[00:00:00.00] David: Alright this is from last night. I got one more from last night that I want to go through. Very briefly. I wanna get to stuff today.
[00:00:10.07] David: Alright, which one wins? Actually I got
several more from last night but this is from what you just handed in. Which one wins? Ten seconds.
[00:00:24.03] David: Five four three... I didn't write this problem, I uh, a group in Washington wrote this problem and I love this problem. Three, two, one, stop.
[00:00:37.20] David: And uh B, eighty nine percent say the block wins. Alright, why does the block win in this case? Let's here an argument for the block winning. A.J.?
[00:00:51.06] A.J.: Um, well the string is wound around, so when you pull it some of the work is going to go into rotational kinetic energy.
[00:01:00.06] David: When you pull it some of the work is going into the rotational kinetic energy. Alright. So and when you pull on the block, all of the work you do goes into the block's kinetic energy. This is an argument for why the block wins. Other arguments. Maayan
[00:01:13.15] Maayan: It's the same as the spinning, as the ball rolling down the ramp as opposed to the block sliding down the ramp.
[00:01:18.18] David: It's the same as the ball rolling down the ramp. In which case...
[00:01:22.08] Maayan: It's loosing to rotational
David: In which case you lost rotational energy to the rotational motion. And you had the block. Michael.
[00:01:27.17] Michael: No it isn't.
David: Uh oh.
(murmuring)
[00:01:31.29] Michael: It is not the same as the ball rolling down the ramp. The ball rolling down the ramp involves friction, static friction. One of the premises of this problem was there is no friction.
[00:01:42.29] Michael: Which which gave us quite a lot of problems when we were discussing it in our recitation. So whatever you believe happens, it's fundamentally isn't the same.
[00:01:52.03] Michael: Where I ended up is that I looked at the forces on the center of mass and found that there was only one and it was F. And from that it would have to be that the acceleration was F and it would reach the end at the same. But I wasn't really happy with it.
[00:02:09.26] David: So you say, you say it's the same because they have the same total force acting on them. But you're not really happy with that.
[00:02:18.14] Michael: I'm not happy with it.
David: Alright, Um, maybe I'll, in a minute, I might ask you to express your unhappiness, but there are other folks. Oona.
[00:02:26.01] Oona: When you're done pulling on it, you're gonna have more rope on your side than after the first case.
[00:02:32.03] David: Yep
Oona: Because it has to unwrap.
[00:02:35.28] David: When you're done pulling it, you're gonna have more rope in your hand.
Oona: Yeah, which means it'll take longer. Because pulling each section of rope--
[00:02:43.22] David: It'll take longer to pull so--
Oona: takes the same amount of time. But there will need to be more rope.
[00:02:48.21] David: So it would take longer to pull so it--it would it would take more. Alright, alright, so that's an argument for why it would take the block less time because you have less rope in your hand. Sam.

[00:02:59.03] Sam: Um, we haven't done angular momentum but I kinda assumed that it was somewhat similar to angular velocity and rotational kinetic energy in that like they're both gonna have the same force
[00:03:11.26] David: Yeah
Sam: over the same time so they should have the same momentum. But for the cylinder, like half of that will be going to angular momentum. And half of it is translational. Whereas for the block it's all translational.
[00:03:21.05] David: Ah, alright, we have not done and that's what I want to get to today is angular momentum. Angular momentum and momentum are different quantities. You cannot add them together any more than you can add my salary to my height.
[00:03:31.18] David: They are, they are different quantities, it would be nice though, uh. It, it, they are different quantities, so we can't say that some of the angular momentum goes into linear momentum that's not possible.
[00:03:44.12] David: But we could say, we could say rotational energy goes into translational energy which is, the uh the main, is the argument that a bunch have had that argument.
[00:03:52.20] David: That the energy, that's the same quantity. Rotational energy is energy is linear energy. It's just a different way of summing it all up. So, so, so we haven't started angular momentum yet. But uh, coming up. Um, alright. Josh.
