Building an Interest in Physics using TinkerCad!

Oregon State University

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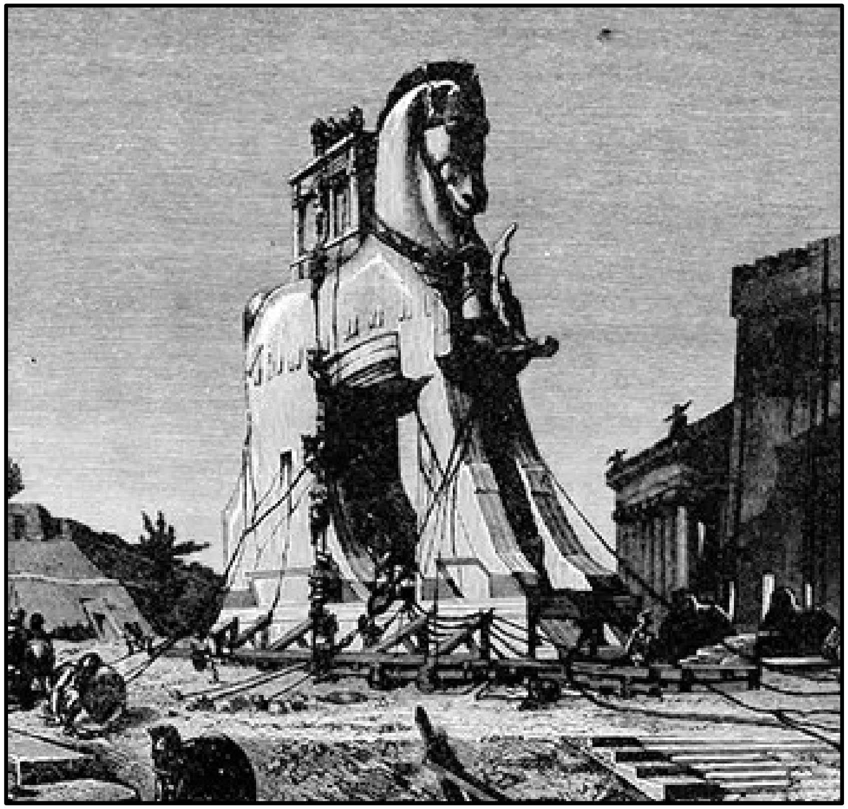
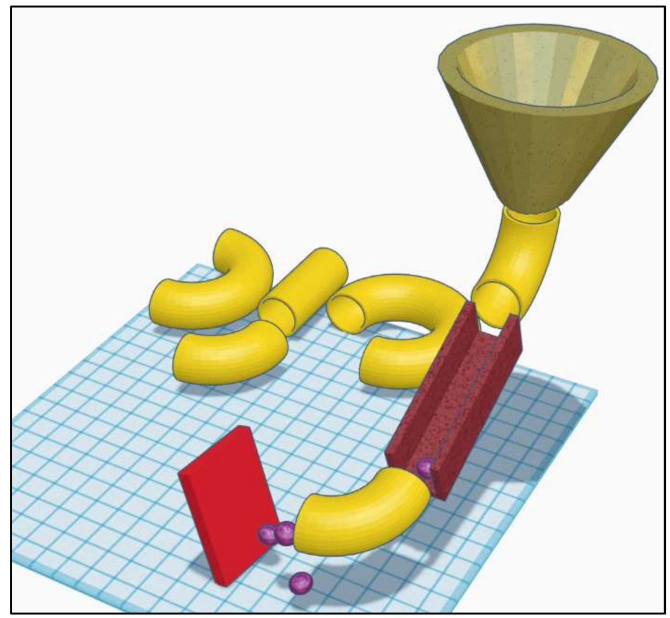
Trojan Horse Education

"Come for the cool animation, stay for the physics."



