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8.01 Physics I: Classical Mechanics, Fall 1999
Transcript – Lecture 25

During the past four lectures, we have dealt with angular momentum, torques and rolling objects and rotations.

And many of you then think, "Oh, my goodness, now we have to remember a whole zoo of equations," but that's not true.

If you simply know how to make a conversion from linear symbols to rotation, which is immediately trivial, of course--

position becomes angle; velocity becomes angular velocity; acceleration becomes angular acceleration, and so on--

then you can make the conversions very easily.

If you remember that the kinetic energy is one-half m v squared, then the kinetic energy of rotation then becomes one-half I omega squared.

This is on the Web.

Every view graph that I show you in lectures is always on the Web, and you should look under "lecture supplements," and then you can make yourself a hard copy.

So I thought this might be useful for you to remember.

Today I want to discuss in detail what it takes for an object to be in complete static equilibrium.

For an object to be in static equilibrium, it is not enough that the sum of all forces is zero.

But what is also required, that the sum of all torques relative to any point that you choose is also zero.

And that will be the topic today.

If this is an object free in space and let's say the center of mass is here, and I have a force on this object in this direction and another force on this object in opposite direction but equal in magnitude, then the sum of all forces is zero.

But you better believe it that there is no equilibrium.

There is a torque...

and if this distance equals b, then the torque on that object relative to any point that you choose--

it doesn't matter which one you take--

the magnitude of that will be b times f.

And if there is a torque, there's going to be an angular acceleration.

Torque is I alpha.

And so it's going to rotate.

In this case, it will rotate about the center of mass, so it's not static equilibrium.

The torque in this case would be out of the blackboard.

So it's going to rotate like this.

So we got to keep a close eye on torques, as much as we have to on the forces themselves.

So, today I have chosen a ladder as my subject of static equilibrium.

I put a ladder against a wall.

Here's the wall, and this is the ladder.

At point P, where the wall is, there is almost...

let's say there is no friction.

Mu of P is zero.

At point Q here, where it's resting on the floor, there is friction.

The static friction at point Q--

we'll simply call that mu.

The ladder has a mass M, and it has a length l.

So here is the center of mass of that ladder, right in the middle.

And this angle equals alpha.

We know from experience that if this angle is too small that the ladder will slide, and so I want to make the topic today "What should that angle be so that it does not slide?" Well, we have here a force Mg; that's gravity.

Then we have a normal force here--

I call that NQ.

We have friction in this direction, because clearly the ladder wants to slide like this, so the frictional force will try to prevent that, will be in this direction.

At point P there is no friction, so there can only be a normal force.

And I call that N of P.

So these are the only forces that act on this object.

And now we can start our exercise.

We can say, all right, the sum of all forces in the x direction have to be zero.

So that means that N of P must be in magnitude the same as the frictional force.

Now the sum of all forces in the y direction have to be zero.

So that means that Mg must be N of Q.

N of Q must be Mg.

But now we need that the sum of all torques have to be zero.

It doesn't matter which point you choose--

you can pick any point.

You can pick a point here, or here, or there, or there.

You can pick C, you can pick P.

I choose Q.

The reason why I choose Q is because then I lose both this force and that force, and I only have to deal with this one and that one.

And so I'm going to take the torque relative to point Q.

So we have NP.

We have the cross-product of the position vector to this point times the force.

Since the length is l and the angle is alpha, this is l sine alpha, so I'm going to get NP times l sine alpha.

And I call the torque that is in the blackboard, I call that my positive direction, and the torque that is out of the blackboard, I give that a negative direction.

So this one is in the blackboard, so I call that positive.

The next one, Mg, is going to be negative torque, and so now I need the cross-product between the position vector and Mg, so that is the length here, which is one-half l cosine alpha times Mg--

Mg one-half l cosine alpha, and that now must be zero.

So I find, then, that N of P--

that is, the normal force at point P--

I lose my l, equals M divided by two times the cotangent of alpha, and that must be the frictional force.

So I know what the frictional force is given by this result.

Now, I don't want this ladder to slide, so now I have a requirement that the frictional force must be less or equal to the maximum frictional force possible.

And the maximum frictional force at this point Q is mu times the normal force.

So my requirement now is that N over 2 times the cotangent of alpha must be less or equal to Mg times mu.

Mu times Mg.

Did I lose a g here? Yes, I did.

I have here a g, and I have here a g.

Correct? Because if I have this force here and this position vector, then I have Mg.

So there is a g here.

