2023

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free-Response Question 4

- ☑ Scoring Guidelines
- ☑ Student Samples
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Question 4: Short Answer Paragraph Argument — 7 points

(a)	For a correct expression for the angular acceleration of the pulley in terms of the appropriate quantities: $\alpha_{\mathrm{D}} = \dfrac{2F_T}{MR}$	**1 point**

Example Response

$\alpha_{\mathrm{D}} = \dfrac{RF_T}{\frac{1}{2}MR^2}$ ***OR*** $\alpha_{\mathrm{D}} = \dfrac{2F_T}{MR}$

Total for part (a) — 1 point

(b)	For indicating that the torque, τ, is the same for both pulleys	**1 point**
	For indicating that the impulse, $\tau\Delta t$, (or change in momentum ΔL) is the same for both pulleys because τ and Δt are the same	**1 point**
	For indicating that the rotational inertia, I, of the disk and hoop are different	**1 point**
	For providing reasoning that because the rotational inertia, I, are different for the disk and hoop, the kinematic quantities ($\Delta\theta,\ \omega,\ \alpha$) are also different for the disk and hoop	**1 point**
	For **one** of the following: • Relating I and ω to reason that ΔK is greater for the disk • Indicating that because $\Delta\theta$ is greater for the disk the work done on the disk is greater	**1 point**
	For a logical, relevant, and internally consistent argument that follows the guidelines described in the published requirements for the paragraph-length response	**1 point**

Example Response

The rotational inertia, I, of the hoop is larger than the rotational inertia of the disk because the hoop's mass is all on the outside instead of distributed throughout like the disk. Equal forces are applied to both pulleys at the same distance, which means that the torques exerted on the pulleys will also be equal. Since the same torque is applied to both pulleys for the same time period, the change in angular momentum will be the same for the disk and hoop. The magnitude of the angular velocity for the hoop will be smaller than that of the disk since angular velocity is inversely proportional to the rotational inertia $\left(\omega = \frac{L}{I}\right)$.

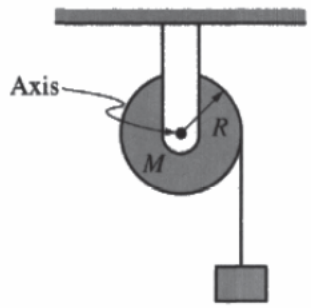
Since kinetic energy is proportional to rotational inertia and the square of angular velocity $\left(K_R = \frac{1}{2}I\omega^2\right)$, *the difference in angular velocity more greatly affects the rotational kinetic energy. That means the disk will have a greater rotational kinetic energy than the hoop.*

Total for part (b) 6 points

Total for question 4 7 points

Question 4

Begin your response to QUESTION 4 on this page.



4. (7 points, suggested time 13 minutes)

A block of unknown mass is attached to a long, lightweight string that is wrapped several turns around a pulley mounted on a horizontal axis through its center, as shown. The pulley is a uniform solid disk of mass M and radius R. The rotational inertia of the pulley is described by the equation $I = \frac{1}{2}MR^2$. The pulley can rotate about its center with negligible friction. The string does not slip on the pulley as the block falls.

When the block is released from rest and as the block travels toward the ground, the magnitude of the tension exerted on the block by the string is F_T.

(a) Determine an expression for the magnitude of the angular acceleration α_D of the disk as the block travels downward. Express your answer in terms of M, R, F_T, and physical constants as appropriate.

$\alpha = \frac{\tau_{net}}{I}$ $\alpha = \frac{rF\sin\theta}{\frac{1}{2}MR^2}$ $\alpha = \frac{2F_T\sin 90}{MR}$

$$\alpha = \frac{2F_T}{MR}$$

Question 4

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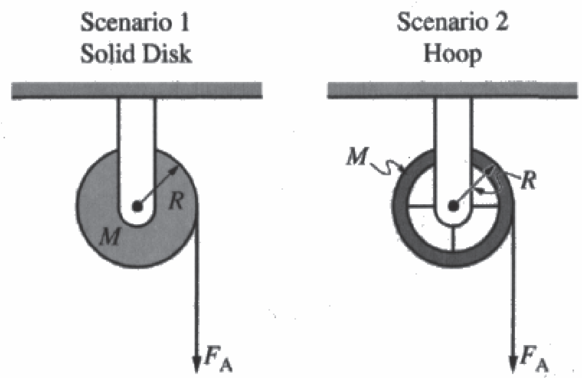

