# Physics 23 <br> Chapter 4 Part Two 

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Tension, Friction


## Example:

Given that the pull by the string on Block A is 300 N , what is the pull by the string on Block B?


Recall the point made earlier: Whatever is the pull by one end of a string, the same pull is exerted by the other end:

Therefore, the pull by the string on Block B is 300 N.

What is the tension in the string?
The tension in a string is whatever is the pull exerted by each end of the string. In this case, the pulls are 300 N , so, by definition,

$$
\mathrm{T}=300 \mathrm{~N}
$$

| Example: |  |
| :--- | :--- |
| An object weighing 500 N is hanging at <br> the end of a string. <br> What is the tension in the string? <br> Block is at rest, so the pull up by the <br> string equals the pull down by Earth: <br> 500 N |  |
| Answer: Whatever force one end of a <br> string exerts on whatever is at that end, <br> that force is the tension in the string. <br> Therefore, $\mathrm{T}=500 \mathrm{~N}$. |  |
| The other end of the string exerts a force <br> of 500 N on the ceiling, the same as the <br> pull the other end of the string exerts, as <br> expected. | Poull by Earth <br> on block <br> on ceiling block string |

## Example:

(a) What is the acceleration of the blocks in the figure below?


Same as:
12.0 kg

$\mathrm{a}=36 \mathrm{~N} / 12 \mathrm{~kg}$
$=3 \mathrm{~m} / \mathrm{s}^{2}$
(a) What is the tension in the string?

$\begin{aligned} 36-\mathrm{T} & =8.0(3) \\ \mathrm{T} & =12.0 \mathrm{~N}\end{aligned}$
(b) What are the pulls exerted by each end of the string?

The tension in a string is the force each end of the string exerts on whatever is at the ends. Therefore, the pulls by the string at each end is 12.0 N .


| (\%)(\%) | Video Lecture: Equilibrium with Three Forces Problem |
| :---: | :---: |

Example:

The traffic signal lightbox weighing 117.6 N is shown in Figure 1. It is suspended from two wires, as indicated. What are the tensions A and B in the wires?

Simplifying, we imagine an object of the same mass located at the origin of an $x-y$ coordinate system, and subject to the three forces, A, B, and C.

The lightbox is not accelerating along the x axis, so the sum of the forces' $x$-components is zero:

$$
\begin{align*}
& A_{x}+B_{x}+C_{x}=0 \\
& -\mathrm{A} \cos 37+\mathrm{B} \cos 53+0=0 \tag{1}
\end{align*}
$$

The lightbox is not accelerating along the $y$ axis, so the sum of the forces' y-components is likewise zero:

$$
\begin{align*}
& A_{y}+B_{y}+C_{y}=0 \\
& A \sin 37+B \sin 53-117.6=0 \tag{2}
\end{align*}
$$

Solving the two equations numbered above for the two unknowns, A and B , we get
$\mathrm{A}=70.77 \mathrm{~N}$
$\mathrm{B}=93.92 \mathrm{~N}$

## Example:

A carnival "strongman" on a stage faces his audience sat the front of a stage. A rubber ring (mass $m$ ) attached to the center of a long rope is held in his teeth.

He tosses the ends of the rope to widely-separated burly men in the front row and challenges them to pull him off the stage. They each pull with a $200-\mathrm{lb}$ force. The angle that each pull vector make with respect to the front of the stage is $5^{\circ}$.

What pulling force P must the strongman's jaw apply to the ring for the him to remain unmoved?

The figure below is looking downward from above at the stage below. The +y -axis points toward the audience.


We need $\mathrm{F}_{\mathrm{y}}$ to be zero, otherwise the strongman would be pulled off the stage:
$0=A_{y}+B_{y}+P_{y}$
$=200 \sin 5^{\circ}+200 \sin 5-\mathrm{P}$
$\mathrm{P}=35 \mathrm{lbs}$

## Static Friction

The figure shows a block on a tabletop. A force $\mathbf{P}$ attempts to pull the block to the right, but a counter-acting frictional force $\mathbf{f}$ prevents the block from moving.

The block remains stationary; the frictional force is called the "static" friction.