And so there is a g here, and so I lose my Mg, and so you'll find that the cotangent of alpha is smaller or equal than 2 mu, or the tangent of alpha is larger or equal than 1 over 2 mu.

And so that is the condition for the ladder to be stable.

And when you look at this result, it tells you that the larger mu is...

the larger mu is, the smaller that angle, and that's very pleasing.

That's exactly what you expect.

And if mu is very low, then the situation is very unstable.

Then it will slide almost at any angle.

If we take some numerical examples--

for instance, I take mu equals 0.5, then alpha would be 45 degrees, and if the angle is any less, then it will slide.

If you take mu is 0.25, then the critical angle where it will start to slide, I think, is somewhere near 63 degrees, but you can check that for yourself.

So the angle has to be larger than that number for the ladder to be stable.

This result is very intuitive, namely that if the angle is too small that the ladder starts to slide.

I have a ladder here against this wall.

We have tried to make this here as smooth as we possibly can.

It's not perfect.

So it's only a poor-man's version of what I discuss there, but in any case, the friction coefficient with the floor is substantially larger than the friction coefficient here.

And what is no surprise to you, that if the angle alpha is too small, then there's no equilibrium.

The angle of alpha has to be larger than a certain value, as you see there, and then it's stable.

That's all I want you to see now.

But now we're going to make the situation more interesting, and in a way I'd like to test your intuition.

Suppose I set the angle of the ladder exactly at the critical point.

In other words, I'm going to set it so that the cotangent of alpha is exactly 2 mu, so it is hanging in there on its thumbs, just about to start sliding.

And now I'm going to ask one of you to walk up that ladder, to start here and slowly walk up that ladder.

Do you think that stepping on that ladder, starting off, is super dangerous? That the ladder immediately will start to slide? Or do you think that actually your being at the bottom will make it more stable? Who thinks that it will immediately start to slide? A few people.

Who thinks that it will not start to slide when you step on the lowest...

All right.

We'll see what happens later on.

Now, this person is going to climb the ladder, and then there comes a time that it passes point C and reaches point P.

Will it now be safe to do that, or do you think that now it's going to be very dangerous? What do you think? Who thinks that you shouldn't get too high up on the ladder? Who thinks it makes no difference--

you can go all the way up to the end? There are always a few very courageous people.

Okay, so this is what I'm going to analyze with you, and most of you have the right intuition, but we're going to look at this in a quantitative way as I know how to.

So we're going to put a person with mass little m on that ladder, and we put the person here.

So this force here is little mg, and let's make this distance d.

And now we're going to redo all these calculations.

We start completely from scratch.

The sum of all forces in the x direction has to be zero.

No change.

N of P must be F of f.

Now the sum of all forces in the y direction has to be zero.

Now there is a change.

So now we have that N of Q must become larger, must be equal to capital M plus little m times g, so the maximum friction, which is mu times NQ, now becomes mu times M plus m times g.

So the maximum friction goes up.

Now we need that the torque, and I pick my point Q--

relative to point Q--

equals zero.

Well, the first two terms haven't changed, so I have N of P times l sine alpha minus Mg times one-half l times the cosine of alpha.

But now we have a third term, namely this position vector, and this force, and so now we're going to get this distance--

which is d cosine alpha--

times this force.

So we have here minus mg times d cosine alpha, and that now equals zero.

So I'm going to take N of P out of here.

And I can take g cosine alpha out.

So if I take g cosine alpha out, I have Ml divided by two left over plus little md, and then I have to divide by l sine theta.

Not theta, but alpha.

And so now I can write for cosine alpha divided by sine alpha, I can write cotangent alpha, and I'll bring the l inside here, so I have g cotangent alpha times M over 2 plus little md divided by l.

And that now must be the frictional force, because NP is still the frictional force.

Let me make sure that I have this right.

Yes, I do.

g cotangent alpha, M over 2, little md over l--

that is the frictional force.

Notice that the frictional force is going up, because this term is added, and we didn't have that term before.

Before we only had this term that you see here.

So you first thought may be that the situation has become more dangerous, because if there is more friction, well, the ladder was set exactly at that critical point--

it was hanging on there by its thumbs.

So if the friction goes up, you may say, "My goodness, it will probably start to slide." However, what you overlook, then, is that the maximum friction has also gone up, and so we have to evaluate this now in comparison with the maximum friction.

And the best way to do this is to think of this first as making d equal zero.

So we said the person starts at the bottom of the ladder and we ask this person to gradually climb up.

Now, notice when d equals zero that the frictional force is exactly the same...

what it was before--

there is no difference.

