Past-paper walk-through

Torque and Work ▪ 6.2

eXercise

Questions in this set

- 2026 Q4
- 2016 Q3

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 4

2026 ▪ Q4

A unicycle is placed on a stand such that the wheel does not touch the ground. The rotational inertia of the wheel about the axle is I_W. One end of a crank arm can be attached to the wheel, as shown in the side view.

[Figure: A side-view illustration of a unicycle (seat, seat post, frame, wheel with spokes, and stand legs) standing on the ground with the wheel raised off the ground, labeled "Unicycle." A dashed-line callout box magnifies the wheel region, labeled "Side View," showing the wheel's outer rim labeled "Wheel," the central hub labeled "Axle," and a straight bar extending from the axle outward labeled "Crank Arm."]

In Scenarios 1 and 2, crank arms of different lengths are connected to the wheel. In each scenario, the wheel is initially at rest. A force of magnitude F is then exerted at the end of each crank arm. The direction of the force remains perpendicular to each

Question 4

crank arm at all times. The mass of each crank arm is negligible. The scenarios differ as described.

- Scenario 1: The length of the crank arm is ℓ_1. The angular speed of the wheel immediately after the crank arm has been turned through one rotation is ω_1.
- Scenario 2: The length of the crank arm is ℓ_2, where $\ell_2 > \ell_1$. The angular speed of the wheel immediately after the longer crank arm has been turned through one rotation is ω_2.

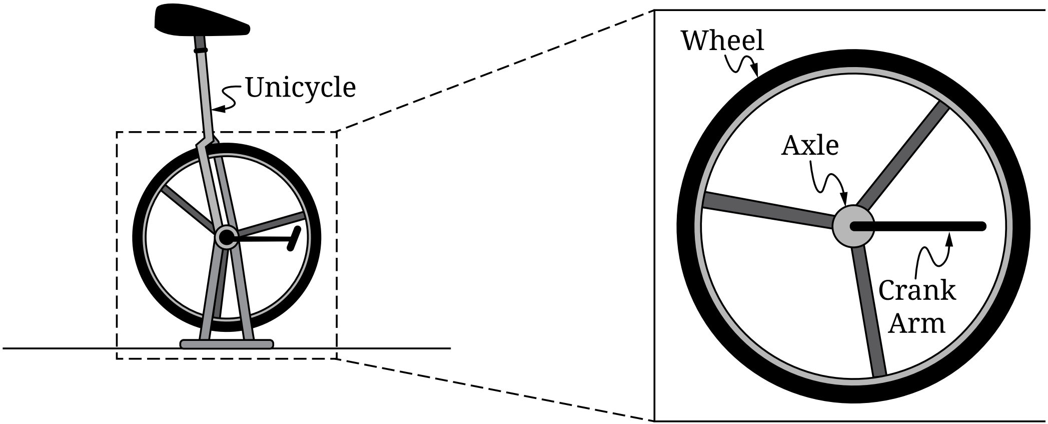
(a) Indicate whether ω_2 is greater than, less than, or equal to ω_1 by writing one of the following.

- $\omega_2 > \omega_1$
- $\omega_2 < \omega_1$
- $\omega_2 = \omega_1$

Question 4

Justify your answer. Your justification may reference equations but must include conceptual reasoning beyond algebraic solutions.

Question 4



Question 4

2026 ▪ Q4

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In Scenarios 1 and 2, crank arms of different lengths are connected to the wheel. In each scenario, the wheel is initially at rest. A force of magnitude F is then exerted at the end of each crank arm. The direction of the force remains perpendicular to each crank arm at all times. The mass of each crank arm is negligible. The scenarios differ as described.

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- Scenario 2: The length of the crank arm is ℓ_2, where $\ell_2 > \ell_1$. The angular speed of the wheel immediately after the longer crank arm has been turned through one rotation is ω_2.

(b) Derive an expression for the angular speed ω_1 of the wheel in Scenario 1 immediately after the crank arm has been turned through one rotation. Express your answer in terms of I_W, F, ℓ_1, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 4

2026 ▪ Q4

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In Scenarios 1 and 2, crank arms of different lengths are connected to the wheel. In each scenario, the wheel is initially at rest. A force of magnitude F is then exerted at the end of each crank arm. The direction of the force remains perpendicular to each crank arm at all times. The mass of each crank arm is negligible. The scenarios differ as described.

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- Scenario 1: The length of the crank arm is ℓ_1. The angular speed of the wheel immediately after the crank arm has been turned through one rotation is ω_1.
- Scenario 2: The length of the crank arm is ℓ_2, where $\ell_2 > \ell_1$. The angular speed of the wheel immediately after the longer crank arm has been turned through one rotation is ω_2.

