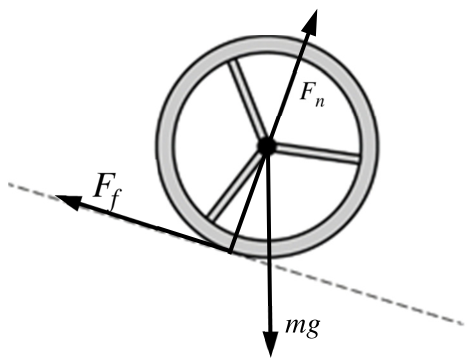
Question 1

7 points total | **Distribution of points**

(a)

i. 2 points



For a labeled arrow representing the gravitational force, starting at the wheel's center and directed downward — 1 point

For labeled arrows representing the friction and normal forces or a single arrow representing the resultant of the friction and normal forces (i.e., the force exerted on the wheel by the surface), with no extraneous forces — 1 point

The friction force should start at the wheel-ramp contact and be directed up and left along the ramp.

The normal force should start at the wheel-ramp contact and be perpendicular to the ramp and toward the wheel's center. It does not have to go exactly through the center but must come reasonably close.

ii. 1 point

Correct answer: The friction force

No points are earned if the wrong force is given.

For correctly explaining that friction is the only force that exerts a torque with respect to the wheel's center of mass — 1 point

This point is also earned for a causal chain of reasoning about forces: e.g., the gravitational force leads to a normal force (and acceleration down the ramp), which leads to a frictional force, which exerts a torque (or changes the angular velocity).

Question 1 (continued)

Distribution of points

(b) 2 points

For an expression for the sum of the force components parallel to the ramp that recognizes that there are two forces with components parallel to the ramp — 1 point

The expression need not be correct or consistent with the force diagram in part (a).

$$\sum F_{\parallel} = Mg\sin\theta - F_f$$

For indicating that the frictional force is $(0.4)Mg\sin\theta$ (explicitly or implicitly) and correctly solving for the acceleration in terms of correct variables — 1 point

$$\sum F_{\parallel} = Mg\sin\theta - (0.4)Mg\sin\theta$$

$$a = \frac{\sum F_{\parallel}}{M} = \frac{Mg\sin\theta - 0.4Mg\sin\theta}{M} = \frac{0.6Mg\sin\theta}{M}$$

$$a = 0.6g\sin\theta$$

(c)

i. 1 point

Correct answer: Block

No credit for answer without explanation.

For a correct explanation in terms of forces — 1 point

Example: The wheel experiences a counteracting frictional force, so the block has a greater net force exerted upon it and therefore has greater acceleration.

ii. 1 point

For a correct explanation in terms of energy conservation — 1 point

Example: Both object-Earth systems lose the same amount of potential energy and therefore gain the same amount of kinetic energy. With the ice block — but not the wheel — all the kinetic energy is translational, and none is rotational, so the block is faster.

P1 Q1 A1

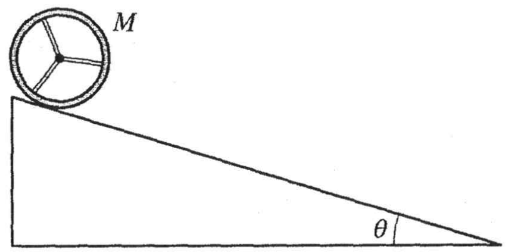
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

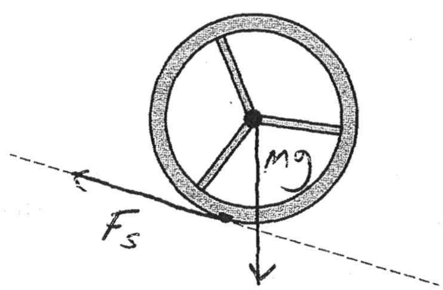


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

The force of static friction.

Briefly explain your reasoning.

The static friction force is being applied at a point at a radius with respect to the center of mass, causing a torque and subsequent change in angular velocity.