Scenarios 1 and 2 show two different pulleys. In Scenario 1, the pulley is the same solid disk referenced in part (a). In Scenario 2, the pulley is a hoop that has the same mass M and radius R as the disk. Each pulley has a lightweight string wrapped around it several turns and is mounted on a horizontal axle, as shown. Each pulley is free to rotate about its center with negligible friction.

In both scenarios, the pulleys begin at rest. Then both strings are pulled with the same constant force F_A for the same time interval Δt, causing the pulleys to rotate without the string slipping. After time interval Δt, the change in angular momentum of the disk is equal to the change in angular momentum of the hoop, but the change in rotational kinetic energy for the disk is greater than that of the hoop.

(b) Consider scenarios 1 and 2 at the end of time interval Δt. In a clear, coherent paragraph-length response that may also contain equations and drawings, explain why the change in angular momentum of both pulleys is the same but the change in rotational kinetic energy is greater for the disk.

The change in ang. momentum is the same because the τ_{net} and t are the same and $\tau_{net} t$ = change in ang. momentum. K_R is greater for the disk because the hoop has a greater I, so a lower ω. And ω matters more in the equation for K_R because ω is squared.

Question 4

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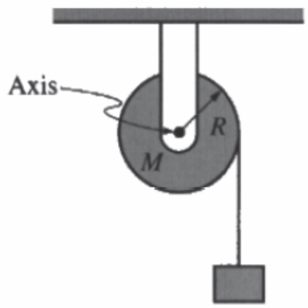


4. (7 points, suggested time 13 minutes)

A block of unknown mass is attached to a long, lightweight string that is wrapped several turns around a pulley mounted on a horizontal axis through its center, as shown. The pulley is a uniform solid disk of mass M and radius R. The rotational inertia of the pulley is described by the equation $I = \frac{1}{2}MR^2$. The pulley can rotate about its center with negligible friction. The string does not slip on the pulley as the block falls.

When the block is released from rest and as the block travels toward the ground, the magnitude of the tension exerted on the block by the string is F_T.

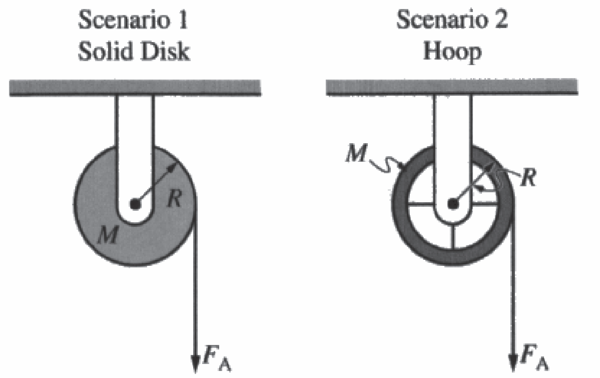
(a) Determine an expression for the magnitude of the angular acceleration α_D of the disk as the block travels downward. Express your answer in terms of M, R, F_T, and physical constants as appropriate.

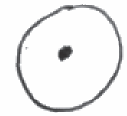
$$\alpha_D = \frac{R F_T \sin\theta}{\frac{1}{2}MR^2}$$

$$= \boxed{\frac{2 F_T \sin\theta}{MR}}$$

Question 4

Continue your response to QUESTION 4 on this page.





less inertia   More inertia

Scenarios 1 and 2 show two different pulleys. In Scenario 1, the pulley is the same solid disk referenced in part (a). In Scenario 2, the pulley is a hoop that has the same mass M and radius R as the disk. Each pulley has a lightweight string wrapped around it several turns and is mounted on a horizontal axle, as shown. Each pulley is free to rotate about its center with negligible friction.