https://www.historyforkids.net/trojan-horse.html



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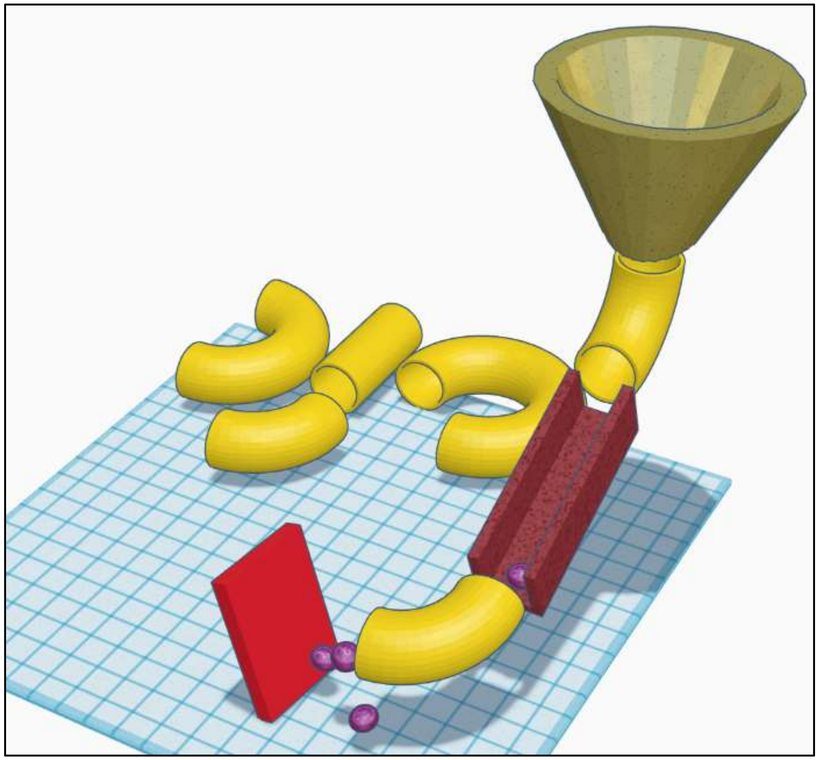
Why Are We Talking About This?

TinkerCad has always had a 3D Design Mode. Just recently, they added a Physics Mode they call **"SimLab".**

When you are in this mode of operation, TinkerCad objects can fall under the influence of gravity. They can collide with each other, slide along surfaces, and roll through tubes.



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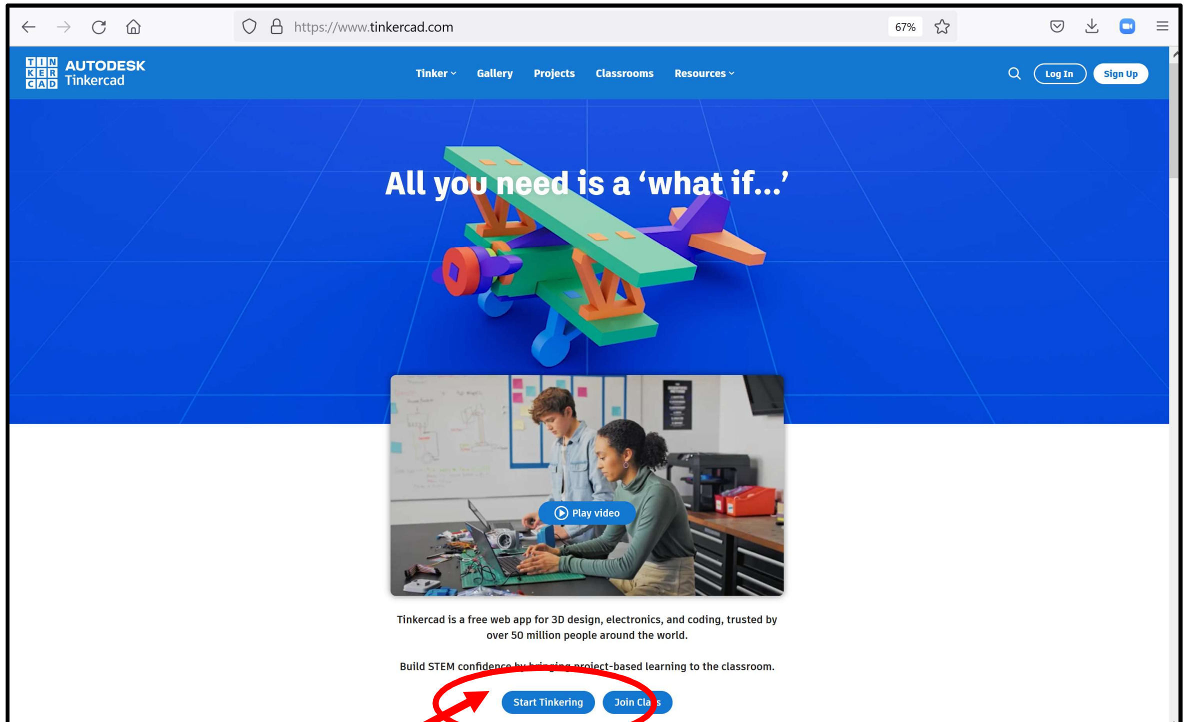
Getting Started

