Past-paper walk-through

Rolling ▪ 6.5

eXercise

Questions in this set

- 2021 Q4
- 2016 Q1

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

2021 ▪ Q4

[Figure: A cylinder of mass m_0 sits at the top of an incline of length L_0 and height H_0, which descends to a horizontal surface. The horizontal distance from the base of the incline is also marked L_0.]

(7 points, suggested time 13 minutes)

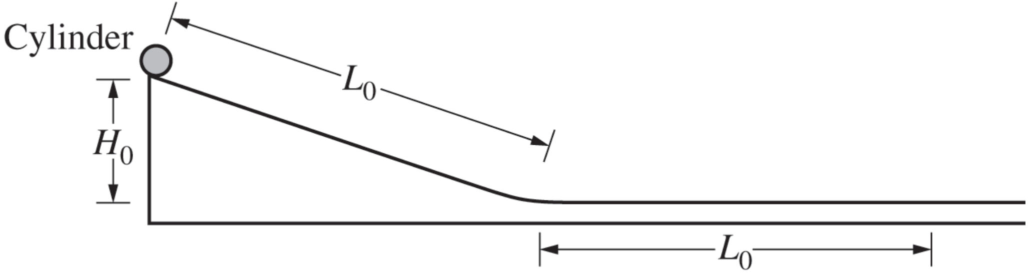
A cylinder of mass m_0 is placed at the top of an incline of length L_0 and height H_0, as shown above, and released from rest. The cylinder rolls without slipping down the incline and then continues rolling along a horizontal surface.

(a) On the grid below, sketch a graph that represents the total kinetic energy of the cylinder as a function of the distance traveled by the cylinder as it rolls down the incline and continues to roll across the horizontal surface.

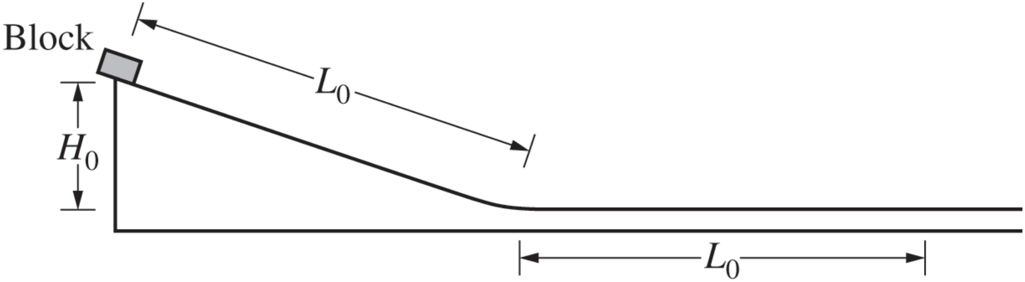
Question 4

[Graph grid: vertical axis labeled "Total Kinetic Energy" (dashed gridlines, unlabeled numeric scale); horizontal axis labeled "Distance Traveled" with marked points at O, L_0, and $2L_0$; empty dashed grid for the student to sketch on.]

Question 4



Question 4



Question 4

2021 ▪ Q4

[Figure: A cylinder of mass m_0 sits at the top of an incline of length L_0 and height H_0, which descends to a horizontal surface. The horizontal distance from the base of the incline is also marked L_0.]

(7 points, suggested time 13 minutes)

A cylinder of mass m_0 is placed at the top of an incline of length L_0 and height H_0, as shown above, and released from rest. The cylinder rolls without slipping down the incline and then continues rolling along a horizontal surface.

(b) [Figure: A block of mass m_0 sits at the top of a separate incline of length L_0 and height H_0, which descends to a horizontal surface. The horizontal distance from the base of the incline is also marked L_0.]

The cylinder is again placed at the top of the incline. A block, also of mass m_0, is placed at the top of a separate rough incline of length L_0 and height H_0, as shown

Question 4

above. When the cylinder and block are released at the same instant, the cylinder begins to roll without slipping while the block begins to accelerate uniformly. The cylinder and the block reach the bottoms of their respective inclines with the same translational speed.

In terms of energy, explain why the two objects reach the bottom of their respective inclines with the same translational speed. Provide your answer in a clear, coherent paragraph-length response that may also contain figures and/or equations.

Solution 4

(a)

Mark scheme

- Sketch: total kinetic energy rises along a straight line of positive slope from the origin as the cylinder accelerates down the incline, reaching its maximum value at distance L_0 (the bottom of the incline); then it stays constant (a nonzero horizontal line) from L_0 to $2L_0$, since the cylinder rolls without slipping (no energy loss) across the horizontal surface. Points: (1) a straight positive-slope line from the origin reaching a maximum at L_0, (2) a nonzero horizontal line between L_0 and $2L_0$.

Solution 4

(b) Mark scheme

- Both the cylinder and the block start with the same gravitational potential energy in their respective object-Earth systems (same mass m_0, same height H_0). As the block slides down its rough ramp, the block-Earth system's mechanical energy converts to kinetic energy, with some dissipated as heat by friction. As the cylinder rolls without slipping down its incline, the cylinder-Earth system's mechanical energy converts entirely into kinetic energy, split between translational and rotational kinetic energy (no dissipation, since rolling without slipping does no work against friction). Because both start with equal PE and the cylinder loses none of it to dissipation while the block does, the cylinder's final rotational kinetic energy equals the amount of the block-Earth system's initial mechanical energy

Solution 4

that was dissipated by friction. Points: (1) both objects start with the same gravitational PE, (2) a correct statement of the cylinder's energy transformations, (3) a correct statement of the block's energy transformations, (4) indicating the cylinder's final rotational KE equals the block-Earth system's energy dissipated by friction, (5) a logical, internally consistent paragraph-length argument.

