PHYS 121: Homework #03 and Reading Assignment

06 February 2024

This Written Homework is due Monday, September 12 at 11 PM and must be submitted online as a PDF file via Canvas.

Announcements:

- First Hour Exam, worth 5% of your grade on ***Friday, February 16.*** Details to be posted later this week.

Physics 121: Spring 2024: Reading assignment:

REQUIRED: Read P121 Solutions to Homework and Review Sheet:

- Solutions to Homework #01, if you have not already read this.
- Solutions to Homework #02.
- Read Course Document #04: Cycle 1 Review Sheet, Part 1, if you have not already read these.
- Read Course Document #07: Cycle 1 Review Sheet, Part 2, if you have not already read these.
- Read Course Document #09: Cycle 1 Review Sheet, Part 3.

REQUIRED: *Physics 121 Online Class Notes* Cycle 1, Chapters 10 and 11, posted on the Canvas, as follows:

- **Read Chapter 10:** An introduction to linear momentum. We define momentum in the context of re-formulating Newton's Second Law.
- **Read Chapter 11:** We use the idea of the Center of Mass so that we can talk about the application of Newton's Second Law to a system of bodies collectively instead of just one body at a time. $\vec{F}_{net}(external) = M_{sys}\vec{a}_{CM}$. Only external forces count for evaluating the net force on a system. Note that for Cycle 1 we will not be asking student to calculate the center-of-mass of rigid bodies.
- **Read Chapter 13:** We introduce one of the most feared concepts in introductory mechanics, torque. Torque is not force. It is the rotational analog of force. Focus on pages 13-1 to 13-3. Also read pages 13-4 to 13-9, about Statics problems.

- **Read Chapter 14:** Skim this chapter. We are not going to be asking anyone to calculate the moment of inertia of anything in Cycle 1 but getting the idea that $IproptoMR^2$ is helpful for what we will do in the future.

- **Read Chapter 15:** Skim this chapter. We are not going to be contending with oscillations in Cycle 1, and as instructor I want to quibble with that negative sign RWB puts into Hooke's Law for springs. But take a quick look to see where we are going with this later in the year.

Physics 121: Fall 2023: Homework #03

The Homework is due via Canvas at:
11 PM Sharp, Monday, February 12, 2024

Important note: The homework will be graded on a scale of 0 to 15 points. **Not all problems will be graded.**

Problem 1: Science-Fiction Marshmallow Battle

A strange science-fiction battle takes on a tiny moon in deep space; here, the moon is so small that we can completely ignore gravity. A deranged invading space monster of given mass 28.2 kg kicks off a rocky structure to achieve a horizontal speed of 3.45 m/s directly toward a startled space cadet. The cadet is braced firmly on the surface of the moon and is armed with a rapid-fire automatic marshmallow blaster gun which fires multiple sticky marshmallows toward the monster, each of mass 11.5 grams and each with a speed of 53.4 m/s. The cadet attempts to stop the monster with the marshmallow gun, slowing the monster down by hitting the monster with marshmallow after marshmallow until the monster is finally brought to a stop. **How many marshmallows will the cadet have to fire at the monster to stop the monster's horizontal motion?** (Assume each fired marshmallow harmlessly ***sticks*** to the monster. Assume that the monster is flying horizontally, with no vertical motion and no friction or other forces on the monster except for those due to the collision with the marshmallows. Explain your work. Indicate what Physics Concept (law of physics) you used to solve this problem.

Also: is kinetic energy conserved here? Explain how you know this.

Hints: If the velocity of the monster is defined as positive, the velocities of the marshmallows must be negative. We are essentially asking for the number N corresponding to the the minimum number of marshmallows fired by the cadet to bring the monster from positive velocity to zero (or lower). Define a system that includes the monster and the N marshmallows, determine the linear momentum of the system before and after the N collisions, apply the appropriate Conservation Law, and then solve for N.

Problem 2. A medicine ball with given mass $M = 8.11$ kg drops vertically, eventually hitting the floor. Just before impact, the ball has a given downward *speed* of 5.11 m/s. It then rebounds straight back with a given upward speed of 4.42 m/s.