TinkerCad is a free web-based CAD package from AutoDesk It is a solid modeler, so you always have legal 3D objects suitable for 3D Printing You get to it at: **http://www.tinkercad.com/**

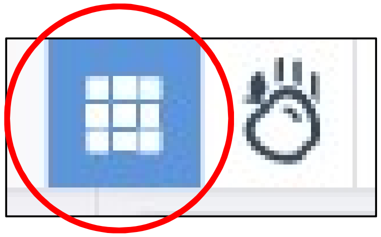
Even though *any* browser *should* work, TinkerCad seems to work best with **Google Chrome**



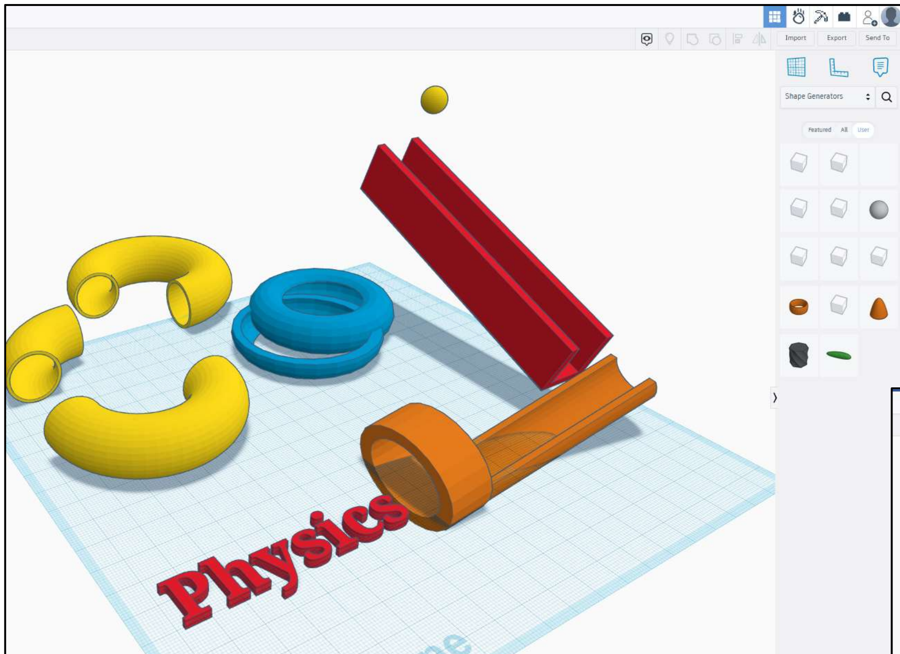
Click here to start

Thanks to Autodesk for developing TinkerCad and keeping it free!

