Torque and rotational dynamics

Physics 211
Syracuse University, Physics 211 Spring 2020
Walter Freeman

April 22, 2020

Announcements

I'm sorry about the audio from the recording last Thursday. I messed up my OBS settings.

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I've gotten a huge amount of mail from people telling me that things are wrong with their Exam 3 grading. I am still working through those.

1. "I don't have a grade for problem X"
2. "I got a low grade for problem X, can you look at it and tell me why?"
3. "I got a low grade for problem X, can you regrade it for me?"

I'll get to these as quickly as I can but there are a lot of them and one of me. Sorry!

There will be a short Homework 14, due on April 30 (next Thursday).

Clinic hours coming up:

- Friday, 9:30-11:30 (Walter) and 1-3 (Matt)

Help for your papers

I hope you've all figured out your topics for your papers and are starting to think about them. They're due a week from tomorrow. (We'll create a Blackboard submission link.)

Any questions about the papers?

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Answers to a few frequently-asked ones:

- You can write about a broader movement (flat-eartherism, anti-vaxxers, climate deniers, etc.); it doesn't need to be a single statement by a single person
- The claim doesn't have to be made by a professional scientist; it may be made by anyone.
- It *does* need to at least claim to be scientific (broadly defined), though.

Help for your papers

If you're looking for advice on your papers, contact:

- Me (wafreema@syr.edu or on #paper-discussion on Discord)
- Mario Olivares (maolivar@syr.edu)
- Nori Zaccheo (nzaccheo@syr.edu)
- Julian Thornton (jrthornt@syr.edu)

Finishing up the semester

- **Later today (Thursday): HW14 posted.**
- **Tomorrow (Friday)**: Last recitation will be tomorrow. You really should attend (hint, hint).
- **Next Tuesday, April 28**: Last day of class. I will have help hours 3-5 PM in the Clinic.
- **Wednesday, April 29**: No class. I will have help hours 8AM-10AM in the Clinic.
- **Thursday, April 30**: I'll lead a review session from 1-4 PM. HW14 due.
- **Friday, May 1**: I'll lead another review session from 1-4 PM. Papers due at end of day.
- **Saturday, May 2**: I'll lead a review session from 8-11 PM.
- **The following Monday, May 4**: Final exam posted at 3 PM (scheduled start of exam), due Tuesday, May 5, at 3 PM.

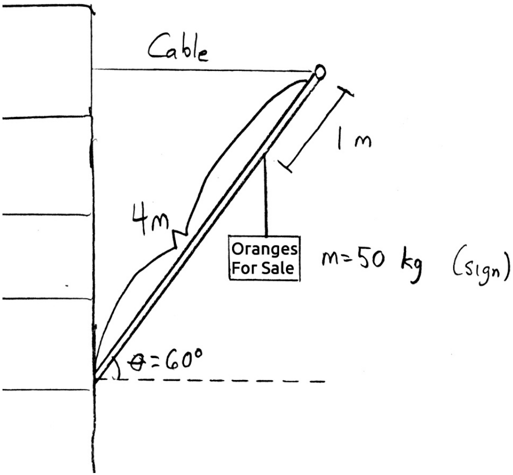
Today's agenda

- Review anything from HW13 and Wednesday's recitation
- Work sample problems
- Tie together torque and conservation of energy in rolling

Any questions about Homework 13?

If there's something you didn't understand at first, ask now! Anyone in class today may have an extension until the end of the day today if you want to revise your submission based on our conversation here.

Calculating torque: another example



A fruit seller hangs a sign outside their shop from a rod connected with a hinge to the wall. If the rod has a mass of $M = 40$ kg, what must the tension in the cable be to support it?