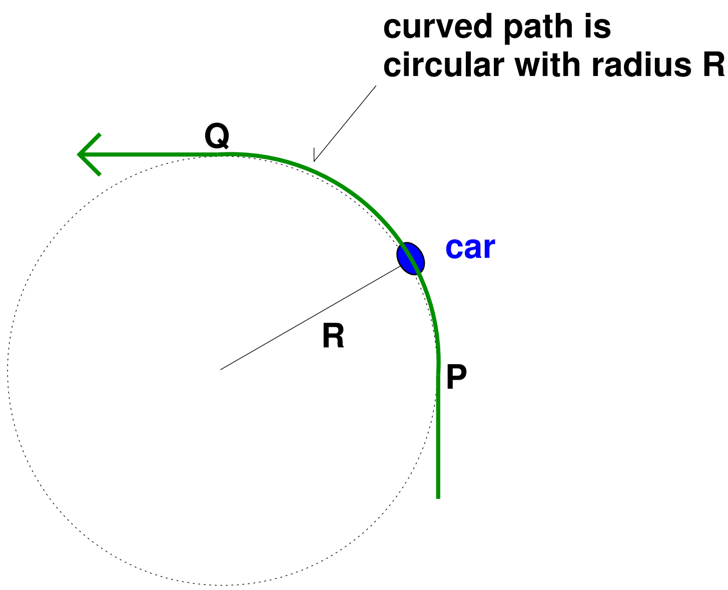
Part (a) – What is conserved with respect to the system that is defined as *the medicine ball* during the entire collision? Is Mechanical Energy Conserved? Is Linear Momentum Conserved? Explain how you know this?

Part (b) – What is the ***total impulse*** imparted to the ball as a result of contact with the floor?

Part (c) – If the ball is in contact for a time interval $\Delta t = 0.056$ seconds, what is the *average force* exerted on the floor during this collision?

Problem 3: Conceptual Question – Straight from 2011 First Hour Exam:

Important: This is a series of *conceptual* questions. Each part requires essentially no calculations. If you find yourself working algebra here you are going down the wrong path.



You are driving a car that is moves with constant given speed V. Your mass is given as m and the mass of the car (not including yourself) is given as M. The road is completely flat and level. The car enters a curve in the road that can be described as a circular arc with given radius R as shown above in a "bird's-eye" view of the path of the car. Assume you are properly secured into your seat as you drive.

Part (a) – What is the magnitude of the **net force** on you, the driver, as you go around the curve? Explain how you know this.

Part (b) – A student says:

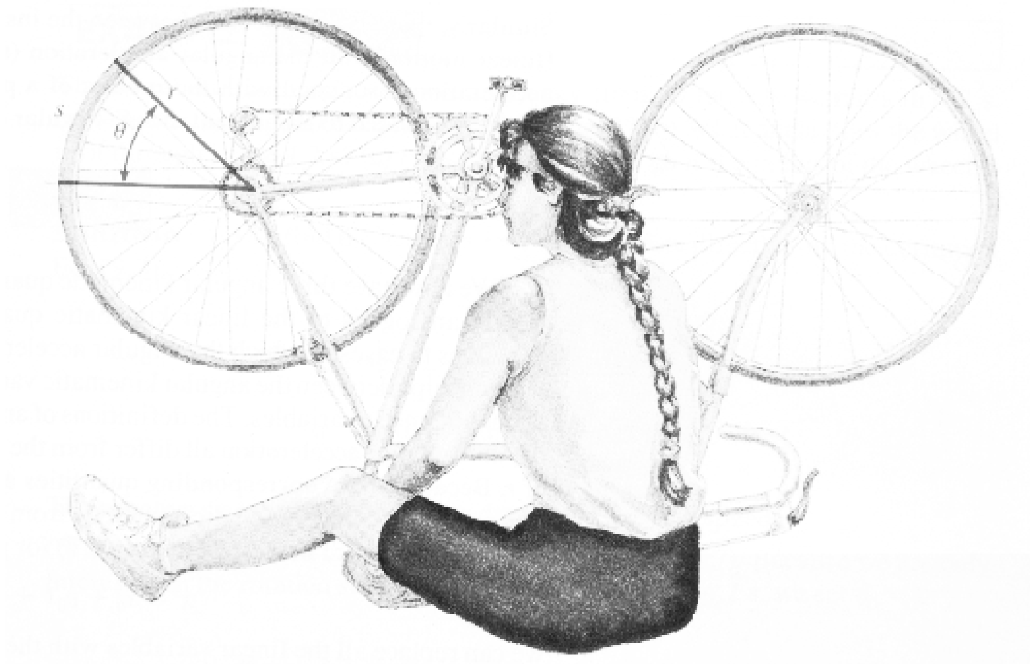
> *"As the car comes around the curve, there must be a net force on the driver to the driver's* right. *In other words, the net force points* away *from the center of the circle."*

Is the student correct or incorrect? Explain how you know this.