As the pulling force P is increased, the static friction likewise increases to match the pull, and the block remains stationary.

At a certain point, the pulling force "wins," and the block begins to accelerate. Just prior to that moment, the frictional force had grown to its maximum possible value, which depends on the roughness of the two surfaces in contact, and on the weight of the block.


The maximum frictional force that the tabletop can exert on the block depends on a "roughness" parameter called, "the coefficient of static friction," symbolized " $\mu_{\mathrm{s}}$," and the contact force C between the tabletop and the block.

$$
\text { Max Friction }=\mu_{\mathrm{s}} \mathrm{C}
$$

## Example:

A block weighing 200 N rests on a tabletop. The coefficient of static friction for the surfaces is $\mu_{\mathrm{s}}=0.20$.
(a) What is the largest static friction forcing the tabletop can exert without the block sliding?

Max Friction $=0.20(200 \mathrm{~N})$

$$
=40 \mathrm{~N}
$$

(b) What is the largest pulling force that could be applied without the block sliding?

Answer: 40 N

## Kinetic Friction

The figure at the right shows a block sliding on a tabletop. This is not a "static" situation here, as was the case in the recent work above.

When an object is sliding over a surface, the friction that the surface exerts on the object is called "kinetic" friction. Unlike static friction, there is no maximum kinetic friction: kinetic frictional force is always the same.

The property of surfaces that relate to roughness during sliding is called "the coefficient of kinetic friction," $\mu_{\mathrm{k}}$. The equation below shows how to calculate the kinetic friction.

$$
\mathrm{f}_{\mathrm{k}}=\mu_{\mathrm{K}} \mathrm{C}
$$



Example:
On a tabletop is sliding a $400-\mathrm{N}$ block. The coefficient of kinetic friction is 0.15 . What is the kinetic friction?

The contact force equals the block's weight:

$$
\begin{aligned}
\mathrm{C} & =400 \mathrm{~N} \\
\mathrm{f}_{\mathrm{k}} & =0.15(400 \mathrm{~N}) \\
& =60 \mathrm{~N}
\end{aligned}
$$

| (\%)(\%) | Video Lecture: Static Friction Problem |
| :---: | :--- |


| Example: | Solution: |
| :---: | :---: |
| The coefficient of static friction between the crate and the ground in the figure below is 0.15 . <br> What must be the tension in the rope in order to cause the crate to move? <br> In a previous example the contact force was the weight of the crate, $\mathrm{C}=\mathrm{mg}$. In the case we now consider, the contact force will not be the weight mg of the crate. It will be less. <br> The solution to this problem is at the right. | When the crate is on the verge of sliding, static friction will have risen to its maximum-possible value: $\begin{aligned} \mathrm{f} & =\mu_{\mathrm{s}} \mathrm{C} \\ & =0.15 \mathrm{C} \end{aligned}$ <br> Not yet moving: $a_{x}=0$ $\mathrm{F}_{\mathrm{x}}=\max _{\mathrm{x}}$ $\mathrm{T}_{\mathrm{x}}+\mathrm{C}_{\mathrm{x}}+\mathrm{f}_{\mathrm{x}}+\mathrm{w}_{\mathrm{x}}=0$ <br> $\mathrm{T} \cos 30+0-0.15 \mathrm{C}+0=0$ <br> $\mathrm{T}=0.1732 \mathrm{C} \quad$ (Equation 1) <br> Not accelerating vertically: $a_{y}=0$ $\mathrm{F}_{\mathrm{y}}=\mathrm{ma}_{\mathrm{y}}$ $\mathrm{T}_{\mathrm{y}}+\mathrm{C}_{\mathrm{y}}+\mathrm{f}_{\mathrm{y}}+\mathrm{w}_{\mathrm{y}}=0$ <br> $\mathrm{T} \sin 30+\mathrm{C}+0-50(9.8)=0$ <br> $\mathrm{C}=490-0.5 \mathrm{~T} \quad$ (Equation 2) <br> Substitute C into Equation 1: $\mathrm{T}=0.1732(490-0.5 \mathrm{~T})$ <br> Solve for T: $\mathrm{T}=78.10 \mathrm{~N}$ |