GO ON TO THE NEXT PAGE.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

$$\Sigma F = \frac{ma}{m} = \frac{Mg\sin\theta - 0.4Mg\sin\theta}{M}$$

$$a = 0.6g\sin\theta$$

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel __X__ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

The block only has a single force acting upon it: gravity. The wheel has two: gravity and friction, which is opposing the downward motion. Since friction is slowing the wheel down, the block of ice will reach the bottom of the ramp with the greatest speed.

ii. Briefly explain your answer again, now reasoning in terms of energy.

All of the block's gravitational potential energy is being converted directly into linear kinetic energy. The wheel's GPE is being converted into both linear kinetic energy and rotational kinetic energy. Since both objects have the same starting GPE, the block will reach the bottom with the greatest velocity because all of it's GPE is being converted to [scribbled out] linear KE.

GO ON TO THE NEXT PAGE.

P1 Q1 B1

PHYSICS 1
Section II
5 Questions
Time—90 minutes

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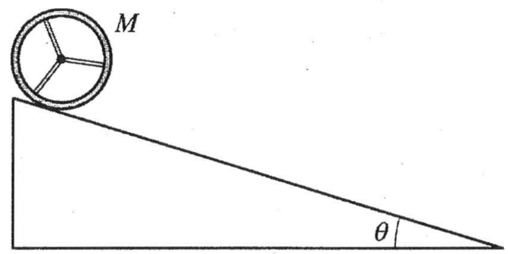

1. (7 points, suggested time 13 minutes)

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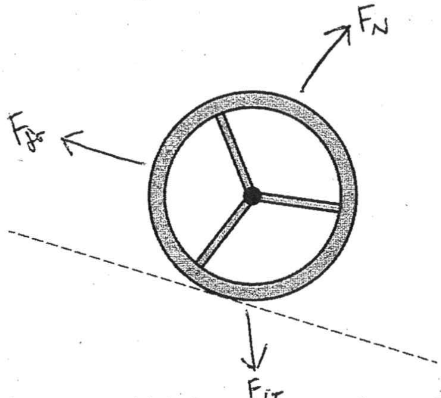
(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

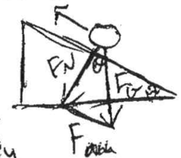
The force of static friction

Briefly explain your reasoning.

Because the static friction is there so that the wheel "rolls without slipping", it causes torque to occur and therefore in order for the wheel to roll down the ramp, it must have angular velocity so it spins down.

GO ON TO THE NEXT PAGE.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.



F_G = Force of gravity

$F > F_{fr}$ for it to accelerate

$F_G \sin\theta > F_{fr}$

$0.4(F_G \sin\theta) = F_{fr}$

$F = ma$

$a = \frac{F}{m}$

$a = \frac{F_G \sin\theta - F_{fr}}{M}$

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ✓ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

The block reaches first because it does not need rotational kinetic energy, it only uses translational. Because the wheel needs both rotational and translational, the overall force is greater but will take longer to accelerate down to the bottom.

Switch answers

ii. Briefly explain your answer again, now reasoning in terms of energy.

The block reaches the bottom faster because there is no Force of friction going against its motion. Because friction is negligable, there is nothing holding it back from accelerating down the ramp. However, both downward forces are equal, so it comes down to how friction effects it.

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PHYSICS 1

Section II

5 Questions

Time—90 minutes

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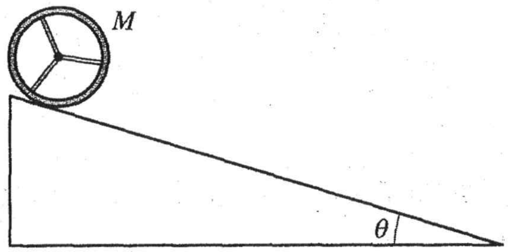

1. (7 points, suggested time 13 minutes)