Part (c) – What is the magnitude of the force of ***friction*** on the car due to the road as you go around the curve? Hint: it is not zero. Explain how you know this?

Part (d) – What is the **Total Work** done by all forces on the car as it moves on the curve from point P (corresponding to where the car enters the curve) to the point Q (corresponding to where the car leaves the curve)? Explain how you know this? Important: you must use one or more Physics Concept(s) here

Problem 4:



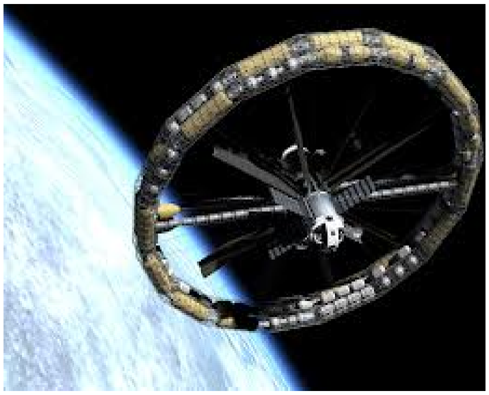
A *constant* given torque τ of 0.073 Newton-meters is applied to a free-spinning bicycle wheel of mass m = 4.3 kg, radius R of 0.27 meters as shown. The rotational inertia of the wheel is **given** by the expression: $I = mR^2$.

a) What is the angular acceleration of the wheel? (Hint: Use the rotational analog of Newton's 2nd Law).

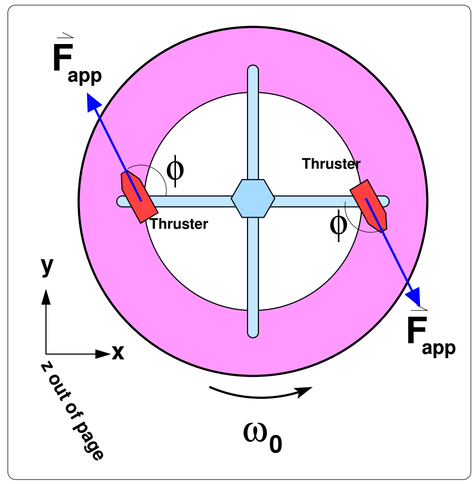
b) Assuming the wheel starts at rest, how much time will it take for the wheel to be spun to a final rotational velocity of ω = 22.2 radians/second? (Hint: This is analogous to translational motion with constant acceleration).

c) A small piece of mud is stuck to the outside edge of of the wheel. What is the *centripetal acceleration* on the piece of mud after time T = 5.0 seconds of torque have been applied? (Hint: find the angular velocity, and then consider the piece of mud as instantaneously moving with Uniform Circular Motion).

Problem 5: Stopping a Spinning Space Station



Spinning space station orbits Earth



Consider a hypothetical future space station that consists of a torus attached by spokes to a central hub as show above. Suppose the space station has an given initial angular speed of ω_0 and a rotational inertia $I = CMR^2$ where M is the given mass of the space station, R is the given outer radius of the torus, and C is a given numerical constant.

In this situation, the space engineers need to repair the station and in order to do this, they need to stop the rotation and bring the station to rest. Therefore, the engineers affix two large *thrusters* to the space station as shown. Each thruster is attached to a fixed position on the space station corresponding to a given distance r from the center and at a given angle ϕ relative to the radial direction. When activated, each thruster will result in a force of given constant magnitude F_{app} applied to the station as shown. Note that a coordinate system is given here, with x-direction corresponding to the right, y-direction corresponding to the top of the page, and z-direction corresponding to out of the page.

