Welcome back. I’m sure that you’ve been busy since our last program, and I hope you all did well on your unit test on Newton’s Laws of Motion. Now don’t think that you can just forget what you’ve learned so far. Physics doesn’t work like that. We’ll keep using what you’ve learned and build onto it to learn some more. In fact, our next unit involves an idea we introduced when we studied vectors and then used over and over again in our study of Newton’s Laws. Every program of this unit will be devoted to the study of mechanical forces.

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**Instructor**

<table>
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**VO**

We live in a world in motion. In order to be set into motion or to have their motion changed, objects must have a force exerted upon them.

Forces exerted by the muscles of a tailback allow them to run down the sidelines.

The expulsion of exhaust gases at extremely high velocity allows airplanes to take off and rockets to be launched into orbit.

The force the wind exerts on the wind turbines causes them to turn, generating electricity for thousands of people.

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**Read objectives on screen.**

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**Instructor**

We’ll start our study of forces with ropes, strings, chains, and pulleys. Want to know why?

Well, it’s like this. If I want to pull something toward me I can do one of two things: grab it and exert the pulling force directly or attach a rope to it and pull it. The force is transferred from me to the object and vice versa through the tension in the rope. We can attach a spring scale to the rope and use it to measure its tension, which is the same throughout the rope. Now what is the purpose of the pulley? We’ve used a single pulley like this before to change the direction of a force.

**lab cart on screen**

VO

Remember this lab? We used the force of gravity, which always pulls down, to pull a cart horizontally along the track.

**Instructor**

Now we’ll have our students use a 500-gram mass, strings, pulleys, and spring scales in different ways. We’ll cover up the spring scale so that you can predict what it will read. Let’s stick to one significant digit to make things easy. After you’ve predicted, then we’ll show you the actual reading. Ready?

**student on screen**

VO

Our students are using a 200 gram mass, which weighs about 2 newtons. First, they hang it from a string that is attached to a spring scale. What do you expect the tension on the string to be?
Who said 2 newtons? Since our string’s weight is so small, compared to the weight of the mass, we can consider it to be negligible. So the tension in the string is just the weight of our hanging mass.

(student on screen)
VO
Now let’s drape the string over a pulley and pull down on the string to support the load. What do you think the scale will read?

The tension is still two newtons. The pulley simply changes the direction of the force. What will happen to the tension if we change the angle of the string?

Did you say that the tension won’t change? You’re right. Our student is still pulling on the string with enough force to support the load. The pulley simply changes the direction of the force, so the tension in the string stays the same.

Instructor
Now that you know how strings, ropes, and chains work to transmit forces through tension, we’re ready to draw some force diagrams. These are essential to solving force problems. The first thing we need to do is establish some rules for drawing force vectors.

(green chalkboard on screen)
VO
A free-body diagram shows all the forces acting on an object.

Force vectors start at the point of application and are drawn away from the object.

This means that pushes are drawn as pulls from the other side

Weight vectors are drawn straight down from the object’s center of gravity. The center of gravity, sometimes called the center of mass, is the point where all the weight of an object seems to act. For uniform objects, the center of gravity is in the middle.

(graphic of bird on screen)
VO
Let’s draw a few force diagrams together, starting with a free-body diagram of the forces acting on the mass hanging from a string. You do not have to copy the picture because it’s better to draw a separate diagram using a dot to represent the hanging mass. There are two forces acting on the mass. We know that the earth pulls down on it with the force of gravity equal to the object’s weight. So we’ll draw an arrow down and label it “F sub w.” The other force is the tension on the string pulling upward on the mass. We’ll draw it the same length as the weight because the mass is not moving, so the net force must be zero. We’ll label this “F sub T” for tension.

Even though this tension also pulls down on the finger, we’re not interested in it, only in the forces acting on the hanging mass.

Now look at the bird at rest on its perch. Draw a free-body diagram of the forces acting on the bird. Use a dot to represent the bird, and draw the force vectors from the dot. Your teacher will pause the tape and give you time to try this.
First, you should have drawn the weight of the bird acting down.