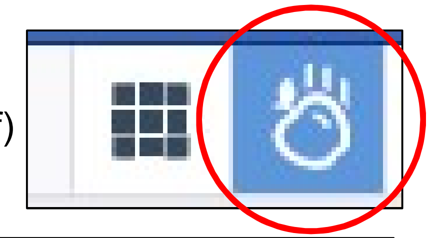
Design Mode vs. Physics Mode

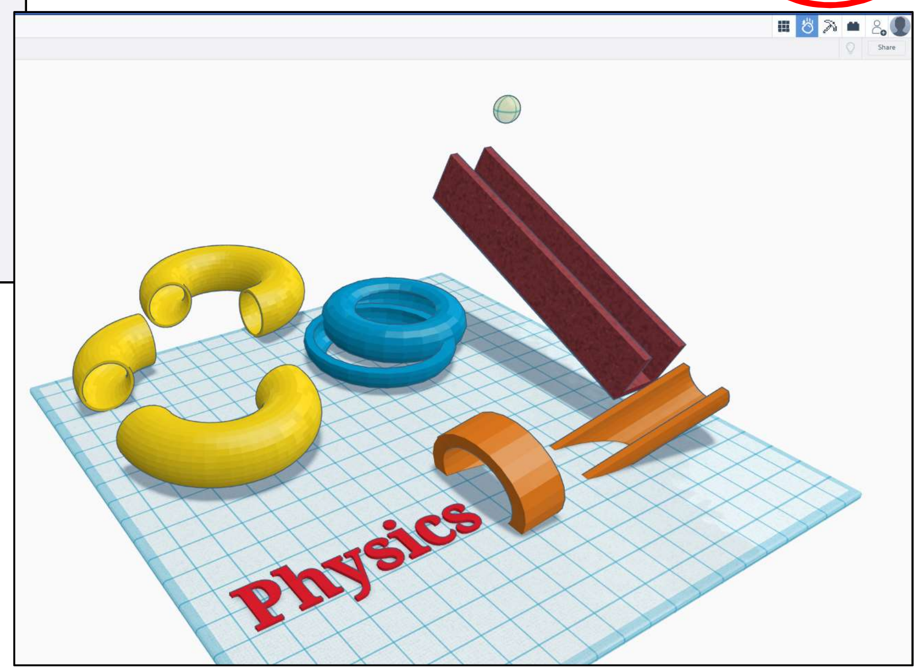


Design Mode (what you're used to)



Physics Mode (new stuff)

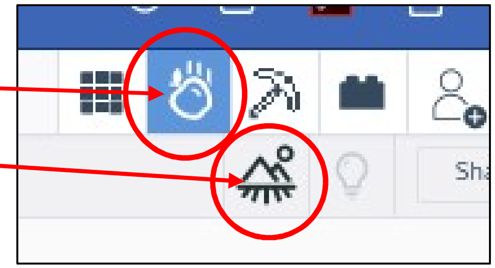


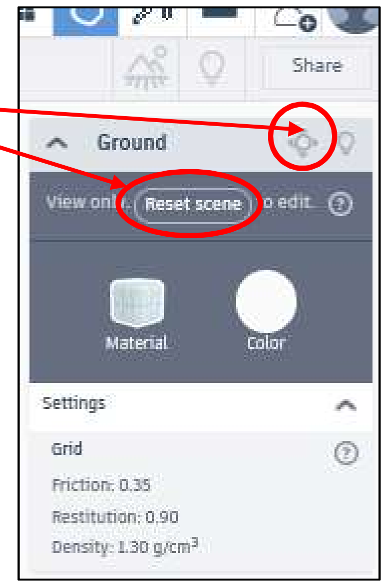


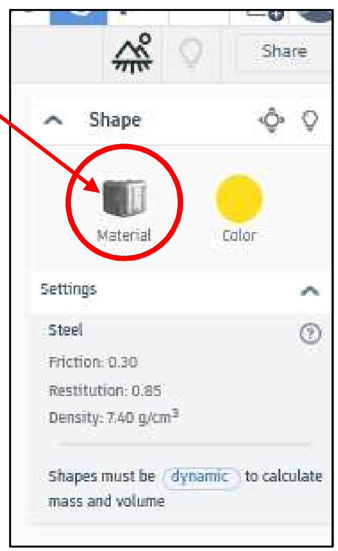
BTW, this icon is a falling Newton's apple, in case you don't recognize it. I didn't. ☺

The Steps

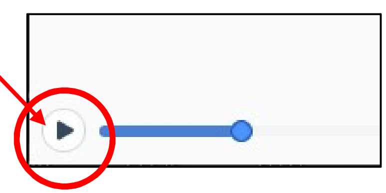
1. Build a model as usual, keeping in mind what sort of motion you are going to want these objects to have.
2. Switch to **Physics Mode**.
3. Open up the **Scene Settings**.
4. Click on **Reset Scene**.
5. By default, all objects start out as "Dynamic", meaning that they will start falling when gravity is turned on. But, some objects need to be "Static" so that they can collide with other objects but do not start falling themselves. Select an object and then click here to toggle between Dynamic and Static.
6. Objects can be made of different materials. Select an object and click here to change its material. Look ahead in these notes to see what kind of physics properties each material has.