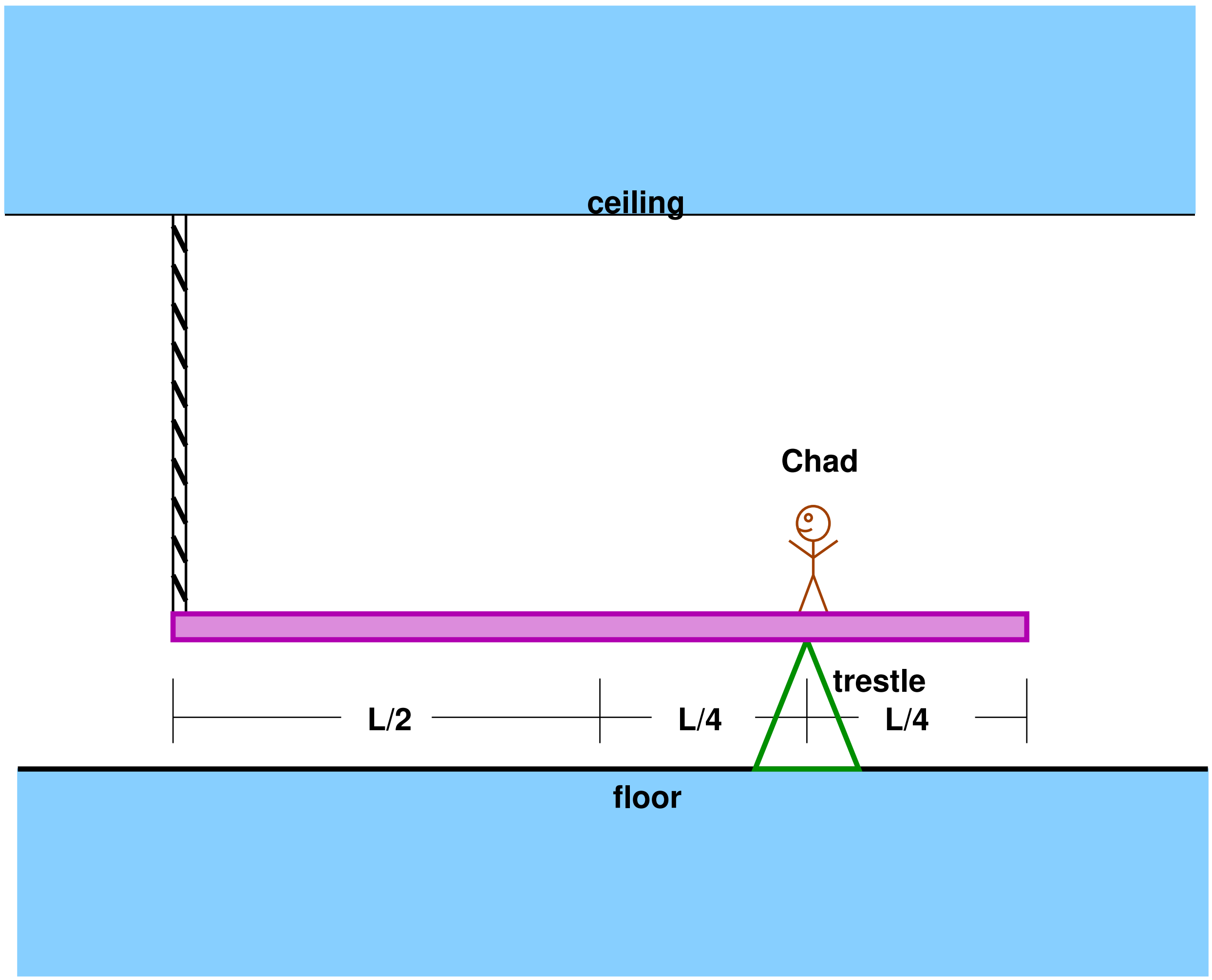
Part a) – What is the magnitude of the total *torque* τ applied to the space station that results from the action of both of the thrusters? Give your answer in terms of given parameters only. Explain your work.

Part b) – What is the magnitude of the *angular acceleration* α of the space station that results from the action of both of the thrusters? Give your answer in terms of given parameters only. Explain your work.

Part c) – What is the *linear acceleration* $\vec{a}$ of the entire space station as a single body that results from the action of both of the thrusters? Indicate both the magnitude and the direction. Give your answer in terms of given parameters only. Explain your work. Hint: The Rolling Constraint does *not* apply here.

Part d) – Assume that at time $t = 0$ both thrusters are activated. How many total rotations of the space station will occur before the space station is brought completely to rest? Give your answer in terms of given parameters only. Explain your work. Hint: one rotation equals 2π radians of angle.

Problem 6: Hanging Chad



Chad stands on a a large heavy uniform board. Chad has a mass m. The board has a mass M and a total length L. The board is suspended by a rope on the left side and a trestle which pushes the board upward at a position that is precisely three-fourths the length of the board from the left side as shown in the figure above. Chad is positioned directly above the trestle.

Draw complete and carefully labeled Free Body Diagrams (FBDs) for both Chad and the board. Also draw a complete and carefully labeled Extended Free Body Diagram (XFBD) for the board.

Determine T, the magnitude of the Tension on the board due to the rope. Also determine N_{BT}, the magnitude of the Normal force on the board due to the trestle. Express your answer in terms of the given parameters. Be sure to explain your work.