2019

AP® CollegeBoard

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 1

Inside:

Free Response Question 3

☑ Scoring Guideline

☑ Student Samples

☑ Scoring Commentary

General Notes About 2019 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

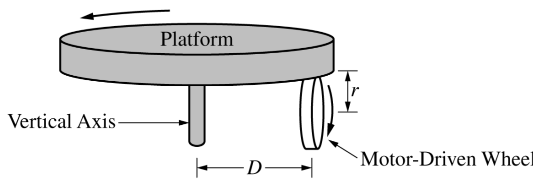
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m}/\text{s}^2$, but the use of $10\ \text{m}/\text{s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 3

15 points



A horizontal circular platform with rotational inertia I_P rotates freely without friction on a vertical axis. A small motor-driven wheel that is used to rotate the platform is mounted under the platform and touches it. The wheel has radius r and touches the platform a distance D from the vertical axis of the platform, as shown above. The platform starts at rest, and the wheel exerts a constant horizontal force of magnitude F tangent to the wheel until the platform reaches an angular speed ω_P after time Δt. During time Δt, the wheel stays in contact with the platform without slipping.

(a) LO INT-7.A.b, CHA-4.A.b, SP 5.A, 5.E
2 points

Derive an expression for the angular speed ω_P of the platform. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

For correctly substituting into the rotational form of Newton's second law			1 point
$\tau = I\alpha \therefore FD = I_P\alpha$			
$\alpha = \frac{FD}{I_P}$			
For correctly substituting into a rotational kinematic equation to calculate the angular speed			1 point
$\omega_2 = \omega_1 + \alpha\Delta t = 0 + \left(\frac{FD}{I_P}\right)\Delta t$			
$\omega_P = \frac{FD\Delta t}{I_P}$			

(b) LO INT-7.D.a, SP 5.A, 5.E
2 points

Determine an expression for the kinetic energy of the platform at the moment it reaches angular speed ω_P. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

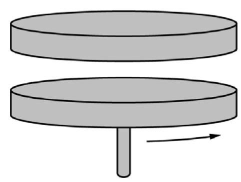
For using the equation for rotational kinetic energy		1 point
$K = \frac{1}{2}I\omega_P^2 = \left(\frac{1}{2}\right)(I)\left(\frac{FD\Delta t}{I}\right)^2$		
For an answer consistent with part (a)		1 point
$K = \frac{(FD\Delta t)^2}{2I}$		

Question 3 (continued)

(c) LO INT-7.C, SP 5.A, 5.E
2 points

Derive an expression for the angular speed of the wheel ω_W when the platform has reached angular speed ω_P. Express your answer in terms of D, r, ω_P, and physical constants, as appropriate.

For indicating that the linear speed of the platform is equal to the linear speed of the wheel		1 point
$v_P = v_W$ OR $(r\omega)_P = (r\omega)_W$		
For correctly relating the linear speeds to the angular speeds in the above equation		1 point
$D\omega_P = r\omega_W$		
$\omega_W = \dfrac{D\omega_P}{r}$		



When the platform is spinning at angular speed ω_P, the motor-driven wheel is removed. A student holds a disk directly above and concentric with the platform, as shown above. The disk has the same rotational inertia I_P as the platform. The student releases the disk from rest, and the disk falls onto the platform. After a short time, the disk and platform are observed to be rotating together at angular speed ω_f.

(d) LO CON-5.D.c, SP 5.A, 5.E
2 points

Derive an expression for ω_f. Express your answer in terms of ω_P, I_P, and physical constants, as appropriate.