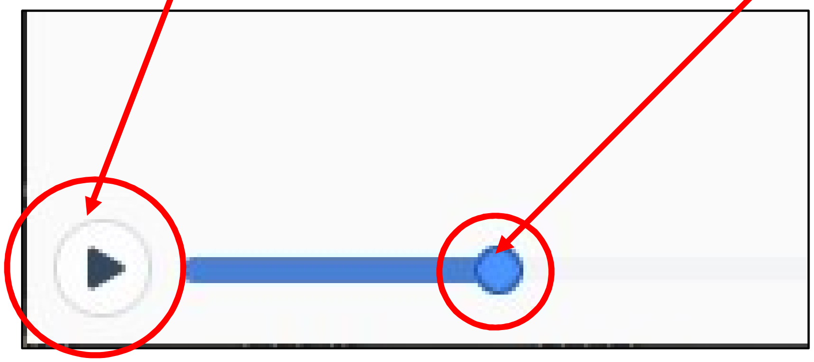
7. Click here to start the simulation.



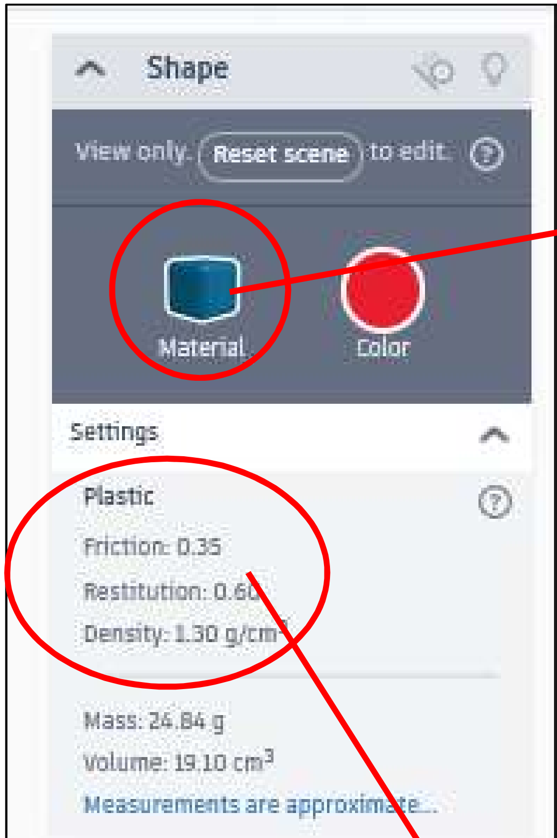
Click in the Lower-Left Corner to Start the Physics Animation

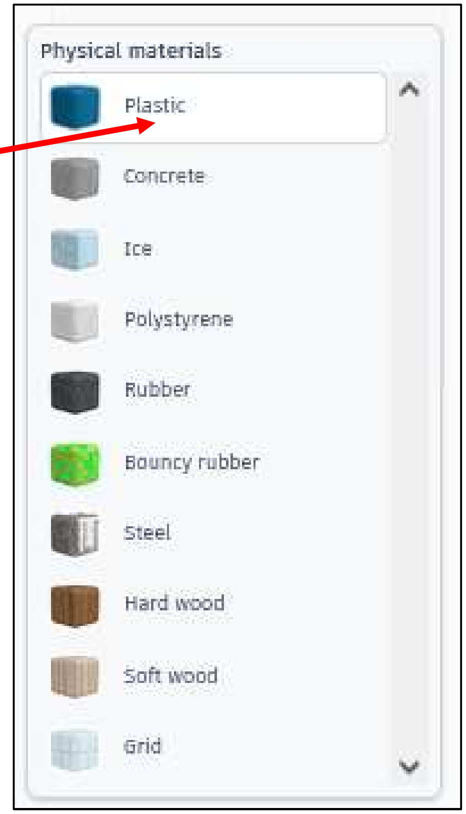
8. If you pause the animation, you can manually "scrub" the animation back and forth with this knob