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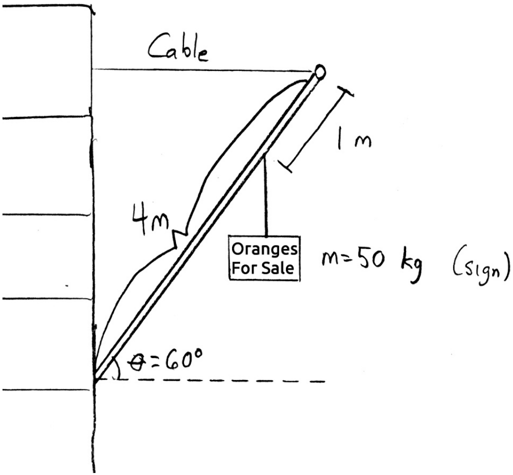

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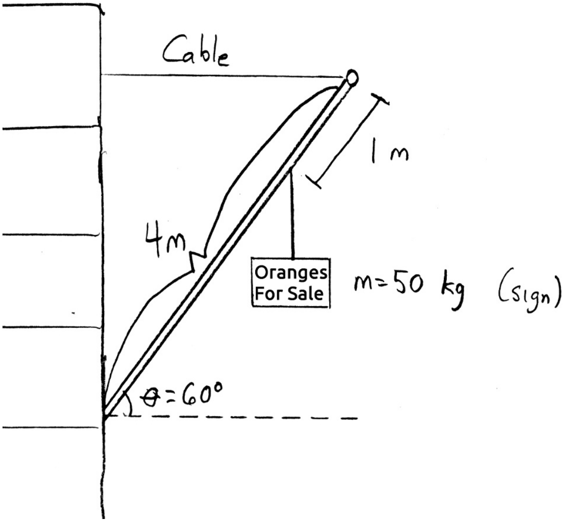
Strategy:

- The rod doesn't rotate, so $\sum \tau = 0$
  - Draw an extended free body diagram
  - Choose a pivot point at the location of a force we don't know and don't care about
  - Calculate the torque applied by each force
  - Solve for T

Calculating torque: another example



(Notation: mass of rod is M, mass of sign is m, length of rod is L)

Extended FBD: Draw all forces *at the location where they act*

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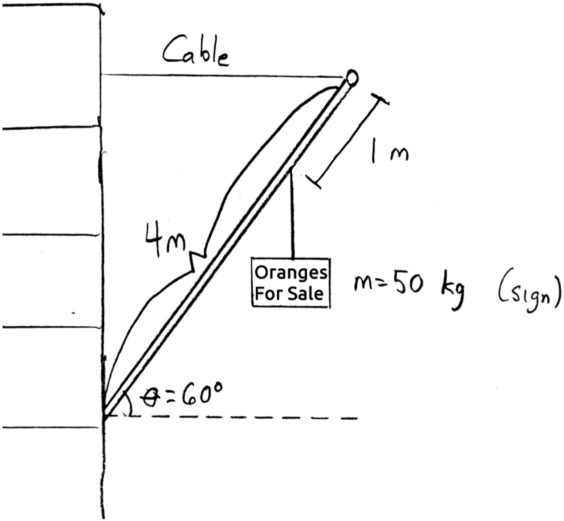

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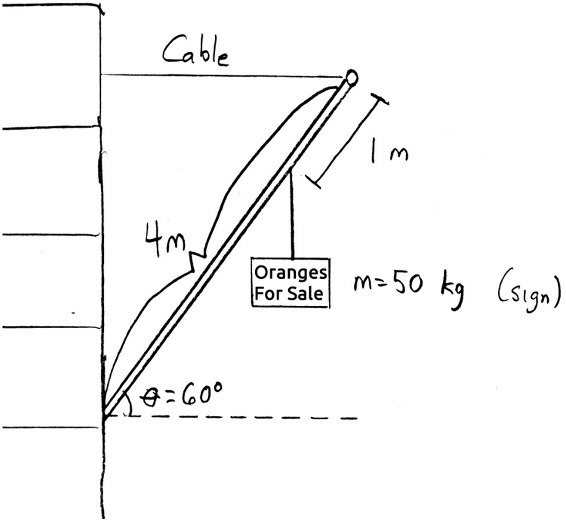

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It can be helpful to use a table to keep track of the torques.

