

## Fundamental Mechanics: Final Exam (Version 1)

15 May 2023

Name: \_\_\_\_\_

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### Instructions

- There are 17 questions on 10 pages.
- Show your reasoning and calculations and always explain your answers.

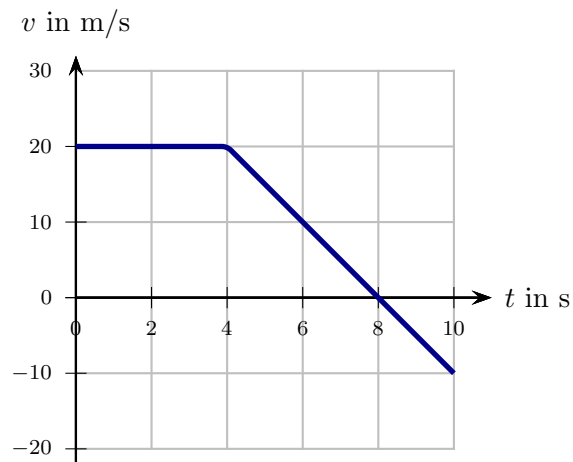
### Physical constants and useful formulae

$$g = 9.80 \text{ m/s}^2 \quad G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 \quad \text{Disk/solid cylinder: } I = \frac{1}{2} MR^2$$

$$\text{Hoop/hollow cylinder: } I = MR^2 \quad \text{Hollow sphere: } I = \frac{2}{3} MR^2 \quad \text{Solid sphere: } I = \frac{2}{5} MR^2$$

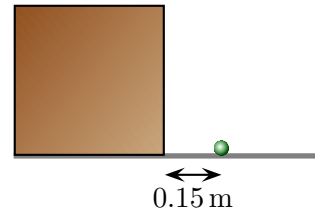
### Question 1

The velocity vs time graph for an asteroid is as illustrated. At  $t = 0$  s the asteroid is at  $x = 0$  m. Determine the asteroid's position at  $t = 10$  s.



**Question 2**

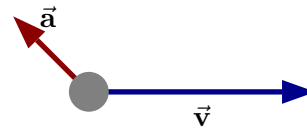
A cat bats a ball, which then rolls along the horizontal surface of a box, 0.85 m above the ground. The ball launches off the top lands at the illustrated spot, 0.15 m from the bottom edge of the box. Determine the speed with which the ball left the top of the box. Ignore air resistance.



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**Question 3**

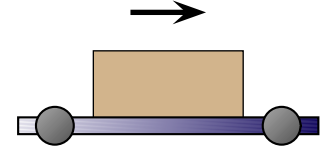
An object has the illustrated acceleration and velocity vectors at one instant. Describe whether the object is speeding up, slowing down or moving at constant speed. Describe whether the object moves in a straight line or curves up or down. Explain your answers using vectors.



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#### Question 4

A box lies on a rough horizontal surface of a cart. The cart and box both move at the same constant speed in a straight line to the right. During the period while everything moves at constant speed to the right, which of the following (choose one) is true?



- i) The cart exerts no friction force on the box.
- ii) The cart exerts a friction force on the box. This force points right.
- iii) The cart exerts a friction force on the box. This force points left.
- iv) Whether there is a friction force or not depends on the speed of the cart.

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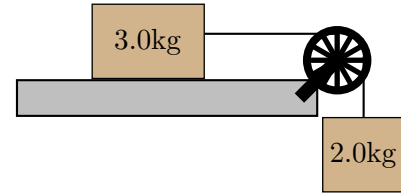
#### Question 5

A 150 kg crate is pulled by a horizontal rope. It moves in a straight line along a rough horizontal floor at a constant speed of 5.0 m/s. The coefficient of kinetic friction between these surfaces is 0.40 and the coefficient of static friction is 0.60. Determine the tension in the rope.

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**Question 6**

Two blocks are connected by a string, which runs over a massless pulley. One block is suspended and the other block can move along a frictionless horizontal surface. The string connected to the block on the surface runs horizontally. Ignore air resistance and friction in this problem.

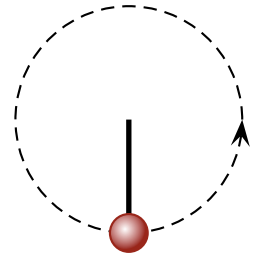


a) Determine the acceleration of the blocks.

b) Determine the tension in the string.

**Question 7**

A ball with mass  $m$  swings at the end of a string in a vertical circle. Which of the following (choose one) is true regarding the tension,  $T$ , in the string when the ball is at the *lowest point* in the circle?



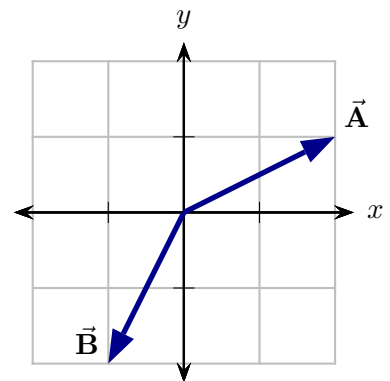
- i)  $T = mg$  regardless of speed.
- ii)  $T > mg$  regardless of speed.
- iii)  $T < mg$  regardless of speed.
- iv)  $T > mg$  when the speed is large enough and  $T < mg$  when the speed is small enough.