For using an expression for the conservation of angular momentum		1 point
$L_1 = L_2 \therefore I_1\omega_1 = I_2\omega_2$		
For correctly substituting into the above equation		1 point
$I\omega_P = (2I)\omega_F$		
$\omega_F = \dfrac{1}{2}\omega_P$		

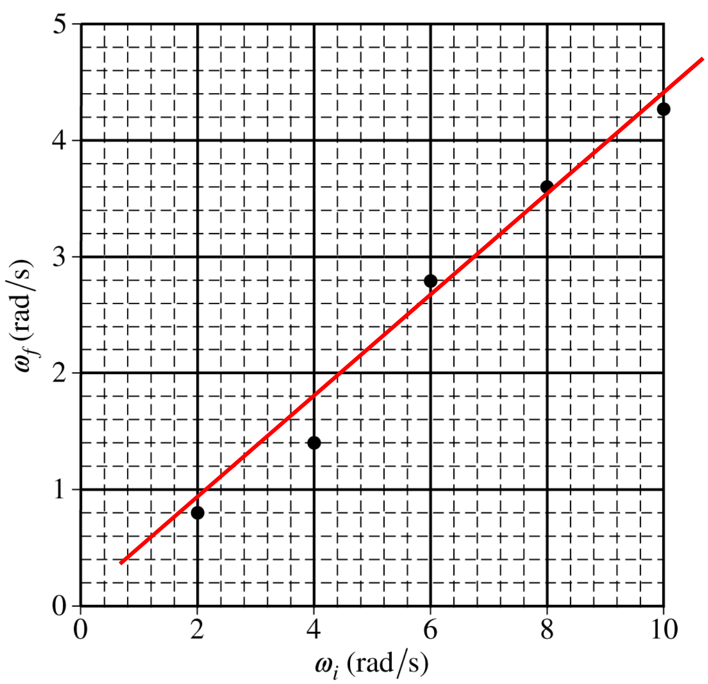
Question 3 (continued)

A student now uses the rotating platform $\left(I_P = 3.1\ \text{kg} \bullet \text{m}^2\right)$ to determine the rotational inertia I_U of an unknown object about a vertical axis that passes through the object's center of mass. The platform is rotating at an initial angular speed ω_i when the unknown object is dropped with its center of mass directly above the center of the platform. The platform and object are observed to be rotating together at angular speed ω_f. Trials are repeated for different values of ω_i. A graph of ω_f as a function of ω_i is shown on the axes below.

(e)

i. LO CON-5.D.c, SP 4.C
1 points

On the graph on the previous page, draw a best-fit line for the data.



For an appropriate best-fit line for the graph above		1 point

Question 3 (continued)

(e) continued

ii. LO CON-5.D.c, SP 4.D, 6.C
2 points

Using the straight line, calculate the rotational inertia of the unknown object I_U about a vertical axis passing through its center of mass.

For using conservation of angular momentum to derive an expression that includes I_U		1 point
$L_i = L_f \;\therefore\; I_P\omega_i = (I_P + I_U)\omega_f$		
$I_U = I_P\left(\dfrac{\omega_i}{\omega_f}\right) - I_P$		
For substituting points from the best-fit line into the expression above		1 point
$I_U = \left(3.1\ \text{kg}\bullet\text{m}^2\right)\left(\dfrac{(4.0-1.0)\ \text{rad/s}}{(9.3-2.4)\ \text{rad/s}}\right) - \left(3.1\ \text{kg}\bullet\text{m}^2\right) = 4.1\ \text{kg}\bullet\text{m}^2$		
Note: The point (0, 0) can be used implicitly if the best-fit line goes through the origin.		

(f) LO CON-5.D.c, SP 7.A, 7.C
2 points

The kinetic energy of the spinning platform before the object is dropped on it is K_i. The total kinetic energy of the platform-object system when it reaches angular speed ω_f is K_f. Which of the following expressions is true?

____ $K_f < K_i$ ____ $K_f = K_i$ ____ $K_f > K_i$

Justify your answer.

For selecting $K_f < K_i$ with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Because the two disks will be rotating with the same final angular speed, this is an inelastic collision, and kinetic energy will be lost during the collision.		