That frictional force has not changed when d equals zero.

But what has changed is the maximum friction.

The maximum friction has this little m in it, and that's independent of d.

There is no d anywhere here.

So if the maximum friction goes up, and the friction itself remains the same, clearly the ladder has become more stable, and so you can step on the lowest tread and nothing will happen.

On the contrary, the situation will become more stable.

As the person starts to move up, the frictional force gradually increases, because this term goes up, but the maximum friction remains the same--

it's independent of d, and so now there comes a time that this force becomes larger than the maximum friction and then the ladder will start to slide, and that, of course, is what we want to find out now.

So now the situation is only safe as long as the frictional force is smaller or equal to the maximum value possible.

And that's the case when g cotangent alpha...

but remember, we set it at the critical angle, so that cotangent alpha is 2 mu.

So I can replace this by 2 mu, because that's the way I set up my experiment.

I start that way.

I don't start with a random angle; I start exactly at the angle so that the ladder is sort of just hanging in there.

So cotangent alpha is 2 mu.

M divided by 2 plus m times d divided by l, this now has to be less or equal to this value--

mu times M plus m times g.

Notice I lose my g.

I lose my mu.

I have here 2 times M over 2, which is M, and I have one M here, so I lose my capital M, and so I find that 2md over l has to be less or equal to m.

I lose my m, and I find that d has to be smaller or equal to l over 2.

And that is not unlike most of your intuition, namely as long as the person who steps on the ladder stays on this side, the situation will become more stable.

Certainly when the person starts here, the stability has enormously increased.

As you gradually approach that point here--

the center of mass, where d is exactly l over 2--

then, of course, the situation becomes again extremely critical here, but when you're over this point, it's no longer critical, and the ladder will start to slide.

So in a nutshell, then, we set the ladder at the critical situation.

It's about to start sliding.

We put a person on here, it becomes more stable.

The person walks up slowly, the frictional force will increase, because of this term, the maximum friction will not change--

it has already gone up because the person is on the ladder--

and as the person approaches this point, the situation becomes less and less stable all the time.

Right at this point, we are back to where we were, the situation is about as critical as it was before the person steps on it.

And then the person proceeds; then the ladder will slip.

And I can show that to you--

at least I can make an attempt.

I have here that same ladder, and now what I will do is I will set the angle alpha not exactly at the critical point but a little lower, so that when I let it go, we'll all see that it will slide.

So it's past the critical angle; the angle is smaller.

But now I have four kilograms here.

I wasn't going to ask any one of you to walk up this ladder, believe me, and I wasn't going to do it myself either.

So you see it is unstable.

And now I put the four kilograms on here.

And I can let go, and the ladder has become stable.

Do I take it off--

there it goes.

So the person standing very low made it more stable, exactly consistent with what we just saw.

Now I make the angle alpha a little larger than critical, so the ladder is happy.

It's happy.

But now the person is going to do something dangerous.

He's going to walk and stand here--

and he shouldn't do that, as you see.

That's exactly what you have seen there.

So the friction plays an essential role for us to get static equilibrium, and that is often the case.

There are many examples in our daily lives where friction can be used to our advantage, and a very special case, which I will discuss with you now, is often used by sailors--

by holding, controlling a very massive object, a very large force, controlling it with a very small one.

And you do that by making use of friction.

You wrap a rope around a pole, or around a rod, and you use the friction between the rope and that rod to your advantage, and it works as follows.

Here is this rod--

it doesn't have to be horizontal as this one--

and I hang on this side of the rod, I hang with a string a very massive object.

Capital M.

So the tension here, T2, would be Mg--

assuming that it is not accelerating, that it is at rest.

I wrap this rope around here several times, and here I hang an object which is substantially less in mass, which is m, little m, and the tension equals mg.

If there is no friction at all in this bar, then...

and the rope is near massless, then T1 will be the same as T2, so the situation will start to accelerate.

However, if we make use of the friction, then we can have a stable situation.

We can have static equilibrium, so that this one is not moving and this one is not moving, and then we can have T2 to be way, way larger than T1, by using friction to our advantage.

Let's blow up that center portion.

Radius R, and let us have this rope here--

I'll give the rope a color.

It doesn't have to come off vertically, of course.

It could be at any angle.

There it is, and so here is my T1 and here is my T2.

And we take the situation that the pull on this side is way larger than on that side so that this rope wants to slip in this direction.

That's what it would like to do.