[00:04:08.03] Josh: Um, for the, um, I mean it's almost the same argument. Um, the thing with the cylinder is that it's easier to pull. So that um, with the same force, the cylinder wants to rotate faster. Well, uh, it'll be easier to rotate the cylinder um but like, so um, you do more work with less force.
[00:04:31.15] David: You can do more work—
Josh:—It would be like—
[00:04:33.26] Josh: You can do like more force will um require more work. I don't know if that makes sense.
[00:04:42.05] David: So, so which one, which one do you say wins?
Josh: I say it's a tie
David: You say it's a tie also.
[00:04:47.10] Josh: Yes
David: Um, and you're saying in response to this counter argument, like you have more rope in, you're saying—
Josh: it's easier to rotate.
[00:04:55.00] David: It's easier to rotate. You get the cylinder so rope comes off it more quickly, more easily. You know what I want. It's--a lot of people have things to say. This is stirring up some controversy. Here's what I would like you to do.
[00:05:07.16] David: Actually, I'd like you to do this with people sitting around you. Is this one apparently is pretty controversial. It sounds to me like there are two really great--there are multiple really compelling arguments on different sides.
[00:05:18.28] David: This is what by the way what I love about doing physics. Is hitting a moment of confusion like this and thinking "Oh cool, something to figure out." So, here's the thing to figure out.
[00:05:28.05] David: The compelling argument on one side is I think what, what, um several of you have said, which is it's like rolling down the ramp, it is when you pull on it, you do work on it, and the case of the cylinder, some of that work, some of that energy goes into rotating it and not into it's--the motion of the center of mass.
[00:05:49.06] David: And, but in the cause of the block, all of the work you do on the block goes into accelerating it.

[00:05:53.26] David: Um, another version of that argument is that you have more rope in your hand at the end when you're pulling on the cylinder than when you're pulling on the bock, so it must take longer to get the block--to get the cylinder to move than to get the block to move. That's an argument that the block wins.
[00:06:09.00] David: There's a pretty convincing argument on the other side, too, which is that they have the same force acting on them. F equals M A. So if they have the same mass, they have the same total force on them, they should have the same acceleration.
[00:06:22.07] David: So one of these is wrong. the one that's wrong has some flaw in it that you could reconcile. It has some flaw that you could say "Here's why that reasoning doesn't work."
[00:06:33.28] David: So pick the side you want to believe and find the flaw in the reasoning on the other side. So take some time, I'll give you two minutes to talk to each other, I'll start the clicker and you can click if you have a new thought about it.
(murmuring)
[00:06:50.18] David: Five, four, three, [Voice: I don't know] two, one, and stop. Survey says, we're still majority, so majority says the block, now there's, there's been some movement towards saying that it's a tie.
[00:07:10.07] David: So what I want to hear--I don't want to hear why your answer's right, I want to hear why the other answer is wrong. What's the flaw in the reasoning on the answer that you don't believe. Jacob.
[00:07:20.21] Jacob: Okay, so B is wrong because this question is probably counter intuitive.
(laugher)
[00:07:29.03] David: Your argument that B is wrong is that I like the question. You're basing this on my psychology.
[00:07:34.22] Jacob: I always recommend using psychology [inaudible]
[00:07:37.00] David: I--it's says on my exams, or I think I took it off because it was dorky. It says don't try and do this exam by my psychology and it use to say I'm really messed up. But give me a physical argument.
[00:07:48.29] Jacob: I have a serious answer. So originally I thought the cylinder, I'm sorry, the block would win, but it's the same force over the same distance.
[00:07:57.00] David: Yep
Jacob: some of the work is going into the rotational energy then it would have less kinetic energy, and it would finish last.
[00:08:04.29] David: Yes.
Jacob: But, I think they key point is for the cylinder the work, the distance over which it is done is not the start to finish distance, but its circumference. It might have more work done it, which equals out.
