 91 A propeller slows uniformly from **475 rev/min** to **187 rev/min** in **4.00 s**. What is its **angular acceleration**?

- (a) 7.54 rad/s^2 (b) -4.80 rad/s^2 (c) $+7.54 \text{ rad/s}^2$ (d) $+4.80 \text{ rad/s}^2$

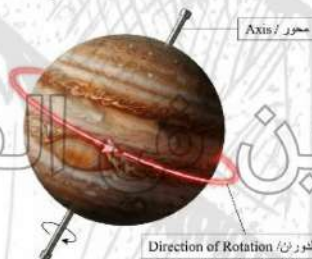
- 92 A flywheel increases its **angular speed** from **5 rad/s** to **15 rad/s** in **5 s**. What is the **angular acceleration**?

- (a) 6 rad/s^2 (b) 4 rad/s^2 (c) 3 rad/s^2 (d) 2 rad/s^2

- 93 A fan slows from **10 rad/s** to **6.30 rad/s** in **5.00 s**.
What is the magnitude of **angular acceleration**?
(a) 1.35 rad/s² (b) 0.921 rad/s² (c) 0.740 rad/s² (d) 0.360 rad/s²
- 94 A blender blade spins from rest to **9000 rev/min** in **4.5 s**.
What is the angular acceleration in rad/s²?
(a) 756 rad/s² (b) 2000 rad/s² (c) 12.6 rad/s² (d) 209 rad/s²
- 95 A CD starts rotating from rest and reaches an **angular speed** of **6π rad/s** in **3.0 s**.
What is the angular acceleration?
(a) 6π rad/s² (b) 4π rad/s² (c) 2π rad/s² (d) π rad/s²
- 96 A centrifuge rotor is accelerated for **20 s** from rest to **10,000 rpm**.
What is its average angular acceleration?
(a) 558 rad/s² (b) 17.3 rad/s² (c) 1050 rad/s² (d) 52.5 rad/s²
- 97 A merry-go-round has **angular acceleration** **0.30 rad/s²**.
After accelerating from rest for **2.8 s**, **what angle** does it rotate through?
(a) 8.0 rad (b) 2.0 rad (c) 2.4 rad (d) 1.2 rad
- 98 Angular ____ is equal to the change in **angular velocity** divided by the time required to make that change.
(a) displacement (b) acceleration (c) velocity (d) frequency
- 99 **Which statement** is true regarding **angular displacement** and **angular velocity**?
(a) Angular displacement is always constant.
(b) Angular displacement and angular velocity are dependent on each other.
(c) Angular displacement is always equal to angular velocity.
(d) Angular displacement and angular velocity are independent of one another.
- 100 If the **linear acceleration** of a truck is **1.85 m/s²** and the **angular acceleration** of its wheels is **5.23 rad/s²**, what is the **radius** of the wheels?
(a) 5.6 m (b) 2.8 m (c) 0.70 m (d) 0.35 m
- 101 A roller coaster experiences a change in **angular velocity** of **2.4 rad/s** in **0.64 s**.
What is its average angular acceleration?
(a) 4.6 rad/s² (b) 3.8 rad/s² (c) 2.4 rad/s² (d) 1.6 rad/s²
- 102 A car dashboard shows **angular acceleration** **α = 68 rad/s²** and **linear acceleration** **a = 14 m/s²**. What is the **diameter** of the wheel?
(a) 4.8 cm (b) 4.1 cm (c) 0.21 cm (d) 15 cm