Question 3 (continued)

(g) LO INT-6.E, SP 7.A, 7.C
2 points

One of the students observes that the center of mass of the object is not actually aligned with the axis of the platform. Is the experimental value of I_U obtained in part (e) greater than, less than, or equal to the actual value of the rotational inertia of the unknown object about a vertical axis that passes through its center of mass?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

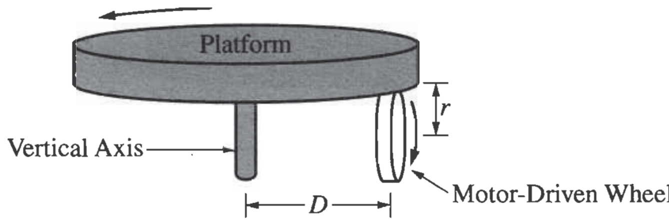
For selecting "Greater than" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Because the center of mass of the object is off the axis of the platform, the parallel axis theorem would be used to calculate the total rotational inertia of the platform-object system. Using $I = I_{CM} + Mh^2$, the experimental value will be increased by Mh^2.		

Learning Objectives

INT-6.E: Derive the moments of inertia of an extended rigid body for different rotational axes (parallel to an axis that goes through the object's center of mass) if the moment of inertia is known about an axis through the object's center of mass.
CHA-4.A.b: Calculate unknown quantities such as angular positions, displacement, angular speeds, or angular acceleration of a rigid body in uniformly accelerated motion, given initial conditions.
INT-7.A.b: Calculate unknown quantities such as net torque, angular acceleration, or moment of inertia for a rigid body undergoing rotational acceleration.
INT-7.C: Derive expressions for physical systems such as Atwood Machines, pulleys with rotational inertia, or strings connecting discs or strings connecting multiple pulleys that relate linear or translational motion characteristics to the angular motion characteristics of rigid bodies in the system that are: **(a)** rolling (or rotating on a fixed axis) without slipping. **(b)** rotating and sliding simultaneously.
INT-7.D.a: Calculate the rotational kinetic energy of a rotating rigid body.
CON-5.D.c: Calculate the changes of angular momentum of each disc in a rotating system of two rotating discs that collide with each other inelastically about a common rotational axis.

Science Practices

4.C: Linearize data and/or determine a best-fit line or curve.
4.D: Select relevant features of a graph to describe a physical situation or solve problems.
5.A: Select an appropriate law, definition, or mathematical relationship or model to describe a physical situation.
5.E: Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway.
6.C: Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
7.A: Make a scientific claim.
7.C: Support a claim with evidence from physical representations.



3. A horizontal circular platform with rotational inertia I_P rotates freely without friction on a vertical axis. A small motor-driven wheel that is used to rotate the platform is mounted under the platform and touches it. The wheel has radius r and touches the platform a distance D from the vertical axis of the platform, as shown above. The platform starts at rest, and the wheel exerts a constant horizontal force of magnitude F tangent to the wheel until the platform reaches an angular speed ω_P after time Δt. During time Δt, the wheel stays in contact with the platform without slipping.

(a) Derive an expression for the angular speed ω_P of the platform. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

$\omega_p = 0 + \alpha(\Delta t)$ $\quad \tau_{net} = I_p \alpha = F \cdot D$ $\quad \alpha = \frac{F \cdot D}{I_p}$

$\omega_p = \frac{F D \Delta t}{I_p}$

$\frac{kg\, m^2/s \cdot F}{m^2 \cdot kg}$

(b) Determine an expression for the kinetic energy of the platform at the moment it reaches angular speed ω_P. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

$K_{rot} = \frac{1}{2} I_p \omega_p^2 = \frac{I_p F^2 D^2 \Delta t^2}{2 I_p^2} = \frac{(F D \Delta t)^2}{2 I_p}$

(c) Derive an expression for the angular speed of the wheel ω_W when the platform has reached angular speed ω_P. Express your answer in terms of D, r, ω_P, and physical constants, as appropriate.