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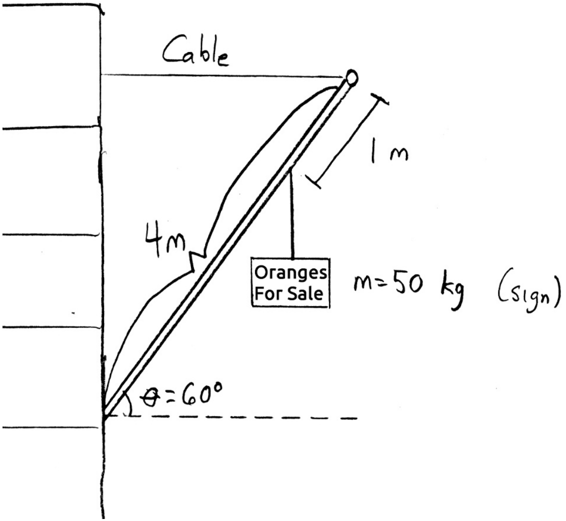

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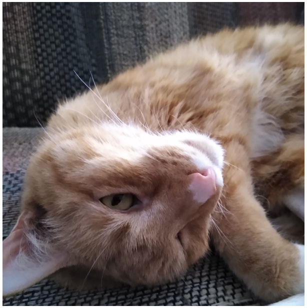
Extended FBD: Draw all forces *at the location where they act*

Where should we choose our pivot?

It can be helpful to use a table to keep track of the torques.

Force	Magnitude	Radius	Sine of angle	Sign (+/-)	Torque

A cat and a ball of yarn



A friend and I adopted this fluffball as a kitten back in 2004; they live in Minnesota now. He's sick, so send him virtual pettins and comfort!

Loki the mischievous cat sees a ball of yarn sitting on a table. He steps on the loose strand of yarn and then nudges the ball off the table. How fast does it accelerate downward? ($I = \frac{2}{5}mr^2$ for a ball.)

Strategy:

- We know the ball obeys both $F = ma$ and $\tau = I\alpha$
- α and a are related since the yarn doesn't stretch, so the rate at which it starts to spin and the rate that it starts to fall must be related
- Draw an extended FBD to figure out forces and torques

The work done by tension

We know the work-energy theorem for translational motion (for constant $\vec{F}$):

$$W_{\text{trans}} \equiv \Delta \frac{1}{2} m v^2 = \vec{F} \cdot \Delta \vec{s}$$

Replacing m, $\vec{F}$, $\vec{s}$, and v^2 with their rotational counterparts, we get:

$$W_{\text{rot}} \equiv \Delta \frac{1}{2} I \omega^2 = \tau \Delta \theta$$

This is the *rotational work-energy theorem.*

Before, we treated “rotational energy” and “translational energy” as the same sort of thing, and added them together.

But we can treat them as separate, too:

$$KE_{\mathrm{trans,i}} + W_{\mathrm{trans}} = KE_{\mathrm{trans,f}}$$
$$KE_{\mathrm{rot,i}} + W_{\mathrm{rot}} = KE_{\mathrm{rot,f}}$$

Conservation of energy in rolling motion

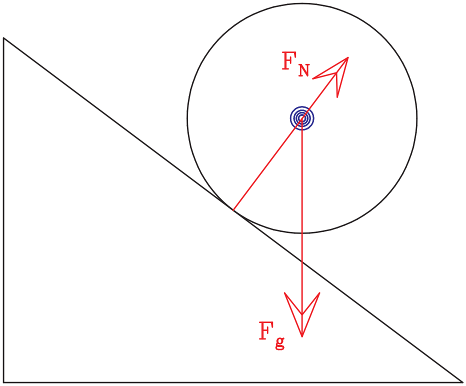
As the yarn-ball falls from a table of height h...