(c) In Scenario 3, the unicycle is placed on the ground such that the unicycle can move forward without the wheel slipping on the ground. A force of the same magnitude F is exerted at the end of the crank arm of length ℓ_1, as in Scenario 1. The direction of the force remains perpendicular to the crank arm at all times. The resulting angular speed of the wheel immediately after the crank arm has been turned through one rotation is ω_3.

Indicate whether ω_3 is greater than, less than, or equal to ω_1 by writing one of the following.

Question 4

- $\omega_3 > \omega_1$
- $\omega_3 < \omega_1$
- $\omega_3 = \omega_1$

Briefly **justify** your answer. Your justification may reference equations but must include conceptual reasoning beyond algebraic solutions.

Question 3

2016 ▪ Q3

[Figure 1: A circular platform of radius $R = 2d$ viewed from above, with a vertical rod of length d fixed at the central axis (a small circle marking the pivot at the center). A spring of natural (unstretched) length $d/2$ sits along the rod, connected to a block (shown as a small dark rectangle) at distance $d/2$ from the outer end of the rod.]
[Figure 2: The same circular platform now rotating counterclockwise (as viewed from above) at angular speed ω (curved arrow at top indicating rotation direction). The block has moved outward; the spring is now stretched, shown with two segments each labeled $d/2$ (i.e., the spring plus the gap between block and rod end each measure $d/2$).]
A uniform rod of length d has one end fixed to the central axis of a horizontal, frictionless circular platform of radius $R = 2d$. Fixed at the other end of the rod is an ideal spring of negligible mass to which a block is attached. The block is set in

Question 3

frictionless grooves so that it can only move along a radius of the platform, as shown in Figure 1 above. The equilibrium length of the spring is $d/2$. Below is a table showing the mass of the block and the masses and rotational inertias of the rod and platform.

	Mass	Rotational Inertia
Block	m	
Rod	$m_R = 3m$	$\frac{m_R d^2}{3}$ (about the end of the rod)
Platform	$m_P = 5m$	$\frac{m_P R^2}{2}$ (about the central axis)

A motor begins to slowly rotate the platform counterclockwise as viewed from above until the platform reaches a constant angular speed ω. Under these conditions, the spring has stretched by an additional length $d/2$, as shown in Figure 2.

Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

Question 3

(a) Derive an expression for the spring constant of the spring.

Question 3

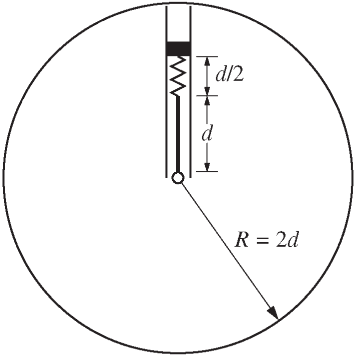

Figure 1

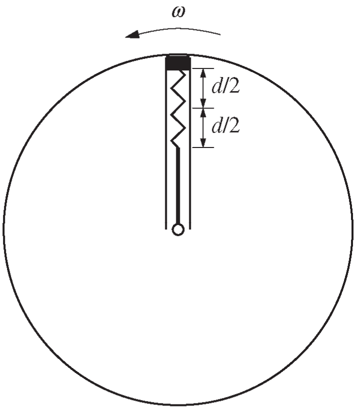

Figure 2

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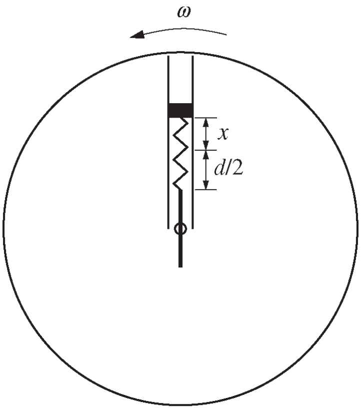

Figure 3

Question 3

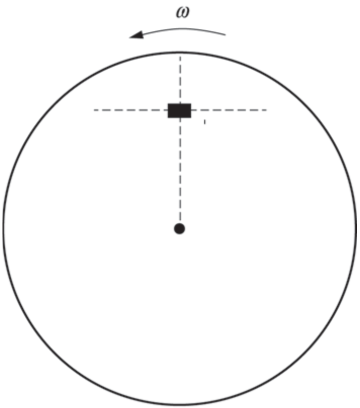

Figure 4

Question 3

2016 ▪ Q3

[Figure 1: A circular platform of radius $R = 2d$ viewed from above, with a vertical rod of length d fixed at the central axis (a small circle marking the pivot at the center). A spring of natural (unstretched) length $d/2$ sits along the rod, connected to a block (shown as a small dark rectangle) at distance $d/2$ from the outer end of the rod.] [Figure 2: The same circular platform now rotating counterclockwise (as viewed from above) at angular speed ω (curved arrow at top indicating rotation direction). The block has moved outward; the spring is now stretched, shown with two segments each labeled $d/2$ (i.e., the spring plus the gap between block and rod end each measure $d/2$).]