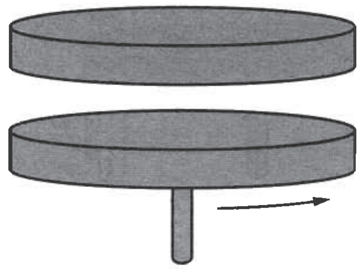
$V_p = V_W$

$\omega_p \cdot D = \omega_w \cdot r$

$\omega_W = \frac{\omega_p \cdot D}{r}$

Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.



When the platform is spinning at angular speed ω_P, the motor-driven wheel is removed. A student holds a disk directly above and concentric with the platform, as shown above. The disk has the same rotational inertia I_P as the platform. The student releases the disk from rest, and the disk falls onto the platform. After a short time, the disk and platform are observed to be rotating together at angular speed ω_f.

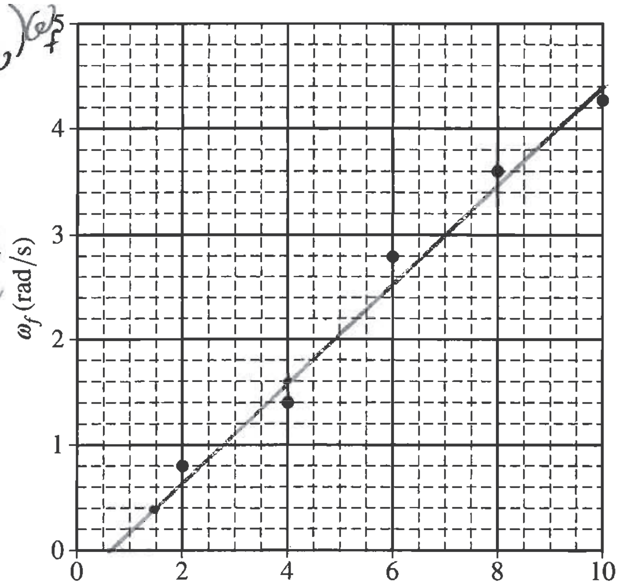
(d) Derive an expression for ω_f. Express your answer in terms of ω_P, I_P, and physical constants, as appropriate.

$I_p \omega_p = 2 I_p \omega_f \qquad \omega_f = \frac{\omega_p}{2}$

A student now uses the rotating platform $\left(I_P = 3.1\ \text{kg}\cdot\text{m}^2\right)$ to determine the rotational inertia I_U of an unknown object about a vertical axis that passes through the object's center of mass. The platform is rotating at an initial angular speed ω_i when the unknown object is dropped with its center of mass directly above the center of the platform. The platform and object are observed to be rotating together at angular speed ω_f. Trials are repeated for different values of ω_i. A graph of ω_f as a function of ω_i is shown on the axes below.

$I_p \omega_i = (I_p + I_U)\omega_f$

$\omega_f = \frac{I_p}{I_p + I_U} \cdot \omega_i$



GO ON TO THE NEXT PAGE.

(e)

i. On the graph on the previous page, draw a best-fit line for the data.

ii. Using the straight line, calculate the rotational inertia of the unknown object I_U about a vertical axis passing through its center of mass.

$\omega_f = \frac{I_P}{I_P + I_U} \cdot \omega_i$

$\text{Slope} = \frac{1.2}{2.5} = 0.48$

$\omega_f (\text{rad/s}) = 0.48 \cdot \omega_i (\text{rad/s}) - 0.32$

$0.48 = \frac{I_P}{I_P + I_U}$ $0.48 I_P + 0.48 I_U = I_P$

$I_U = 3.36 \text{ kg} \cdot \text{m}^2$

(f) The kinetic energy of the spinning platform before the object is dropped on it is K_i. The total kinetic energy of the platform-object system when it reaches angular speed ω_f is K_f. Which of the following expressions is true?