In both scenarios, the pulleys begin at rest. Then both strings are pulled with the same constant force F_A for the same time interval Δt, causing the pulleys to rotate without the string slipping. After time interval Δt, the change in angular momentum of the disk is equal to the change in angular momentum of the hoop, but the change in rotational kinetic energy for the disk is greater than that of the hoop.

Key

(b) Consider scenarios 1 and 2 at the end of time interval Δt. In a clear, coherent paragraph-length response that may also contain equations and drawings, explain why the change in angular momentum of both pulleys is the same but the change in rotational kinetic energy is greater for the disk.

ω - angular velocity
K_{rot} - rotational kinetic

Considering that both pulleys with the hoop & disk have the same mass M & radius R, there's a reason why they have the same change in angular momentum but the disk has a ~~greater~~ greater change in K_{rot}. The reason for the same change in angular momentum is that although the disk has less inertia than the hoop (because the mass is closer to the center of mass than the hoop), the pulley is going to have a faster ~~ω~~ for ~~the~~ the disk than the hoop simply because it has less inertia & it will accelerate faster. And since the ω is less for the hoop, it has an equal momentum to the disk because of its greater inertia. The reason why the K_{rot} for the disk is greater than the hoop is because $K_{rot} = \frac{1}{2} I \omega^2$, meaning that a difference between the two's angular speeds will cause a significant difference in K_{rot}. But in the situation where we were comparing the ~~rotational~~ angular momentums, where $L = I\omega$, nothing was squared so it would lead to them being equal & no significant difference in momentum between the pulley with the disk & the one with the hoop.

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Question 4

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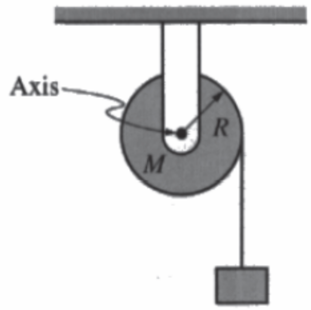


4. (7 points, suggested time 13 minutes)

A block of unknown mass is attached to a long, lightweight string that is wrapped several turns around a pulley mounted on a horizontal axis through its center, as shown. The pulley is a uniform solid disk of mass M and radius R. The rotational inertia of the pulley is described by the equation $I = \frac{1}{2}MR^2$. The pulley can rotate about its center with negligible friction. The string does not slip on the pulley as the block falls.

When the block is released from rest and as the block travels toward the ground, the magnitude of the tension exerted on the block by the string is F_T.

(a) Determine an expression for the magnitude of the angular acceleration α_D of the disk as the block travels downward. Express your answer in terms of M, R, F_T, and physical constants as appropriate.

$I = \frac{1}{2}MR^2$

$\alpha_D \quad \Sigma\tau = F_T$

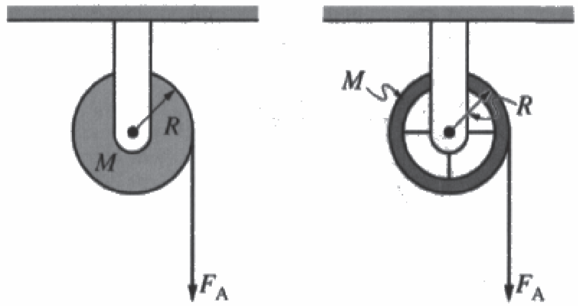
$\alpha_D = \frac{\Sigma\tau}{I} = \frac{F_T}{I} = \frac{2F_T}{2\frac{1}{2}MR^2} = \sqrt{\frac{2F_T}{MR^2}} = \frac{\sqrt{2F_T}}{MR}$

$\boxed{\alpha_D = \frac{2\sqrt{F_T}}{MR}}$

Question 4

Continue your response to **QUESTION 4** on this page.

Scenario 1 Solid Disk | Scenario 2 Hoop



Scenarios 1 and 2 show two different pulleys. In Scenario 1, the pulley is the same solid disk referenced in part (a). In Scenario 2, the pulley is a hoop that has the same mass M and radius R as the disk. Each pulley has a lightweight string wrapped around it several turns and is mounted on a horizontal axle, as shown. Each pulley is free to rotate about its center with negligible friction.