[00:08:17.15] David: So, the argument was, originally you thought it was the s--that the block would win because it would be the same work over the same distance, the force exerted over the same distance would be the same.
[00:08:28.26] David: But that there'd be more translated--more center of mass kinetic energy for the block because it isn't rotating. But now you're thinking, the relevant distance for the cylinder isn't just the distance there, but its the amount of rope that you pull off.
[00:08:42.00] David: Alright. Why the answer you disagree with is wrong. Shivani.
[00:08:46.11] Shivani: Well I was thinking like, we have to, when we say F equals M A, we have to look at what um the force is acting on.
[00:08:54.16] David: Okay.
Shivani: And in the block's case the force is acting its center of mass or like an axis of its center of mass. So that the whole block moves. But um, in the cylinder's case, the force is kind of acting maybe like a part of the side of the cylinder that's rotating.

[00:09:10.20] Shivani: And so it's not acting on its center of mass. Because if the, if the force was um uh acting on its axis of the center of mass, the cylinder would just act the same as the block. Just without spinning, come forward. So we have take into account that some of the force is going into the spin of the cylinder.
[00:09:28.26] David: Fantastic. So you're saying, you're saying, now you're on the other side. So Jacob was saying "I disagree with, with the block winning because," he said "it's more work done in the case of the pulling."
[00:09:40.14] David: You're saying you disagree with tie because the force isn't acting on the whole of the cylinder. The force is acting only on kind of part of the cylinder, which is less mass. Which would mean... oh wait.
[00:09:53.00] Shivani: Well, not less mass, it's just uh--
David: The force is only acting on part of the cylinder so that makes it--
[00:09:57.18] Shivani: Like it's
David: It make's that part of the cylinder--wait no oh, you know I really did think I understood and now I say it back...
[00:10:04.24] Shivani: Well, yeah, like no--
David: I realized I'm snagged.
Shivani: Oh, no, I'm just like--it's just like where the force is acting, because the force is acting on the axis of the center of mass for the block but that's not the same case for the cylinder.
[00:10:17.18] David: Right, but, but now that I'm saying it back to you and I hear myself say it, it sounds like that's an argument that the cylinder would win because, if the force is only acting on part of the cylinder, then part of the cylinder has less mass than the whole cylinder, so shouldn't that have a higher acceleration?
[00:10:31.18] Shivani: Well, I'm saying it's acting on like the side of the cylinder
David: The side of the cylinder.
[00:10:35.19] Shivani: I mean, but you have to take into account that the whole cylinder is moving, so you can't just, like ignore all of the other mass. But like the side of cylinder keeps rotating around the cylinder, so some of the force is acting um on that.
[00:10:49.00] David: Okay
Shivani: and you need to rotate but you also need to pull forward.
[00:10:52.22] Stanley: Couldn't you argue a little bit like the twig and the rock problem or whatever, where uh, you hit the rock in the center of it and it would all move forward and on the edge it would spin a little bit and also move forward.
[00:11:06.02] David: The twig and the rock problem... this was a question from the problem set with a collision and the rock hits the stick that's on the ice.
[00:11:12.00] Stanley: Yeah.
David: And so, and so make the argument, what's the
[00:11:15.24] Stanley: So in the case of the rock hitting the center of the stick is like the rock puts all of its force into the center of mass to start accelerating it translationally.
[00:11:25.00] Stanley: But then when it's hitting the edge, we're like in the cylinder's case, where the force is going to the edge of it rather than through the center of mass, you've got a torque that and it does move forward, but it doesn't move forward as fast.
[00:11:37.20] David: Got it, got it, got it. So you're--so in that situation, the collision that was at the center of mass was more effective at getting the stick to accelerate than the collision at the edge.
[00:11:48.24] Stanley: Yes
David: And the collision at the edge got it spinning and accelerating but the acceleration of the center of mass was not as large. And so, so, but that, are you arguing against the one you disagree with?