$K_{rot} = \frac{1}{2} I \omega^2$

X $K_f < K_i$ ____ $K_f = K_i$ ____ $K_f > K_i$

Justify your answer.

I increased and ω decreased 24.8 8.2688 linearly, preserving momentum.
The square of ω, however, decreased much more, so Krot decreased.

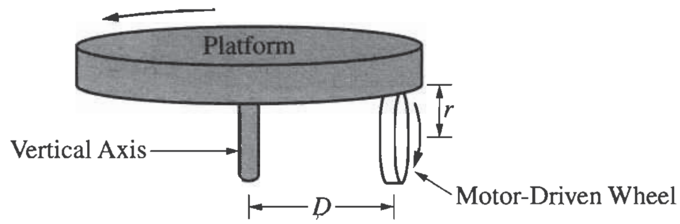
(g) One of the students observes that the center of mass of the object is not actually aligned with the axis of the platform. Is the experimental value of I_U obtained in part (e) greater than, less than, or equal to the actual value of the rotational inertia of the unknown object about a vertical axis that passes through its center of mass?

X Greater than ____ Less than ____ Equal to

Justify your answer.

I_U will be observed to be that of the object when it is some distance x from the center, increasing our perceived value of I_U by about Mx^2.

GO ON TO THE NEXT PAGE.



3. A horizontal circular platform with rotational inertia I_P rotates freely without friction on a vertical axis. A small motor-driven wheel that is used to rotate the platform is mounted under the platform and touches it. The wheel has radius r and touches the platform a distance D from the vertical axis of the platform, as shown above. The platform starts at rest, and the wheel exerts a constant horizontal force of magnitude F tangent to the wheel until the platform reaches an angular speed ω_P after time Δt. During time Δt, the wheel stays in contact with the platform without slipping.

   (a) Derive an expression for the angular speed ω_P of the platform. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

   $\tau_{net} = I\alpha$

   $FD = I\alpha$

   $\alpha = \frac{I}{FD}$

   $\omega_f = \omega_0 + \alpha t$

   $\omega_P = \alpha t$

   $\boxed{\omega_P = \left(\frac{I_P}{FD}\right)\Delta t}$

   (b) Determine an expression for the kinetic energy of the platform at the moment it reaches angular speed ω_P. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

   $K_{rot} = \frac{1}{2} I \omega^2$

   $\boxed{= \frac{1}{2} I_P \omega_P^2}$

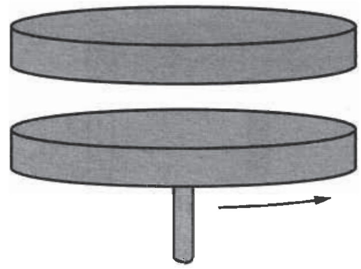
   (c) Derive an expression for the angular speed of the wheel ω_W when the platform has reached angular speed ω_P. Express your answer in terms of D, r, ω_P, and physical constants, as appropriate.

   $\therefore L_0 = L_f$

   $m r \omega_W + I$

Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.