A uniform rod of length d has one end fixed to the central axis of a horizontal, frictionless circular platform of radius $R = 2d$. Fixed at the other end of the rod is an ideal spring of negligible mass to which a block is attached. The block is set in frictionless grooves so that it can only move along a radius of the platform, as shown in Figure 1 above. The equilibrium

Question 3

length of the spring is $d/2$. Below is a table showing the mass of the block and the masses and rotational inertias of the rod and platform.

	Mass	Rotational Inertia
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A motor begins to slowly rotate the platform counterclockwise as viewed from above until the platform reaches a constant angular speed ω. Under these conditions, the spring has stretched by an additional length $d/2$, as shown in Figure 2.

Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(b)(i) Determine an expression for the rotational inertia of the block around the axis of the platform.

Question 3

(b)(ii) Derive an expression for the rotational inertia of the entire system about the axis of the platform.

Question 3

2016 ▪ Q3

[Figure 1: A circular platform of radius $R = 2d$ viewed from above, with a vertical rod of length d fixed at the central axis (a small circle marking the pivot at the center). A spring of natural (unstretched) length $d/2$ sits along the rod, connected to a block (shown as a small dark rectangle) at distance $d/2$ from the outer end of the rod.] [Figure 2: The same circular platform now rotating counterclockwise (as viewed from above) at angular speed ω (curved arrow at top indicating rotation direction). The block has moved outward; the spring is now stretched, shown with two segments each labeled $d/2$ (i.e., the spring plus the gap between block and rod end each measure $d/2$).]

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Question 3

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	Mass	Rotational Inertia
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A motor begins to slowly rotate the platform counterclockwise as viewed from above until the platform reaches a constant angular speed ω. Under these conditions, the spring has stretched by an additional length $d/2$, as shown in Figure 2.

Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(c) Determine an expression for the angular momentum of the entire system about the axis of the platform.

Question 3

[Figure 3: The same circular platform, rotating counterclockwise at ω. The rod's block position is shown partway along the rod, with the spring stretched by amount x and a remaining segment labeled $d/2$ below it.]

While the system continues to rotate, a small mechanism in the pivot moves the rod slowly until the center of the rod is positioned on the axis, as shown in Figure 3 above. The same constant angular speed ω is maintained by the motor driving the platform.

Question 3

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Question 3

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A motor begins to slowly rotate the platform counterclockwise as viewed from above until the platform reaches a constant angular speed ω. Under these conditions, the spring has stretched by an additional length $d/2$, as shown in Figure 2.

Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(d) Derive an expression for the distance x that the spring is stretched when the rod reaches the position shown in Figure 3 above.

Question 3

For parts (e), (f), and (g), assume the center of the rod is still moving toward the axis of the platform.

Question 3

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Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(e) Is the angular momentum of the entire system increasing, decreasing, or staying the same?

_____ Increasing   _____ Decreasing   _____ Staying the same

Question 3

Justify your answer.

Question 3

2016 ▪ Q3

[Figure 1: A circular platform of radius $R = 2d$ viewed from above, with a vertical rod of length d fixed at the central axis (a small circle marking the pivot at the center). A spring of natural (unstretched) length $d/2$ sits along the rod, connected to a block (shown as a small dark rectangle) at distance $d/2$ from the outer end of the rod.] [Figure 2: The same circular platform now rotating counterclockwise (as viewed from above) at angular speed ω (curved arrow at top indicating rotation direction). The block has moved outward; the spring is now stretched, shown with two segments each labeled $d/2$ (i.e., the spring plus the gap between block and rod end each measure $d/2$).]
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Question 3

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Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(f) In order to keep the system rotating with constant angular speed ω, is the motor doing positive work, negative work, or no work on the rotating system?

_____ Positive _____ Negative _____ No work

Question 3

Justify your answer.