[00:12:02.07] Stanley: [I was trying to kinda back her up]
David: You're well, it's kinda like Shivani's. You're--alright--so you're kinda backing up this argument that the force is acting on the edge and so something different is happening and, and so Connor.
[00:12:14.20] Connor: So I think the main think about people who are saying--I agree, I think it's the block--so, for the people who say that it's a tie, their main argument is that--because--it's the same--the force is working over a greater distance so that, so that that makes it what it's, it's, it's the same.
[00:12:31.00] David: Yep.
Connor: But I don't think that it's a greater distance, because you're pulling each of the rope at the same time. And even though the cylinder will make it to the finish line over a greater distance.
David: Yep
[00:12:41.20] Connor: By the time that greater distance was done, the block did it in a shorter distance. And so you pulled the rope the same time, even though the cylinder does get there at the same force, the block got there first. Because it needed less distance to pull.
[00:12:56.17] David: So, alright, this one--I have to just tell you I'm genuinely torn over what to do, because there's lots of awesome stuff to get to, and this is really great.
[00:13:04.23] David: I'm psyched about what you're doing in this conversation. This is doing physics. Um, and there's--some of you have made arguments that I think "Oh, wait, no I have to rethink--oh no, I've got it."
[00:13:13.25] David: I'm not--you're making me, you're making me, you're challenging me to think through the physics which is the best thing. Um, for me.
[00:13:22.14] David: Um. I’m trying to decide whether to explain the answer or whether to leave this for next time.
(murmuring)
[00:13:32.11] David: So you want to say one thing.
Brian: I, I tried it.
David: You tried it. How did you try it?
Brian: I had two RedBull cans, and I tied floss around one and made a knot.
[00:13:40.20] David: I want to, I want to go on record as saying I do not condone RedBull. Alright, but go on. You tried two RedBull cans. And...
Brian: Um, and I tied, like wrapped one
[00:13:50.05] David: So one of them, so you could it it like this, I pull it like this and it's block like.
Brian: Yeah
David: Or I could wrap it up and pull it and it's a cylinder like. And, and what happened?
[00:14:00.10] Brian: The block-like-one won.
David: The block-like-one won. Alright, um.
(cross talk)
[00:14:05.16] Michael: I did something similar--
David: The one that was more like a block won the race. Um. Um, alright, alright, so uh, last word and then I want to poll.
[00:14:18.07] Nitin: So I was trying to rationalize like how if the rope on the cylinder is longer, the rope you pull is longer, how you did it like with the same force.
[00:14:27.04] Nitin: But if you think about it, the cylinder is a lot easier to pull. So the rope--with the same force the rope is going to come off a bit faster.
[00:14:34.00] David: Yes.
Nitin: So that's--
David: Oona said that earlier. Does that mean the block wins or the cylinder wins?

[00:14:39.05] Nitin: So I would say it's a tie.
David: You say it's a tie.
Nitin: You're pulling it off fast enough that the, the...
[00:14:46.24] David: This totally, this totally pains me--so, so let me ask you, I'm gonna ask it like this--Would you be really pissed off at me if I leave this for next time.
[00:14:57.01] Many voices: YES.
(laughter)
[00:14:59.12] David: I don't even have to click it. Alright, alright. So, I would... What?
[00:15:06.05] Oona: Why were you going to click it?
David: Why was I going to click it? But I could have had like..
Oona: But it was obvious.
[00:15:10.00] David: It was obvious. Alright, so, alright, I, I want to--I'm going to--I--this is for me among the things I want--I've told you this.
[00:15:18.12] David:Among the things I want to have happen in the course is thinking about the wold. I've been a little bit worried that we've been drifting into formulas and how do I solve it.
[00:15:27.17] David: And this conversation is very much about making sense of the physical world and what happened. And this is doing physics and this is great.
[00:15:34.13] David: Um, that's why I'm reluctant to--because I'm going to stop the doing physics by telling you what I think the answer is.
[00:15:40.03] David: But, I'm gonna do it because I don't want you pissed off at me. Um, so, the answer, so my--the answer to this one--is that it's a tie.