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- 103 A car has **linear acceleration** 1.8 m/s^2 and wheel **radius** 0.33 m .
What is the **angular acceleration**?
(a) 5.5 rad/s^2 (b) 9.8 rad/s^2 (c) 0.59 rad/s^2 (d) 0.18 rad/s^2
- 104 A flywheel has **diameter** 1.2 m and **angular acceleration** 5.0 rad/s^2 .
What is the **tangential acceleration** at the rim?
(a) 10 m/s^2 (b) 6.0 m/s^2 (c) 5.0 m/s^2 (d) 3.0 m/s^2
- 105 A carousel starts from rest with constant **angular acceleration** $\alpha = 0.06 \text{ rad/s}^2$ for 8.0 s .
If a child's **linear speed** is 1.2 m/s , **how far** is the child from the center?
(a) 1.0 m (b) 0.6 m (c) 1.2 m (d) 2.5 m
- 106 A wheel's **angular velocity** increases from 450 rad/min to 2500 rad/s in half a minute.
What is the **average angular acceleration**?
(a) 83 rad/s^2 (b) 68 rad/s^2 (c) 25 rad/s^2 (d) 250 rad/s^2
- 107 A toy car moves on a circular track with **linear acceleration** 25 m/s^2 .
The track **diameter** is 1.52 m . What is the **angular acceleration** in rev/s^2 ?
(a) 7.9 rev/s^2 (b) 5.2 rev/s^2 (c) 1.5 rev/s^2 (d) 3.8 rev/s^2
- 108 A car wheel has **diameter** 76 cm . The car's **linear velocity** changes by 25 m/s in 11 s .
What is the **angular acceleration** of the wheel?
(a) 7.9 rad/s^2 (b) 2.8 rad/s^2 (c) 6.0 rad/s^2 (d) 4.6 rad/s^2
- 109 The mathematical expression $\omega = \frac{2\pi}{x}$
is one of the formulas used to describe **rotational motion**. Using the information given,
what does the variable represent in the formula?
(a) Period (b) Frequency (c) Angular displacement (d) Angular acceleration
- 110 **Jupiter** is a **solid, rotating object**, and all of its parts rotate with the same **angular velocity** of $1.76 \times 10^{-4} \text{ rad/s}$. Using the information given, how much **time**, in **Earth hours**, does Jupiter require to complete **one full revolution** about its axis?



- (a) 9.92 hours (b) 16.1 hours (c) 24.6 hours (d) 4.96 hours

Section B — Free Response / Practice

- FR8** A car wheel turns from rest to **4.75 rad/s** in **2.25 s**. Calculate the **angular acceleration** of the wheel.

- FR9** Car wheels initially rotate at **3.0 rad/s** and increase to **15 rad/s** in **6.0 s**. What is their **angular acceleration**?

- FR10** A grindstone has **angular acceleration** **0.27 rad/s²** and initial **angular velocity** **−3.3 rad/s**. **How long** does it take to stop momentarily?

- FR11** During a washer rinse spin cycle, the drum reaches **8.0 rev/s** after accelerating from rest in **5.0 s**. **What is its angular acceleration**?

- FR12** If a flywheel increases its average **angular speed** by **2.7 rad/s** in **1.9 s**, **what is its angular acceleration**?

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FR13 A drill starts from rest. After **3.20 s** of constant **angular acceleration**, it turns at **2628 rad/s**. Find the **angular acceleration**.

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FR14 A bicycle wheel has **angular acceleration** **1.5 rad/s²**. A point on its rim has **tangential acceleration** **48 cm/s²**. What is the **radius** of the wheel?

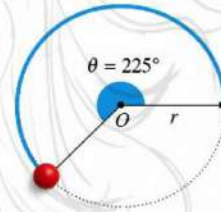
6. FRQ / Critical Thinking / Mixed Practice

Section B — Free Response / Practice

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FR15 A ball travels an **arc length** of **30 cm** on a circular path corresponding to a central angle of **225°**. The motion takes **2 s**.

- Calculate the **radius** of the circular path.
- Determine the **average angular velocity** of the ball.
- Find the linear (tangential) speed of the ball.



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FR16 A CD-ROM spiral track starts **2.5 cm** from the center and ends **5.0 cm** from the center. The **linear velocity** of the track is constant at **1.5 m/s**.

- Find the disk's **angular velocity** at the start of the track.
- Find the disk's **angular velocity** at the end of the track.
- Find the disk's **angular acceleration** if the disk is played for **90 min**.



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FR17 What is the **angular displacement** of each of the following hands of a clock in **10.0 h**?

State each answer in three significant digits.

- a. the second hand b. the minute hand c. the hour hand



FR18 A rotating toy above a crib makes one complete **counterclockwise** rotation in **1 min**.

- a. What is its **angular displacement** in **3 min**?
 b. What is the toy's **angular velocity** in rad/min?
 c. If the toy is turned off, does it have **positive** or **negative angular acceleration**? Explain.



FR19 The Moon has **radius** $r = 1.74 \times 10^6 \text{ m}$ and rotates once on its axis in **27.3 days**.

- a. What is its **period of rotation** in seconds?
 b. What is its **angular velocity** in rad/s?
 c. A rock sits on the surface at the Moon's equator. What is its **linear speed**?
 d. Compare this speed with that of a person at Earth's equator.

FR20 A toy fixed above a baby's bed completes one full rotation in the **clockwise** direction every **1 minute**.

- a. What is the **angular displacement** covered by the toy in **3 minutes**?
 b. What is the **angular speed** of the toy in rad/min?
 c. If the toy is stopped, will the **angular acceleration** be **positive** or **negative**? Explain.



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