Question 3

2016 ▪ Q3

[Figure 1: A circular platform of radius $R = 2d$ viewed from above, with a vertical rod of length d fixed at the central axis (a small circle marking the pivot at the center). A spring of natural (unstretched) length $d/2$ sits along the rod, connected to a block (shown as a small dark rectangle) at distance $d/2$ from the outer end of the rod.] [Figure 2: The same circular platform now rotating counterclockwise (as viewed from above) at angular speed ω (curved arrow at top indicating rotation direction). The block has moved outward; the spring is now stretched, shown with two segments each labeled $d/2$ (i.e., the spring plus the gap between block and rod end each measure $d/2$).]
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Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(g) On the block in Figure 4 below, draw a single vector representing the direction of the acceleration of the block. Draw the vector so that it is starting on, and pointing away from, the block.

Question 3

[Figure 4: The circular platform rotating counterclockwise at ω, with the block shown at the center on the axis (a small dark square marker), a dashed horizontal line through it, and a dot below the platform on the vertical rod line, for the student to draw an acceleration vector on the block.]

Solution 3

(a)

Mark scheme

- Radial form of Newton's second law: spring force equals centripetal force, $F_S = F_C = ma_C$, i.e. $kx = mr\omega^2$. With spring stretch $x = d/2$ and orbit radius $r = 2d$ (per the given geometry): $k\left(\frac{d}{2}\right) = m(2d)\omega^2$. Solving: $k = 4m\omega^2$. 1 pt for indicating $F_S = F_C = ma_C$; 1 pt for a correct substitution for x; 1 pt for a correct substitution for r that lets you solve for k. Correct answer: $k = 4m\omega^2$.

Solution 3

(b)(i)

Mark scheme

- Treating the block as a point mass at radius $r = 2d$:
  $I = \sum mr^2 = m(2d)^2 = 4md^2$. 1 pt for a correct answer, or an answer consistent with the radius used in part (a).

Solution 3

(b)(ii) Mark scheme

- Total rotational inertia is the sum of the platform's, rod's, and block's: $I = I_P + I_R + I_O = \frac{m_P R^2}{2} + \frac{m_R d^2}{3} + mr^2$. Substituting $m_P = 5m$, $R = 2d$ (platform as a disk), $m_R = 3m$ (rod), and $mr^2 = 4md^2$ from (b)i: $I = \frac{5m(2d)^2}{2} + \frac{3md^2}{3} + 4md^2 = 10md^2 + md^2 + 4md^2 = 15md^2$. 1 pt for indicating the system's rotational inertia must include the platform, rod, and object; 1 pt for correctly substituting each piece consistent with (b)i. Correct answer: $I = 15md^2$.

Solution 3

(c)

Mark scheme

- $L = I\omega$. Using $I = 15md^2$ from part (b)ii: $L = 15md^2\omega$. 1 pt for an answer consistent with the answer from part (b)ii.

Solution 3

(d)

Mark scheme

- Same radial equation as part (a): $F_S = F_C = ma_C \Rightarrow kx = mr\omega^2$. Using $k = 4m\omega^2$ (from part (a), or the student's own consistent value) and the new radius $r = d + x$ (rod's center now at the axis, spring stretched by x): $(4m\omega^2)x = m(d+x)\omega^2 \Rightarrow 4x = d + x \Rightarrow 3x = d \Rightarrow x = d/3$. 1 pt for indicating the spring force equals mass times centripetal acceleration; 1 pt for a correct substitution for k (or one consistent with part (a)); 1 pt for a correct substitution for r that lets you solve for x. Correct answer: $x = d/3$.

Solution 3

(e)

Mark scheme

- Answer: Decreasing. As the block moves inward toward the axis, the system's rotational inertia I decreases while ω is held constant; since $L = I\omega$, a decreasing I with constant ω means L decreases. 1 pt for selecting 'Decreasing' (no credit for the justification if the wrong selection is made); 1 pt for a correct justification (I decreases while ω stays the same, so $L = I\omega$ decreases).

Solution 3

(f)

Mark scheme

- Answer: Negative. With ω held constant while I decreases, the rotational kinetic energy $K = \frac{1}{2}I\omega^2$ decreases; by the work-energy theorem the net work on the rotating system is negative, so the motor is doing negative work (removing energy to keep ω constant as I shrinks). 1 pt for selecting 'Negative' (no credit for the justification if the wrong selection is made); 1 pt for a correct justification (ω is constant, I has decreased, so rotational KE has decreased, so the work done must be negative).

Solution 3

(g)

Mark scheme

- The scoring guidelines show the correct acceleration direction as a single arrow starting on the block and pointing down and to the right — i.e. combining a centripetal (inward) component with a tangential component consistent with the block's inward radial motion while the platform rotates counterclockwise. 1 pt for an arrow starting on the box and pointing down and to the right.