[00:15:49.00] Voices: NO. What?
(murmuring)
[00:15:50.27] David: But we have to respond to all of these other arguments. But the reason that it's a tie and--and this is--and a reason that this is a really powerful wonderful question is that it gets at fundamental understanding of this--of these ideas.
[00:16:03.24] David: This expression [writes F=ma] or if you want to write it this way [writes a=F/m] is it's the closest thing we have to holiness in this course.
[00:16:20.05] David: This is, this is the law. This is Newton's law of motion. This is, this is always true. It doesn't--there's no asterisk on this that says anywhere "except where m is rotating."
[00:16:35.15] David: There's asterisk that says "except if m is liquid" "except if m is gas" "except if m is a living person." This is just by virtue of having mass, things that have mass resist acceleration.
[00:16:48.13] David: They want to keep doing linear motion with linear velocity. They want to keep doing what they're doing.
[00:16:54.01] David: If there is a net force on them, they accelerate, they change their velocity. So this law says really clearly if I look at the--if I look--if I, in this case I don't have anything to set this on, so it's tough. If you imagine that the surface of this was frictionless.
[00:17:10.01] David: And, and if the surface here was frictionless, right now there are two objects exerting forces on it. The earth pulling down and the table pushing up. If it were frictionless and I tapped it slightly, it would glide across the table. And that would look pretty cool. Um.
[00:17:25.12] David: If I pulled on it with this cord, the only force acting on it--the only force acting on it would be the tension of the cord T.
[00:17:36.12] David: So the acceleration is a very simple thing--simple in the sense--simple and subtle. The acceleration of this would be the net force T divided by m and it doesn't matter what shape this is.

[00:17:49.08] David: The total acceleration--the acceler--the total force in this would be equal to--and this was the topic of a prelecture several times ago which is thinking of a system of particles,
[00:18:01.18] David: if you remember the acceleration of the center of mass--I think it gets to Shivani's reasoning--the acceleration of the center of mass of a system of particles is equal to the total force on the system divided by the total mass of all of the particles.
[00:18:16.00] David: Whatever the particles are doing. They could be--they could be air circulating and swirling all around. In this case, it's a cylinder. So that part is the argument for--it's a very compelling argument. Now we need to go reconcile these fantastic arguments on the other side.
[00:18:32.17] David: And so one of the fantastic arguments was "is more of the energy"--it was the first argument we heard--"more of the energy is going into spinning this. There is more energy--I am exerting more energy--I am putting more energy in because I'm pulling more cord off.
[00:18:50.00] David: Remember and trying this is a challenge--it's not easy to try it. To try it what you have to do is get some kind of a spring scale to ensure that you are pulling just as hard. It's not easy to pull with the same tension because it moves so easily.
[00:19:04.26] David: So if I try to pull it while spinning, I have trouble with having this at the same tension as if I pull it when it's not spinning. Because the rope gives way so quickly. It's kind of like with the bowling ball on the first week of class.
[00:19:21.00] David: If I want to keep hitting it as hard, I have to sprint after the bowling ball to keep hitting it just has hard because the bowling ball is moving away from me.
[00:19:27.28] David: So maintaining that strength force is a challenge. As I maintain that strength of force, I am pulling more cord faster--there's a larger distance. I'm doing more work.
[00:19:41.07] David: So the cylinder has rotational--it has more kinetic energy. It has rotational kinetic energy and it has translational kinetic energy. They have the same amount of translational kinetic energy.
[00:19:56.10] David: Go ahead.
Pat: So, we're saying that if you have the same force on both the cylinder and the block. But you're doing more work on the
[00:20:09.20] David: The cylinder. So had I asked the question, and this would be a great companion question to this, which one has more total kinetic energy at the finish line. The original argument would be correct.
[00:20:22.09] David: I am exactly doing more work on the cylinder because the cylinder is both rotating. I'm doing work by the torque through an angle, and work by the force acting through a distance on the cylinder. Go ahead.