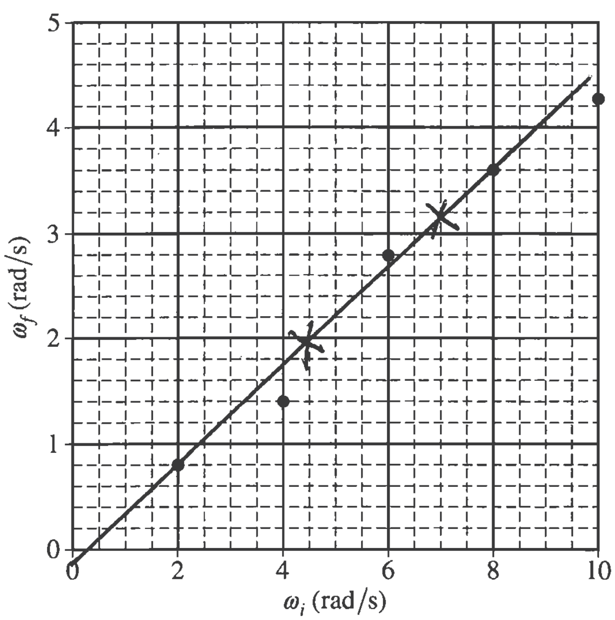


When the platform is spinning at angular speed ω_P, the motor-driven wheel is removed. A student holds a disk directly above and concentric with the platform, as shown above. The disk has the same rotational inertia I_P as the platform. The student releases the disk from rest, and the disk falls onto the platform. After a short time, the disk and platform are observed to be rotating together at angular speed ω_f.

(d) Derive an expression for ω_f. Express your answer in terms of ω_P, I_P, and physical constants, as appropriate.

Fnet=ma Lo=Lf Pi=Pf

A student now uses the rotating platform $\left(I_P = 3.1 \text{ kg}\cdot\text{m}^2\right)$ to determine the rotational inertia I_U of an unknown object about a vertical axis that passes through the object's center of mass. The platform is rotating at an initial angular speed ω_i when the unknown object is dropped with its center of mass directly above the center of the platform. The platform and object are observed to be rotating together at angular speed ω_f. Trials are repeated for different values of ω_i. A graph of ω_f as a function of ω_i is shown on the axes below.



GO ON TO THE NEXT PAGE.

(e)

i. On the graph on the previous page, draw a best-fit line for the data.

ii. Using the straight line, calculate the rotational inertia of the unknown object I_U about a vertical axis passing through its center of mass.

$L_0 = L_f$

$I\omega_0 = (I + I)\omega_f$

$\omega_f = I$

$\omega_f = \frac{I_0}{(I_0 + I_U)}\omega_0$

$\frac{3.1 - 2}{7 - 4.5} = 0.44$

$0.44 = \frac{3.1}{3.1 + I_U}$

$1.364 + 0.44 I_U = 3.1$

$I_U = 3.945$ kg m2

(f) The kinetic energy of the spinning platform before the object is dropped on it is K_i. The total kinetic energy of the platform-object system when it reaches angular speed ω_f is K_f. Which of the following expressions is true?

✓ $K_f < K_i$ ____ $K_f = K_i$ ____ $K_f > K_i$

Justify your answer.

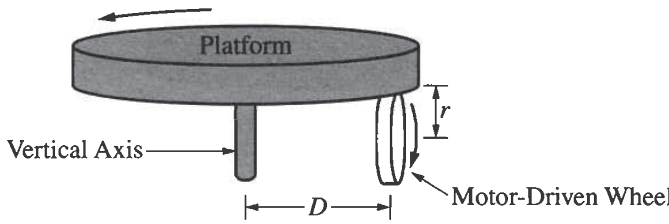
Although angular momentum is conserved, rotational kinetic energy will not be because the collision is not elastic and some kinetic energy will be lost.

(g) One of the students observes that the center of mass of the object is not actually aligned with the axis of the platform. Is the experimental value of I_U obtained in part (e) greater than, less than, or equal to the actual value of the rotational inertia of the unknown object about a vertical axis that passes through its center of mass?

~~Greater than~~ ✓ Less than ~~Equal to~~

Justify your answer.

When it is dropped past the center of mass a torque will be induced causing ωf to be higher than expected, therefore I_U will be lower than expected due to conservation of angular momentum



3. A horizontal circular platform with rotational inertia I_P rotates freely without friction on a vertical axis. A small motor-driven wheel that is used to rotate the platform is mounted under the platform and touches it. The wheel has radius r and touches the platform a distance D from the vertical axis of the platform, as shown above. The platform starts at rest, and the wheel exerts a constant horizontal force of magnitude F tangent to the wheel until the platform reaches an angular speed ω_P after time Δt. During time Δt, the wheel stays in contact with the platform without slipping.