In both scenarios, the pulleys begin at rest. Then both strings are pulled with the same constant force F_A for the same time interval Δt, causing the pulleys to rotate without the string slipping. After time interval Δt, the change in angular momentum of the disk is equal to the change in angular momentum of the hoop, but the change in rotational kinetic energy for the disk is greater than that of the hoop.

(b) Consider scenarios 1 and 2 at the end of time interval Δt. In a clear, coherent paragraph-length response that may also contain equations and drawings, explain why the change in angular momentum of both pulleys is the same but the change in rotational kinetic energy is greater for the disk.

The change in angular momentum of both pulleys is the same (Solid Disk & hoop), but the change in rotational KE is greater for disk b/c $\Delta L = I\omega$ which means that rotational Inertia x angular speed is the same & isn't affected b/c it is same in moment but when talking about rot. KE which has the $K = \frac{1}{2}I\omega^2$ → since change in: $\Delta K = \frac{1}{2}I\omega^2$ when it gets more specific w/ it cause of KE, there is a $\frac{1}{2}$ multiplied by the rotational Inertia multiplied by angular speed squared, which more specific & since scenaro 2 has a hoop it will slow down the rotational Kinetic Energy

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Determine an expression for the angular acceleration of a pulley using torque and rotational inertia.
- Describe torque applied to objects using force and lever arm.
- Compare changes in angular momentum for objects with different mass distributions.
- Indicate the relationship between mass distribution and rotational inertia.
- Compare angular kinematic quantities for objects with different rotational inertia.
- Explain how objects with the same change in angular momentum can have different changes in kinetic energy.
- Write logically, coherently, and concisely.

Sample: 4A
Score: 7

Part (a) earned 1 point for correctly determining an expression for α in terms of appropriate variables. Part (b) earned 6 points. One point was earned for correctly indicating that the torque was the same for both pulleys. The second point was earned for correctly connecting torque and time to the same change in angular momentum. The third point was earned for indicating that the hoop and the disk have different rotational inertias. The fourth point was earned for relating rotational inertia to an angular kinematic quantity change. The fifth point was earned for correctly justifying why the change in the kinetic energy of the disk is greater than the change in kinetic energy of the hoop. The response includes an explanation that changes in angular speed affect the kinetic energy more than changes in rotational inertia. The last point was earned for including a logical, relevant, and internally consistent argument.

Sample: 4B
Score: 4

Part (a) earned no points because, while the response includes an expression for α, the response also includes an unknown quantity θ. Part (b) earned 4 points. The first point was not earned because the response does not include any comparison of torque for the two pulleys. The second point was not earned because the response does not connect either torque and time or impulse to the change in angular momentum. The third point was earned for indicating that the hoop and the disk have different rotational inertias. The fourth point was earned for relating rotational inertia to an angular kinematic quantity change. The fifth point was earned for correctly justifying why the change in the kinetic energy of the disk is greater than the change in kinetic energy of the hoop. The response includes an explanation that changes in angular speed affect the kinetic energy more than changes in rotational inertia. The last point was earned for including a logical, relevant, and internally consistent argument.

Question 4 (continued)

Sample: 4C
Score: 1

Part (a) earned no points because the response incorrectly determines an expression for α. Part (b) earned 1 point. The first point was not earned because the response does not indicate that the torque was the same for both pulleys. There is no mention of torque in the response. The second point was not earned because the response does not connect the same torque and time (angular impulse) to the same change in angular momentum. The third point was not earned because the response does not indicate that the hoop and the disk have different rotational inertias. While the response does mention that rotational inertia multiplied by the angular speed is equal for both disk and hoop, the response does not specify that rotational inertia and angular speed are different for both the disk and hoop. The fourth point was not earned because the response does not relate rotational inertia to an angular kinematic quantity change. While the response does mention that rotational inertia multiplied by the angular speed is equal for both the disk and hoop, the response does not specify that an angular kinematic quantity changes due to a change in rotational inertia. The fifth point was not earned because the response does not justify why the change in the kinetic energy of the disk is greater than the change in kinetic energy of the hoop. While the response gives the equation for rotational kinetic energy, the response does not explain why the changes in kinetic energy are not the same. The last point was earned because, although incorrect, the response includes a relevant and internally consistent argument.