If you look at these small little sections of the rope, it is immediately obvious if the rope wants to slide in this direction, wants to start slipping, that the frictional forces in these little pieces here are all in this direction...

all the way around.

And therefore, it helps T1, so to speak, and so because of the friction, which is opposing T2, T2 can now become much larger than T1.

What you have to do to calculate this analytically, you have to evaluate these individual frictional forces for these very small slices, so that becomes an integral, and then you have to integrate it over an angle, which I will call theta zero.

And I remember when I last lectured 801, that was in 1993, I derived that in class--

the relation between T2 and T1 as a function of this angle theta.

And that took me about five minutes, and after five minutes, half the students were asleep.

Now, I'm not sure whether you want to sleep five minutes, but I don't think, frankly, that you deserve it, so I decided to not do the derivation but to refer you to the book, which is page 361, and you will find, then, that in the situation that the rope wants to start slipping in this direction, that T2 divided by T1 is e to the power mu times theta zero, if the friction coefficient here is mu--

it would be the static friction coefficient.

So that is the result.

And notice that it is independent of the radius of this bar, which is not so obvious, strangely enough.

Whether the bar is this small or this small makes no difference.

It only depends on this angle.

This angle could be very large.

You could wrap it around ten times, as we will do very shortly.

So there's no restriction on theta.

If there were no friction at all, notice then at the moment that it starts to slip, e to the power 0 is 1, that's when T2 equals T1, that's obvious, so you can't play this game if mu is zero.

You need friction.

That is at the heart of this whole problem.

And so now let's put in some numbers so that we get an idea of what we gain.

So let us take the situation that we take let's say three turns. We wrap the rope around three times. So three turns.

That means theta zero equals six pi.

And let the friction coefficient mu be one-fifth, 0.2.

So e to the power mu times theta zero is now about 40.

So what that means is that with a force on this side which is 40 times smaller than a force on that side, I have a balanced situation.

I can hold this in my hand and counter--

if you want to think of it that way--

a force on this side which is 40 times larger.

But if I take six turns, then e to the power mu theta zero will be about 2,000--

2,000! So now I can really control an elephant.

Imagine now that I have here an object, capital M, which would be 5,000 kilograms...

make it 10,000 kilograms.

That's what I'm hanging here.

I can hang here now a mass which is 2,000 times less massive.

That means I could hang there five kilograms.

And the tension here would be 2,000 times less than the tension there.

The system would be about to start slipping, but it's not slipping.

There is complete balance.

So imagine I hold this part in my hand--

here is this 10,000-kilogram weight and I hold this in my hand.

All I need is a force of about 50 newtons, and I'm standing there, and on the other side is this 10,000-kilogram weight.

And now I just make my force a little less than 50 newtons, and what will happen now, it will start to slip.

Remember? Because we calculated here the requirement for just not slipping.

So now I let it go, and then the 10,000-kilogram on the other side will slowly go down.

I can just control it, and I can stop it, and I can control it with a very, very small force.

Now comes a question for you.

Suppose I wanted to raise the 10,000-kilogram.

Could I now pull a little bit more than 50 newtons? Just a teeny weeny little bit more? Would then that 10,000-kilogram come up? I see people shake their heads.

Who thinks it would come up? Who thinks "no way"? Who doesn't think at all? Most of the people.

All right--

sorry, I didn't mean to be nasty.

Um... there's no way that you could pull it up, because if you want to pull this up, the situation completely reverses.

Those frictional forces for this rope to go in this direction will flip over.

In other words, what is now T1 in our calculations will become T2.

So if you want this side to go down, if you want to have it slip in this direction, you're going to have that T1 divided by T2 is now e to the power mu theta zero.

And so now if you have 10,000 kilograms here and if you had six turns, then the force that you need here is 2,000 times larger than 10,000 kilograms, and so you would need 20 million kilograms.

So it would be the dumbest thing to do to lift it.

You don't want to lift it.

You use this device only to balance a very strong force--

that's the way it's used by sailors--

and even to control it, because you can slowly release it, and then the force on the other side will start to move.

But you cannot use it to lift something.

I have here a plastic bin, and in this plastic bin are four of these 15-pound lead bricks.

Would you do me a favor and come up here and convince yourself that three are already in there? I don't want to put them all four in, so I decided I'm only going to put the last one in.

You see those three? Thank you very much.

And I'm going to put the last one in.

It's very heavy.

Do you want to check this, by the way? This is... Careful! It's very, very heavy.

Yeah, okay.

Okay, 15 pounds apiece--

60 pounds we have up there.