(a) Derive an expression for the angular speed ω_P of the platform. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

$W_p = 0 + \alpha \Delta t$ $\quad F = m(a)$

$W_p = \Delta t (F_c)$ $\quad F_c = m\alpha$

$W_p = \Delta t F$

(b) Determine an expression for the kinetic energy of the platform at the moment it reaches angular speed ω_P. Express your answer in terms of I_P, r, D, F, Δt, and physical constants, as appropriate.

$K = \frac{1}{2} I \omega^2$

$K = \frac{1}{2} I_p (W_p)^2$

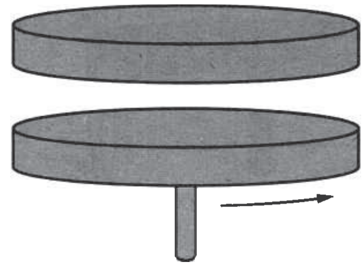
(c) Derive an expression for the angular speed of the wheel ω_W when the platform has reached angular speed ω_P. Express your answer in terms of D, r, ω_P, and physical constants, as appropriate.

$\omega V = W_0 + \alpha t$ $\quad \omega_W = W_p(D) + \pi r^2$

~~$W_p =$~~

Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.

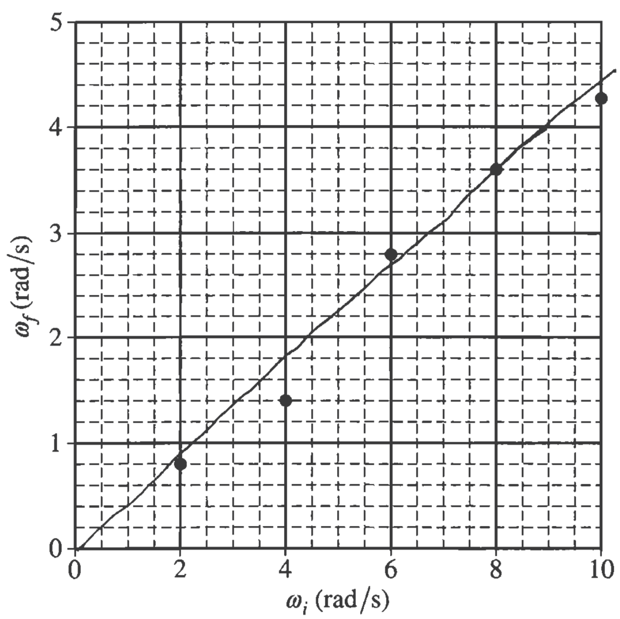


When the platform is spinning at angular speed ω_P, the motor-driven wheel is removed. A student holds a disk directly above and concentric with the platform, as shown above. The disk has the same rotational inertia I_P as the platform. The student releases the disk from rest, and the disk falls onto the platform. After a short time, the disk and platform are observed to be rotating together at angular speed ω_f.

(d) Derive an expression for ω_f. Express your answer in terms of ω_P, I_P, and physical constants, as appropriate.

$W_f = \frac{1}{2} W_P$

A student now uses the rotating platform $\left(I_P = 3.1\ \text{kg}\cdot\text{m}^2\right)$ to determine the rotational inertia I_U of an unknown object about a vertical axis that passes through the object's center of mass. The platform is rotating at an initial angular speed ω_i when the unknown object is dropped with its center of mass directly above the center of the platform. The platform and object are observed to be rotating together at angular speed ω_f. Trials are repeated for different values of ω_i. A graph of ω_f as a function of ω_i is shown on the axes below.



GO ON TO THE NEXT PAGE.

(e)

i. On the graph on the previous page, draw a best-fit line for the data.

ii. Using the straight line, calculate the rotational inertia of the unknown object I_U about a vertical axis passing through its center of mass.