How much *translational work* $W_{\text{trans}} = \vec{F} \cdot \Delta s$ does tension do?

How much *rotational work* $W_{\text{rot}} = \tau \Delta\theta$ does tension do?

An object rolling down a hill

Consider first a ball sliding down a hill without friction.



Which of these forces applies a torque to the ball?

A: Just the normal force

B: Just gravity

C: Both of them

D: Neither of them

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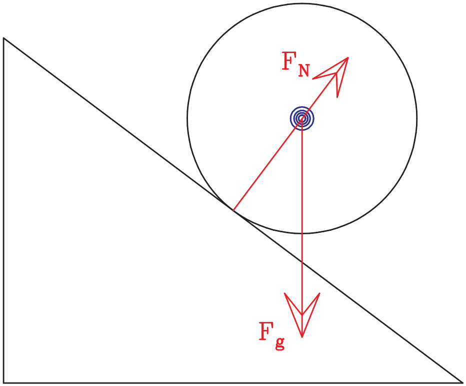

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Friction is required to make the ball spin!

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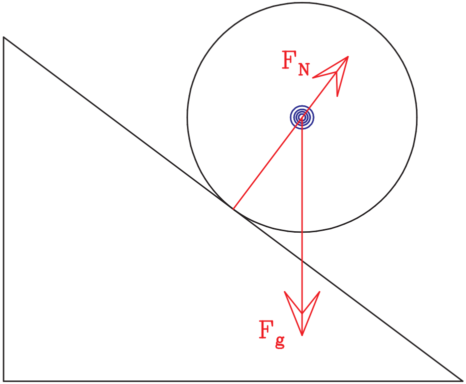
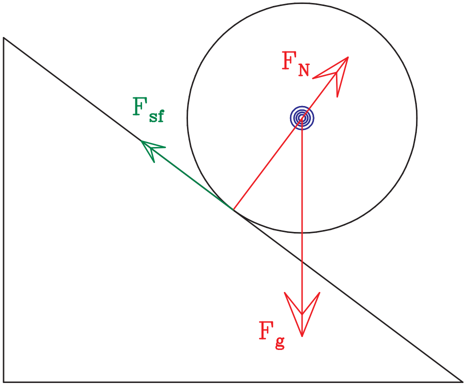
If the ball *rolls without slipping*...



What is true about the frictional force?

A: Static friction points down the ramp
B: Static friction points up the ramp
C: Kinetic friction points down the ramp
D: Kinetic friction points up the ramp
E: There is no friction

If the ball *rolls without slipping...*



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The point of contact would slide downward without friction, so friction points back up the ramp. This is static friction since the ball doesn't slide.

Energy rolling down a hill

Static friction does no total work on the ball:

- it reduces the translational kinetic energy $\frac{1}{2}mv^2$
- it increases the rotational kinetic energy $\frac{1}{2}I\omega^2$
- ... but it leaves the sum $\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$ unchanged

TABLE 6.1 Coefficients of friction

Materials	Static μ_s	Kinetic μ_k	Rolling μ_r
Rubber on concrete	1.00	0.80	0.02
Steel on steel (dry)	0.80	0.60	0.002
Steel on steel (lubricated)	0.10	0.05	
Wood on wood	0.50	0.20	
Wood on snow	0.12	0.06	
Ice on ice	0.10	0.03	

This is not *quite* true – rolling friction does exist. There is a little bit of overall negative work done as tires flex and so on, but it is small.

(From *Physics for Scientists and Engineers*, Knight, 3rd ed.)

Rotational dynamics and power

If $W = \tau \Delta\theta$, then $P = \tau\omega$.

If I want to supply a power P, I can either exert a large torque at a small angular velocity, or a small torque at a large angular velocity.

$\rightarrow$ bicycle/car transmission gears!