And now I'm going to wrap this around this bar, which is your bar.

The radius doesn't matter.

And why don't we start with six rotations? One... two... three...

[loud rustling against microphone]

Oh, my goodness.

Four... five... six.

Okay.

Now I'm going to lower this platform that we have that is holding it up.

I can lower it.

And it will shortly be hanging now on my rope.

There it is.

I can remove this now.

We don't need this anymore, and we don't need this anymore.

Effortless.

30 kilograms--

[whistles softly]

Hardly any force.

Very gentle.

Now let me lower it a little.

There it goes.

Just lower it.

Would be nice if I had to do even less.

Let's put a few more turns on.

One... two... three.

You know what we could do? We could put so many turns on that the weight of the rope itself is enough to balance it.

Let's try it.

Not yet.

Put a few more on.

One... two... three... four.

We have 12 windings now.

And the rope, the weight of the rope is now sufficient to balance the 30 kilograms.

So you see this in action now.

This is a marvel.

Well, let me put a few more on, because I don't want it to come down during the lecture.

I want to be sure that it stays there, and I'm going to secure it here.

So you see how you can use friction to your advantage and get an enormous gain by factors of thousands and more, and this is used quite frequently.

So you saw in a striking example of where friction helped us to balance, and now I want to discuss an object that is hanging and that can freely swing due to gravity.

I want you to appreciate the situation of static equilibrium that the sum of all forces and the sum of all torques have to be zero.

So here is this object which I'm going to hang, maybe on the wall, and here is a point P, and there is a...

let's say a frictionless spin that I put in the wall, so the object can freely swing around.

Let the center of mass be here.

And so there is a force.

If this object has a mass little m, there is a force mg, and here is the position vector r of P, and so it's clear that there is a torque relative to point P.

And if there is a torque relative to point P, it would be r P cross mg.

I put a vector sign over here, because you have to take the cross-product between the two, so you take the...

sine of this angle has to be taken into account.

This object is going to rotate.

It's clearly going to rotate about that point P.

The torque equals I about that point P times alpha, and alpha is the angular acceleration.

How can we ever get a stable situation? Nature is now going to think hard and is going to say, "Gee, I can only have stable equilibrium "if the sum of all forces equals zero "and if the sum of all torques relative to any point equals zero." And nature knows how to do that.

That always will happen if P and the center of mass are along a vertical line.

Because if that's the case, then there will be here a force mg, and then here there will be a force mg upwards.

This object is hanging on that pin, so the pin--

action equals minus reaction--

will push upwards.

So the sum of all forces is zero, and there is no torque.

Take any point you want to--

this point or that point or this point or that point or that point--

there is no torque anymore.

And so now there is complete equilibrium.

So if you had an object, for instance, that looked like this, a thin rod--

there's a very massive object here, so that the center of mass is almost there--

then this situation would be stable.

Or you might say this situation, because now we have the center of mass, mP, vertical line.

So also here we have now mg down, so we have at the pin mg up.

Sum of all forces is zero, sum of all torques is zero.

But there is a big difference between this situation and this situation, which you immediately feel in your stomach, of course, and that is that this is highly unstable.

If you just blow on this a little, it will swing over, it will start to rotate, whereas this is stable.

If I move this to the side, it will come back to that position.

But the basic idea is, then, that the center of mass will always in stable configuration line itself up below the point of suspension.

I have here a triangle, and I have no clue where the center of mass is.

It may be somewhere here.

It may even be in open space, I don't know.

What I can do now, I can suspend it like this, and I know that the center of mass must be below my finger.

Did you notice? It actually rotated.

So that the center of mass lines itself up precisely below my finger, so I can now take a pencil and draw a line here, or I can have a little string, and now I can change my finger to here and I can again draw this line, and where the two intersect is the center of mass.

So the center of mass will always find itself below the point of suspension.

If now I take a piece of putty and I put the piece of putty here, then clearly I change the location of the center of mass quite substantially.

It must have shifted enormously in this direction.

Where is the center of mass? I have no clue.

But look.

I balance it here.

The center of mass must now be somewhere here.

I balance it here.

The center of mass must be somewhere here.

And where the two lines intersect--

could be in this opening--

that's where the center of mass is located.

So it's easy experimentally to find the center of mass.

Earlier in the course, we calculated where the center of mass was.

Perhaps you remember that, when we had some very special geometrical configurations.

I mentioned to you then already that there are ways that you can experimentally determine it, and that can be done very easily in the way I just showed you.