Question 1

2016 ▪ Q1

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.
[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]
(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.

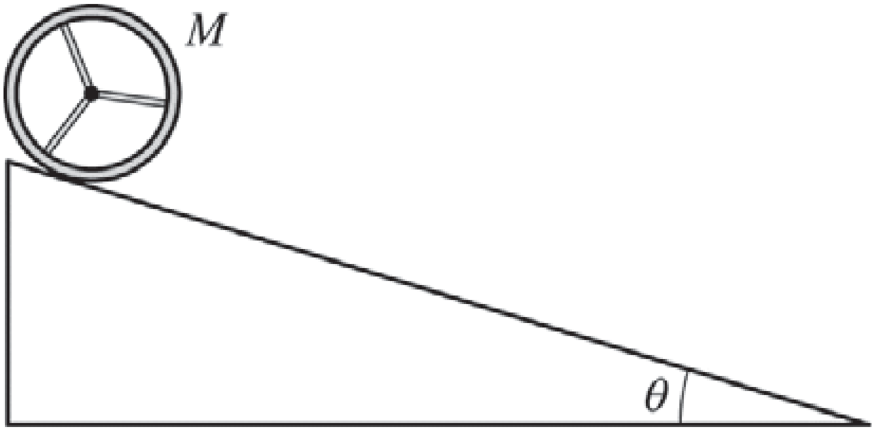
Question 1

[Diagram: a wheel with spokes resting on a dashed line representing the ramp surface, for the student to draw force vectors on.]

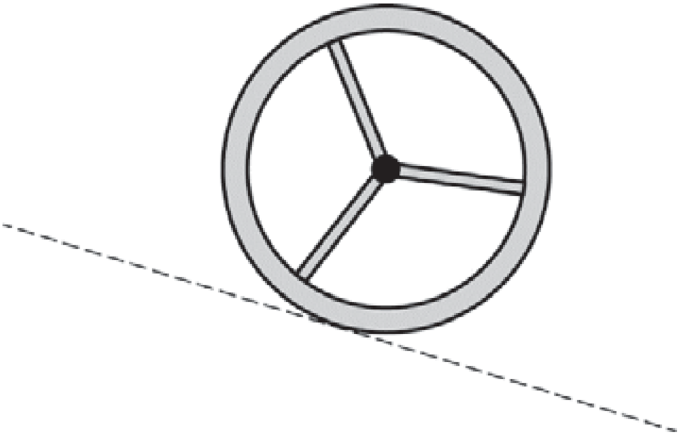
(a)(ii) As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

Question 1



Question 1



Question 1

2016 ▪ Q1

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[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]

(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.

Question 1

2016 ▪ Q1

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[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]

(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.

(c)(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.

Question 1

Briefly explain your answer, reasoning in terms of forces.

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

Solution 1

(a)(i) Mark scheme

- Force diagram on the wheel: (1) a labeled arrow for the gravitational force mg, starting at the wheel's center and pointing straight down [1 pt]. (2) labeled arrows for the friction force F_f and normal force F_n (or a single arrow for their resultant), with no extraneous forces [1 pt] — F_f starts at the wheel-ramp contact point and points up the ramp (along the ramp surface); F_n starts at the wheel-ramp contact point and is perpendicular to the ramp, directed toward the wheel's center (does not need to pass exactly through the center, just reasonably close). Scoring: 1 pt for the correct mg arrow from the center downward; 1 pt for correct F_f/F_n (or resultant) arrows at the contact point with correct directions and no extra forces.

Solution 1

(a)(ii)

Mark scheme

- Correct answer: the friction force. No credit if the wrong force is named. Explanation: friction is the only one of the three forces (mg, F_n, F_f) that exerts a torque about the wheel's center of mass — both mg and F_n act through/toward the center, so they produce no torque about it — so friction is what changes the wheel's angular velocity. Full credit is also given for a causal-chain answer: gravity leads to a normal force (and acceleration down the ramp), which leads to a frictional force, which exerts a torque that changes the angular velocity.

Solution 1

(b) Mark scheme

- Along the ramp: $\sum F_{||} = Mg\sin\theta - F_f$ [1 pt for recognizing there are two force components parallel to the ramp; the expression need not be correct or consistent with the force diagram in part (a)]. The friction force is 40

Solution 1

(c)

Mark scheme

- Context only, no response scored on this leaf: describes a second experiment on the same ramp in which a block of ice, also of mass M, is released from rest at the same instant and same height as the wheel, sliding down with negligible friction. This setup is used by parts (c)(i) and (c)(ii).

Solution 1

(c)(i)

Mark scheme

- Correct answer: Block. No credit for an answer without explanation. Explanation in terms of forces: the wheel experiences a counteracting frictional force (which reduces its linear acceleration along the ramp), so the block — with negligible friction — has a greater net force along the ramp and therefore greater acceleration, reaching the bottom with greater speed.

Solution 1

(c)(ii)

Mark scheme

- Explanation in terms of energy conservation: both the wheel-Earth system and the block-Earth system lose the same amount of gravitational potential energy (same mass, same height drop), so they gain the same total kinetic energy. With the ice block — but not the wheel — all of that kinetic energy is translational, and none is rotational, so the block's translational (linear) speed at the bottom is greater than the wheel's.