**Briefly explain your choice.**

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**Question 8**

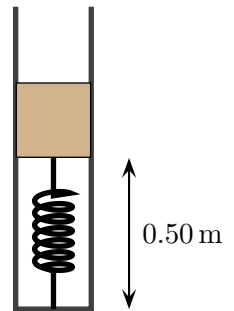
Determine the dot product,  $\vec{A} \cdot \vec{B}$ , of the two illustrated vectors. The axis units are in meters.



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### Question 9

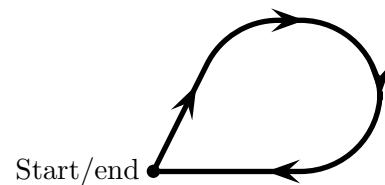
A 2.0 kg block is held at rest against a spring compressing it by 0.40 m. At this point, the base of the block is 0.50 m above the ground. The spring constant of this spring is 800 N/m. These are contained in a cylinder with frictionless walls. The block is released and launches vertically, leaving the spring. Determine the maximum height above the ground that it reaches.



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### Question 10

A heavy wooden block follows the illustrated path (viewed from above) on a rough wooden horizontal table. The end point of the path is the same as the start point. Which of the following (choose one) is true regarding,  $W_f$ , the work done by friction?



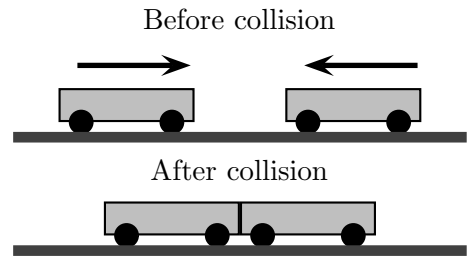
- i)  $W_f < 0$ .
- ii)  $W_f > 0$ .
- iii)  $W_f = 0$ .
- iv) One would need more information about the path to decide between the previous options.

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### Question 11

Two identical carts travel on a frictionless surface toward each other with identical speeds and collide and stick together as illustrated. Which of the following (choose one) is true after the collision?

- i) The carts are at rest and total kinetic energy is the same as before the collision.
- ii) The carts are at rest and total kinetic energy is **not** the same as before the collision.
- iii) The carts are **not** at rest and the total kinetic energy is the same as before the collision.
- iv) The carts are **not** at rest and the total kinetic energy is **not** the same as before the collision.



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### Question 12

A solid disk and a hoop with the same mass and radius each approach the same ramp with the same velocity as illustrated. They both roll without slipping. Let  $h_{\max \text{ disk}}$  be the maximum height reached by the disk and  $h_{\max \text{ hoop}}$  the maximum height reached by the hoop. Which of the following is true?

- i)  $h_{\max \text{ disk}} = h_{\max \text{ hoop}}$
- ii)  $h_{\max \text{ disk}} > h_{\max \text{ hoop}}$
- iii)  $h_{\max \text{ disk}} < h_{\max \text{ hoop}}$



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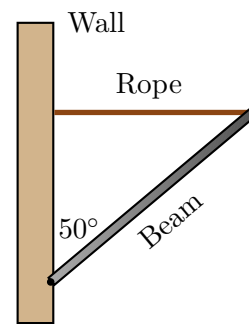
### Question 13

A disk can pivot about the origin. A force  $\vec{F} = 20\text{N}\hat{j}$  is applied to the disk at the point  $\vec{r} = 2\text{m}\hat{i} + 2\text{m}\hat{j}$ . Determine the torque exerted by the force.

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**Question 14**

A 3.0 m long, 250 kg uniform steel beam is anchored to a wall. A horizontal rope is attached to the end of the beam and holds it at rest at the illustrated angle. The thickness of the beam is negligible. Determine the tension in the rope.



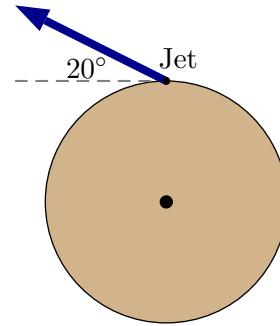
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**Question 15**

A 4.0 kg solid disk with radius 0.25 m can rotate horizontally about a frictionless axle through its center. A small jet is mounted at the edge of the disk and exerts a constant 20 N force at the indicated angle.

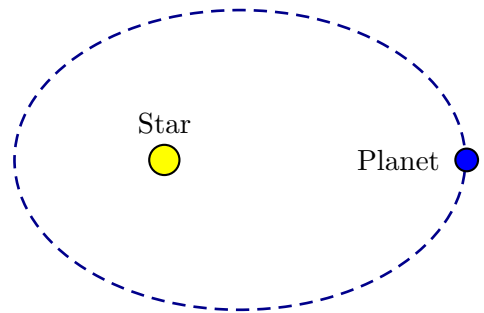
a) Determine the angular acceleration of the wheel.



b) If the wheel is initially at rest determine its angular velocity after the first complete revolution.

### Question 16

A planet moves around a star in an elliptical orbit as illustrated. There are no other planets or stars nearby which have any noticeable effects on the planet depicted here. Which of the following (choose one) is true regarding the planet's speed?



- i) The speed of the planet remains constant throughout its orbit.
- ii) The speed of the planet increases as it gets nearer to the star.
- iii) The speed of the planet decreases as it gets nearer to the star.

**Briefly explain your answer.**

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### Question 17

An object with mass  $m$  is released from rest at a distance  $r$  from the center of Earth (mass  $M_E = 5.98 \times 10^{24}$  kg and radius  $6.37 \times 10^3$  m). Determine an expression for the acceleration of the object the moment after it is released. **Note: to receive full credit for this problem, your solution must with Newton's second law and use this to derive the answer.**

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