$I_U = I_P(2.381)$ $\quad I_U = I_P^+$

(f) The kinetic energy of the spinning platform before the object is dropped on it is K_i. The total kinetic energy of the platform-object system when it reaches angular speed ω_f is K_f. Which of the following expressions is true?

✓ $K_f < K_i$ ____ $K_f = K_i$ ____ $K_f > K_i$

Justify your answer.

K relies on force, which is inversely proportional to mass

(g) One of the students observes that the center of mass of the object is not actually aligned with the axis of the platform. Is the experimental value of I_U obtained in part (e) greater than, less than, or equal to the actual value of the rotational inertia of the unknown object about a vertical axis that passes through its center of mass?

____ Greater than ✓ Less than ____ Equal to

Justify your answer.

Because it is not at the center of mass, the platform is no longer uniform. this causes a decrease in inertia

Question 3

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

Overview

The responses to this question were expected to demonstrate the following:

- The ability to recognize that an unbalanced force exerted on an object some distance from a perpendicular axis gives the object a rotational acceleration.
- The ability to recognize Newton's second law of motion for rotational motion and its correlation to rotational kinematics through a derived equation.
- Recognition between linear motion and rotational motion for a nonslip scenario where two different discs were rotating together.
- Recognition that angular momentum is conserved during a collision between the platforms in the absence of external forces/torques.
- Given data plotted on a graph, students should be able to determine the relationship between two quantities and draw a graph that best represents the data plotted.
- Analysis of the graphed data in order to form a relationship between the data and develop an expression from the graph in order to answer a prescribed objective.
- Recognition that an object's rotational inertia is dependent on how the mass of the object is distributed relative to an axis of rotation.
- How to use a graph to determine a quantity and describe the effect of a potential error in lab results, requiring application of the parallel axis theorem.

Sample: M Q3 A
Score: 13

All parts except for part (d) earned full credit. In part (a) 2 points were earned for correctly substituting into both the torque equation and the rotational kinematics equation. In part (b) the equation for rotational kinetic energy is used, and an answer consistent with the answer from part (a) is found, so 2 points were earned. In part (c) 2 points were earned for indicating the equality of the linear speeds explicitly and for relating the linear and angular speeds correctly. In part (d) no points were earned because the derivation does not start from first principles. In part (e)(i) 1 point was earned for drawing an appropriate best-fit line. In part (e)(ii) 2 points were earned for using conservation of angular momentum and for indicating which points are being used to determine the slope. In parts (f) and (g) 2 points each were earned for selecting the correct option and for providing a correct justification.

Sample: M Q3 B
Score: 7

Parts (e)(i), (e)(ii), and (f) received full credit, 1, 2, and 2 points, respectively. In part (a) there is an incorrect substitution into the rotational version of Newton's second law, but the expression for α is substituted correctly into the rotational kinematics equation, so 1 point was earned. In part (b) the equation for rotational kinetic energy is used, but an answer consistent with part (a) is not obtained, so 1 point was earned. In part (c) the key concept of linear velocity equality is not identified, so no points were earned. In part (d) the equation for conservation of angular momentum is not used, so no points were earned. In part (g) no points were earned because an incorrect option is chosen with an incorrect justification provided.

Question 3 (continued)

Sample: M Q3 C
Score: 2

Part (e)(i) earned full credit, 1 point. In part (a) the rotational form of Newton's second law is not mentioned, and the rotational kinematics equation is not correctly substituted, so no points were earned. In part (b) the equation for rotational kinetic energy is used by substituting in I_p, but an answer consistent with part (a) is not provided, so 1 point was earned. In part (c) no points were earned because no relevant work is provided. In part (d) the key concept of conservation of angular momentum is not identified, so no points were earned. In part (e)(ii) conservation of angular momentum is not used, and no points on the line are referred to, so no points were earned. In part (f) the correct option is chosen, but no relevant justification is provided, so no points were earned. In part (g) no points were earned because an incorrect option is chosen, and an insufficient justification is provided.