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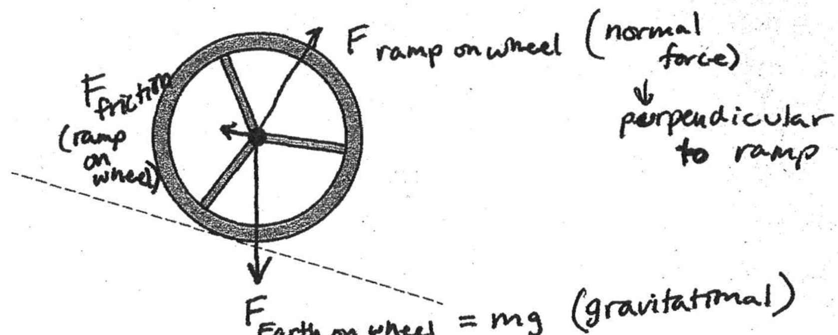
(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning. The gravitational force of the Earth onthe wheel causes a change in the wheel's angular velocity because it is what pullsthe wheel down the ramp, causing the wheel to accelerate.

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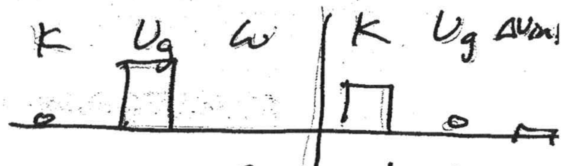
(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

$\Sigma F = Ma$

$F d \cos\theta = \frac{1}{2} m v^2 + \mu N g$

$M \cdot a$

$a = \dfrac{\frac{1}{2} M v^2 + \mu N_g}{M d \cos\theta}$



$mgh + F d \cos\theta = \frac{1}{2} m v^2 + \mu N g$

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ✓ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

The block will reach the bottom faster because all the same forces as the wheel act on the block except for the friction force. While small, this force will slow the wheel down slightly enough so that the ice would make it to the bottom faster.

ii. Briefly explain your answer again, now reasoning in terms of energy.

Because there is negligable friction force, the ice does not lose any measurable kinetic energy, whereas some of the wheel's kinetic energy is converted into ΔUint (heat) due to the friction force (thus slowing it down slightly). ↓ the wheel

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Question 1

Overview

This question assessed learning objectives 3.B.1.1, 3.B.1.3, 4.A.3.1, 4.D.1.1, 5.B.4.1, and 5.B.4.2. It explored student understanding of factors influencing the motion of rigid bodies on an inclined plane, including rolling without slipping motion. Analysis focused on force diagrams, energy conservation, translation and rotation, and applications of Newton's second law.

Sample: P1 Q1 A
Score: 6

One point was earned in part (a)(i) for the gravitational force. The friction force is correctly indicated at the point of contact between the wheel and the ramp, but the normal force is missing, so the second point in (a)(i) was not earned. In part (a)(ii) the friction force is correctly identified, with a correct explanation, as the only force exerting a torque with respect to the center of the wheel. Part (b) shows a correct derivation of the wheel's acceleration. Part (c) shows correct explanations, in terms of both force and energy, for why the ice block has a greater speed than the wheel at the bottom of the ramp.

Sample: P1 Q1 B
Score: 4

No points were earned in part (a)(i) because the forces are not drawn at the points of application. The point was earned in (a)(ii) for explaining why the friction force is the force that exerts a torque about the wheel's center. In part (b) two forces or force components parallel to the ramp are correctly identified, which earned 1 point, but the acceleration is expressed using quantities other than those given in the question. Both points were earned in part (c).

Sample: P1 Q1 C
Score: 2

One point was earned in part (a)(i) for drawing the gravitational force at the center of the wheel. The friction and normal force are not drawn at the point of contact between the wheel and the ramp. In (a)(ii) the gravitational force is incorrectly identified as causing a change in angular velocity about the wheel's center of mass. The gravitational force exerts a torque about the point of contact, but not about the wheel's center. No points were earned in part (b) because the response does not refer to the two components parallel to the ramp. One point was earned in part (c)(i), but in (c)(ii) the speed difference is incorrectly attributed to a loss of energy due to the transformation of mechanical energy into heat by the friction force.