Then you should have drawn the force applied by the perch pushing up to support the bird. We want to start this force vector at the point of application and draw it as a pull from the top, rather than as a push from the bottom. It doesn’t matter whether the bird is being pulled up or pushed up. The result is the same. We labeled this “F sub a” for applied force, but you could have picked something else, like support or perch. Notice that the diagrams for the hanging mass and the bird are the same.

Both are being pulled downward by the earth, and both are being acted on by an upward force. The first object is pulled upward and the second is pushed upward.

Now your teacher will give you these pictures and descriptions of situations. Draw a free-body diagram showing the described force acting on each object.

Local Teachers, turn off the tape and give students problem set number 1 from the facilitator’s guide.

There may be other forces acting on the objects in these pictures, but we are only asked to draw the one force described. Remember to use a dot to represent the object and start the vector at the point of application of the force.

In number one, the refrigerator is pushed from left to right. Start at the dot and draw the force vector to the right.

In number two, the seal is pushing upward to support the ball, so the dot represents the ball and we draw the vector upward.

In three, the worm is being pulled upward and to the right, so we draw the vector like this.

In four, the lawn mower is being pushed downward and to the right, so the force vector is draw like this.

And in number five, the wind is blowing into the man’s face, so start at his face and draw the vector backwards. like this.

Here’s a picture of a boy sitting on a swing that is being pushed horizontally by his sister. Draw a free-body diagram showing the three forces acting on the swing. Sometimes the picture gets in the way of a force diagram, so just represent the swing by a big dot, which will be the point of application of the forces. Your teacher will give you time to try this one on your own.

Our point of application of all the forces will be right here at the swing seat. If you have the picture, you can draw the vectors on it. But since you don’t, let’s draw our dot over here. The first force I think of is the force of gravity or weight, so I’ll draw it straight down and label it “F sub w.” Now let’s draw the sister’s push. Remember that we don’t draw pushes. Instead, we draw them as pulls from the other side. A push to the right is like a pull to the right. So we start at the dot and draw our
vector to the right. We can label it the horizontal force or “F sub x.”

What is the third force acting on the swing? It’s the swing set or tree pulling on the swing through the rope or chain. We’ll draw it at an angle like this and label it the tension force, “F sub T.” You’ll learn more about labeling later. Just try to be descriptive.

Instructor
Since we didn’t tell you anything about the magnitudes of the forces, you couldn’t know how long to draw your arrows, but I hope you get the general idea of drawing a free-body force diagram. You’ll need to draw one for every problem. Remember that pushing you toward the right is the same as pushing you from the left or pulling you from the right, but we don’t talk about ‘from.’

We start at the point of application and go in the direction of the force. Got it?

Now, the first kind of force problem you’ll be working involves two or more forces acting on the same point at the same time, like our swing. These are called concurrent forces.

(green chalkboard on screen)

Instructor
Two or more forces acting on the same point at the same time are called concurrent forces.

Concurrent forces can be replaced by one force, the resultant.

Calculating the resultant of two or more forces is called composition of forces.

Instructor
Composition of forces problems should not be new to you. The term, composition, means putting things together, like composing a symphony or putting ideas together to write a story or report. Composition of forces is just a matter of combining force vectors, using the skills you learned in unit two. In fact, why don’t you try some of these problems right now? Your teacher will provide you with them and give you time to work the problems. Go back to your notes and example problems from unit two if you need help. Remember to give both magnitude and direction.

(text on screen)

VO
Local Teachers: Turn off tape and give students problem set number two from facilitator’s guide.

(Pause Tape Now graphic)

(text on screen)

VO
Problem one is the simplest. Since all the forces are either north or south, all we need to do is add the two north vectors and subtract from the south. And our answer is 51 newtons, south.

You should recognize the need for trig on the second problem. Let’s draw a force diagram first. Start with the big dot, which is the point of application. Then draw one force west and label it 55 newtons, and a longer vector south, labeled 78 newtons.