[00:20:37.27] Pat: So, and so since you were doing more work, would you still--it has greater kinetic energy, but the, the ratio of the translation...
[00:20:49.16] David: It has greater kinetic--the translational part has to be exactly the same thing, they have to have the same acceleration.
Pat: Okay.
[00:20:55.10] David: They have the same acceleration they must be moving at the same speed at all instances of time. So if I just start the clock after point one seconds they have the same speed, after point two seconds they have the same speed. Because they have the same acceleration. Their linear velocity is changing at the same rate.
[00:21:10.27] David: If I think the work, I measure the work by the force I exert on the rope, I have a larger distance for the reason that Oona gave. And other's repeated. I'm pulling more rope. There's a greater distance of rope.

[00:21:27.23] David: If I measure the work at the cylinder, there's two kinds of work to measure or two versions of work to measure. One is the force acting through the distance.
[00:21:37.21] David: And the other is the torque acting through the angle. The torque acting through the angle gets its spinning. So, alright, let's, I wanna, I wanna go on, there are things about this that might still bother you. Connor?
[00:21:49.07] Connor: If this was done with friction would the answer be block?
[00:21:51.23] David: If the--if this were done and there were friction on the surface would the answer, would the answer be the block. Um... I, I have to believe Pat, she says no, it would be the same force of friction. They both have kinetic friction.
[00:22:14.24] Maayan: Cuz the, cuz the cylinder is spinning a lot more, it's creating a lot more frictional [inaudible]
Michael: But the frictional force is directly
[00:22:20.26] David: But the size of the force, the size of kinetic friction force should be equal in both cases so it should be the same in both cases. Yeah?
[00:22:39.11] Chris: But the surface area on the cylinder that's in contact with the surface is less.
[00:22:45.19] David: But the size of the friction, the, the friction is, friction is not holy like F equals MA. Friction is sort of an empirical law and when you actually look very carefully, you find deviations from it.
[00:22:49.01] David: But if this is true, nothing in that says anything about the surface area. I just is how hard, it's just the size of the force. Um, that's isn't generally true. Like if you wear high heels, and you have a pokey high heal and it pokes into, I don't know whether you wear high heels, it pokes into the ground and changes mu.
[00:23:15.15] David: So mu is not the same. Um, so you can change the nature of the surface and change mu. But in general if this is right, then Pat's argument is right and this would be the same size force. Um.
[00:23:29.12] Connor: He said he did it, he said he did it with like RedBull cans, and I did it with like Gatorade bottles and headphone wire so I was just pulling two—
[00:23:36.24] David: —You did it with what?
Connor: With, with Gatorade bottles.
David: Gatorade bottles. Yep, and?
[00:23:41.12] Connor: The block won by a long shot.
David: The block won by a long shot. My guess is what's very hard to do is pull with a constant tension. The same tension.
[00:23:51.09] David: So what you could do--in fact, if you guys want to try this, I could probably get you a spring scale to lend you.
[00:23:56.23] David: And you could go tie your speaker wire or a cord to a spring scale and as you pull it make sure the spring scale reads the same value.
[00:24:05.18] Maayan: That's really hard to do.
David: It will be very hard to do. It will be very hard to do.
[00:24:10.02] David: Um, I used, I used to do a lab where I had students take a spring scale with a cart and have them pull the cart along and keep the spring scale at a constant reading, and you'd see kids sprinting across the room trying to keep up.
[00:24:22.00] David: It was very hard. Once it gets moving. That this moves so easily makes it very hard to keep that tension. So that's I think the reason you had a difference.
[00:24:35.05] David: Um, yes
Maayan: Which of course is why we use wheels to move things.
David: Which is why we use wheels to move things, although we usually don't orient them like that.

[00:24:40.20] David: Um, so, so, um, let's. That was awesome. This would be a question 11, and you have really fantastic arguments. Um, alright, but I'm WAY behind what I had planned to do today.