Now... I want to show you some examples of static equilibrium which are not so intuitive.

You may have seen some of them.

You may actually have played with some of them.

If I take a pencil and I take my pocket knife...

So here is a pencil.

I will show this to you shortly, just a regular pencil.

And I take my pocket knife and I put the knife, I jam my knife in here.

So this is the knife.

And this is now my pocket knife, like so.

This arrangement can easily be made such that the center of mass is below this point, and so if now I put my finger here, I can balance this rather strange object and it will be completely stable.

It will arrange itself so that the center of mass will fall below my finger, and it will be completely happy.

And I want you to see that.

I have here my pocket knife and I have here a pencil.

And you can see there--

or the ones... those of you who are close can see it here.

I'll give you a better light condition for that.

So there we are.

So here is my pocket knife.

I open it now.

And here is the pencil.

And I'm going to jam it in here.

When you do that, be more careful than I was this morning, because the knife cut into my finger.

That's why I have this Band-Aid here.

It can easily lead to a nasty cut.

So the knife is now in this pencil, but now I have to get that center of mass under...

under the pencil.

And now I put my finger here, and it's stable.

So the center of mass rearranges itself so that it goes under the point of suspension and is completely stable.

You can wiggle it as much as you want to.

That's not so intuitive.

I have here a... a very thin bar, a wire, a very stiff wire.

And I can put my hammer here on the end of this wire.

And look at this.

The center of mass is way below my suspension point.

This is stable like hell.

It also hurts like hell, by the way.

You can even swing it.

Center of mass is way here below the suspension point.

Sum of all torques is zero, if it's like this, sum of all forces is zero.

Center of mass below the suspension point.

They have to be exactly vertically lined up.

If they're not vertically lined up, like now, then there is a net torque relative to that point.

If there is a net torque, there will be an angular acceleration, and that's what you see.

If they're exactly lined up, there is no longer any torque.

Aah.

Let's now turn to a rope walker.

We have a rope walker.

Here is the rope walker.

And the rope walker, standing on the rope.

I'll make the rope walker a little smaller--

you'll see shortly why I make it a little smaller.

This is the rope walker.

And this is the rope.

And let the center of mass of the rope walker be right here--

somewhere here.

And the distance between the center of mass and the rope--

let that distance be one meter, and let the mass of the rope walker be 70 kilograms.

I build a light structure--

it could be built of wood--

which the rope walker is going to carry in her hands, or in his hands, just like this.

And it goes down quite a distance.

And I put here a mass of five kilograms, and I put here a mass of five kilograms.

And let's assume that this structure is very lightweight, so that we can ignore that, and let this distance be ten meters.

Where is the center of mass of this system? Seventy kilograms is above the rope.

One meter.

Ten kilograms is ten meters below the rope, so clearly the center of mass of the system as a whole will be below the rope.

And so that person is as stable as anything--

just as stable as my hammer was--

with one problem, that the person could slide off the rope to the sides, and that would be unfortunate, of course.

And therefore you would require, then, that if this is the rope, the cross-section of the rope, then you would make yourself soles on your shoes which are a little bit like this.

So that's only to prevent you from sliding off in this direction and falling.

But the center of mass is below the rope, and so there is really no danger.

You can balance yourself and walk on the rope and nothing would happen.

You could even do this--

go back and forth on the rope.

No problem.

You always come back like this.

Well, we have a very special rope walker.

This is our rope walker.

And this rope walker has indeed very special shoes.

In fact, the shoes of the rope walker is a little wheel, and this is what the wheel looks like.

And here is where the rope will be, and this is the rope that you see here in the lecture hall.

And so the only reason why we need this groove in the wheel is to prevent it from sliding to the sides, as we need it for this person.

But the center of mass--

you see it when I balance it on my finger--

is way below the suspension point.

Because of these weights on both sides, the center of mass is somewhere here, so it is completely stable.

You can even go like this--

no problem.

This is what the rope walker can do, provided it doesn't slide off.

That's why we have this.

Okay, let's ask this rope walker to give us a demonstration.

Let's make her walk.

We don't need that television anymore.

It would be nice if one of the students...

Would you do me a favor and welcome the rope walker as she arrives here? Because we don't want her to crash.

Is that okay with you? So when she comes down, be gentle and give her all the honors that she deserves and then you just make sure that she doesn't fall, because that...
she will be damaged, right? We don't want that.

Okay, so you have seen already how stable the situation is.

And there she goes.

You ready for that? Voil‡! We can all become rope walkers.

Thank you very much.

See you Friday.