If you decided to draw head-to-tail vectors, that’s fine, but for many problems we’ll be doing during this unit, you’ll need to show both the forces starting at the point of application. So I’m going to use this method. All we need to do is fill in the parallelogram with dotted lines and choose the triangle that will give us the smallest angle, theta. Remember that the opposite side, side “a” will be the
smaller vector. So we label sides “a, b, and c,” or if you prefer, opposite, adjacent, and hypotenuse. To find the resultant, we use Pythagorean Theorem and inverse tangent to find the angle. “c” will be the square root of 55 squared plus 78 squared, or 95 newtons. And the inverse tangent of theta equals 55 divided by 78. So theta equals 35 degrees west of south, which you’ll remember is short of long or “a” of “b.”

Our final problem involves three forces. Always look for ways to simplify the problem. If you look closely, you’ll see that there are two eastward forces, so we’ll add them together to give one force of 58 newtons east and the other of 23 newtons north. Now we’ll just go through the same procedure of drawing the two concurrent forces, filling in the sides of the parallelogram, and choosing the triangle you would have gotten if you had drawn the longer vector first for the head-to-tail method. Label theta, and sides “a, b, and c” or opposite, adjacent, and hypotenuse. To find side “c” or the resultant, we use the Pythagorean Theorem and inverse tangent. And our answer is 62 newtons, 22 degrees, north of east.

Instructor
Let’s take composition of forces one step farther. This time let’s concentrate on forces acting on a lightweight ring. Its weight will be negligible in this demonstration. We’ll hang it from a string attached to a spring scale and then hang a 5 newton weight on it. What is the tension on the string?

It’s 5 newtons. That shouldn’t surprise you because you know the string is transmitting the force to the support above it. There’s lots of action-reaction going on here, but let’s concentrate on the ring. Since the ring is not moving, what is the net force on it?

I hope you said zero. Now let’s look at a free-body diagram of the forces acting on the ring. You can see that the upward tension force equals the downward one, so the net force on the object is zero. We say that the object is in a state of equilibrium.

(green chalkboard on screen)
VO
When all concurrent forces acting on an object cancel out and the net force equals zero, the object is in a state of equilibrium.

Instructor
Watch the spring scale as I lift the ring by the string uniformly. The tension reads 5 newtons, the same as when the ring was motionless. Now watch as we lower the ring uniformly. Same thing, right? You may have noticed the needle jerking when we first started the object moving or when we stopped it. Both of those cases were examples of accelerated motion, and that requires a net force in the direction of the acceleration. But as long as the ring is moving uniformly, the net force on it is zero and the object is in a state of equilibrium.

(green chalkboard on screen)
VO
An object in a state of equilibrium can be at rest or in uniform motion.

Instructor
An object with several forces acting on it can still be in equilibrium. Look at the picture of the child on the swing again. Can you see that the swing is in a state of equilibrium? If it’s moving uniformly
or staying still, the net force is zero. Let’s examine the situation like this.

(drawing on screen)

VO
What if the chain snaps suddenly? Now remember that we’re just pretending here for the sake of science. We’ll freeze time so that no harm will come to the boy. Now there are only two forces acting on the swing, the weight of the boy downward and the outward push. How do we find the net force? Exactly like before.

We draw a parallelogram and draw the resultant from the point of application, the big dot. When we unfreeze time, the swing will accelerate in the direction of this resultant force if nothing intervenes. How can we establish equilibrium in this situation to keep the swing from accelerating in this direction?

(drawing on screen)

VO
When we drew the resultant of our concurrent forces, we replaced the two forces with one force that would have the same effect. That’s what a resultant is. So to put our object in a state of equilibrium, we just need to cancel out this force. We need one that is equal in magnitude and in the opposite direction, like so. This is called the equilibrant force.

(green chalkboard on screen)

VO
An equilibrant force is one force that will put an object in a state of equilibrium.

It is equal in magnitude and opposite in direction to the resultant of all concurrent forces acting on the object.

(drawing on screen)

Let’s say that the magnitude of our resultant force is 8.3 newtons. The magnitude of the equilibrant force will be 8.3 N. The direction of the resultant is 27 degrees east of south. What will be the direction of the equilibrant force? Here’s theta for this vector. If you remember your geometry, you know that these angles are called vertical angles and are equal. So the direction is 27 degrees, but this time it’s west of north. The opposite of east of south is west of north.

Instructor
Don’t make the mistake that many physics surfers make by saying that the opposite of north of east would be east of north. They just reverse the order. This is east of north, and you can see that it’s not opposite.

The opposite of north of east is south of west. Got it?

In a moment, your teacher will pause the tape and give you time to look at the three composition of forces problems we solved earlier. We found the resultant in each problem. I want you to find the equilibrant force for each. Come back when you’ve finished and we’ll go over the answers.

(Pause Tape Now graphic)

VO
The resultant of problem one was 51 newtons, south. So the equilibrant force is 51 newtons, north.
In number two, the resultant is 95 newtons, 35 degrees west of south. The equilibrant will have the same magnitude, 95 newtons. The angle will be the same, also, but the direction will be opposite. So the direction is 35 degrees, east of north.

For number three, the equilibrant is 62 newtons, 22 degrees south of west.

*Vo*(text on screen)

**VO**
To make sure you understand, try this problem from beginning to end. Your teacher will pause the tape and put it on the board or overhead. Come back when you’re finished.

Local Teachers: Turn off tape and give students problem set number three from facilitator’s guide.

*(Pause Tape Now graphic)*

**VO**
The first thing we do is simplify our vectors and get down to two. This gives us 17 newtons north and 87 newtons, west. We draw a force diagram and use Pythagorean Theorem and inverse tangent to find the magnitude and direction of the resultant. We get 89 newtons, 11 degrees north of west. But that’s not our answer. We were asked to find the equilibrant force. All we need to do is change the direction. Our answer is 89 newtons, 11 degrees south of east.

Depending on how you did on this problem, your local teacher may want to stop the tape now and give you some more practice on composition of force problems. When you’re ready, come back and we’ll move on to the second type of force problem. We’ll introduce it today and continue working problems in Part One of the next program.

*(Pause Tape Now graphic)*

**Instructor**
Our next type of force problem is resolution of forces. Think about resolving a complex conflict. You have to break it down into simpler parts. That’s what we do when we resolve a force.

*(green chalkboard on screen)*

**VO**
In resolution of forces problems, we find the components of a force, usually one that is acting at an angle.

The most common component forces are vertical, labeled “F sub y,” and horizontal, labeled “F sub x.”

*(picture of sled on screen)*

**VO**
In this picture, the sled is being pulled at an angle. The force applied to the sled through the tension in the rope can be resolved into two components. Watch how it’s done.

It’s helpful to use dotted lines to start a box around the arrowhead end of the vector. This will help us draw our components the proper lengths. Start both components from the big dot, which is the point of application of the force.
This is the vertical component. It is the part of the force that lifts the sled. We label it “F sub y.”

This is the horizontal component, labeled “F sub x.” It’s the part of the force that pulls the sled across the surface.

**Instructor**

In solving future problems, you’ll find that you often need to know these particular components. Let’s get some practice in drawing vertical and horizontal components. When this program is over, your teacher will give you this set of five force vectors. Each vector arrow is the same length but the directions are different. Draw the horizontal and vertical components of each vector, where possible. Start each component at the big dot and make sure that the parallelogram looks like a box. Local teachers, this will be problem set number four from your facilitator's guide.

I’ll start our next program by asking you some questions based on your diagrams, and then we’ll work some resolution of force problems. And we’ll apply what you learn to some practical situations, like explaining why it’s more efficient for the shortest teenager in the family to push the lawn mower. If you’re not the shortest, you should like that. See you next time.