7. Click here to start the simulation



Click on an Object in Physics Mode and Change its Material





Material	COF	COR	Density (g/cm^3)
Plastic	0.35	0.60	1.30
Concrete	0.65	0.75	2.30
Ice	0.30	0.75	0.92
Polystrene	0.50	0.50	0.08
Rubber	0.75	0.30	0.92
BouncyRubber	1.00	0.95	0.92
Steel	0.30	0.85	7.40
Hard Wood	0.40	0.70	0.68
Soft Wood	0.40	0.65	0.13
Grid	0.35	0.90	1.30

COF: Coefficient of Friction ("stickiness")
COR: Coefficient of Restitution ("bounciness")

Material Properties, Summarized and Sorted

TinkerCad Order	Material	COF	COR	Density (g/cm^3)
	Plastic	0.35	0.60	1.30
	Concrete	0.65	0.75	2.30
	Ice	0.30	0.75	0.92
	Polystrene	0.50	0.50	0.08
	Rubber	0.75	0.30	0.92
	BouncyRubber	1.00	0.95	0.92
	Steel	0.30	0.85	7.40
	Hard Wood	0.40	0.70	0.68
	Soft Wood	0.40	0.65	0.13
	Grid	0.35	0.90	1.30
By Material Name	**Material**	**COF**	**COR**	**Density (g/cm^3)**
	BouncyRubber	1.00	0.95	0.92
	Concrete	0.65	0.75	2.30
	Grid	0.35	0.90	1.30
	Hard Wood	0.40	0.70	0.68
	Ice	0.30	0.75	0.92
	Plastic	0.35	0.60	1.30
	Polystrene	0.50	0.50	0.08
	Rubber	0.75	0.30	0.92
	Soft Wood	0.40	0.65	0.13
	Steel	0.30	0.85	7.40
By COF	**Material**	**COF**	**COR**	**Density (g/cm^3)**
	Ice	0.30	0.75	0.92
	Steel	0.30	0.85	7.40
	Plastic	0.35	0.60	1.30
	Grid	0.35	0.90	1.30
	Hard Wood	0.40	0.70	0.68
	Soft Wood	0.40	0.65	0.13
	Polystrene	0.50	0.50	0.08
	Concrete	0.65	0.75	2.30
	Rubber	0.75	0.30	0.92
	BouncyRubber	1.00	0.95	0.92
By COR	**Material**	**COF**	**COR**	**Density (g/cm^3)**
	Rubber	0.75	0.30	0.92
	Polystrene	0.50	0.50	0.08
	Plastic	0.35	0.60	1.30
	Soft Wood	0.40	0.65	0.13
	Hard Wood	0.40	0.70	0.68
	Concrete	0.65	0.75	2.30
	Ice	0.30	0.75	0.92
	Steel	0.30	0.85	7.40
	Grid	0.35	0.90	1.30
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By Density	**Material**	**COF**	**COR**	**Density (g/cm^3)**
	Polystrene	0.50	0.50	0.08
	Soft Wood	0.40	0.65	0.13
	Hard Wood	0.40	0.70	0.68
	Ice	0.30	0.75	0.92
	Rubber	0.75	0.30	0.92
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	Concrete	0.65	0.75	2.30
	Steel	0.30	0.85	7.40

COF: Coefficient of Friction ("stickiness")
COR: Coefficient of Restitution ("bounciness")

As a Reference, Here are Some Other Coefficients of Friction

Materials		μ	
		Dry & clean	Lubricated
Aluminum	Steel	0.61	
Copper	Steel	0.53	
Brass	Steel	0.51	
Cast iron	Copper	1.05	
Cast iron	Zinc	0.85	
Concrete (wet)	Rubber	0.30	
Concrete (dry)	Rubber	1.0	
Concrete	Wood	0.62	
Copper	Glass	0.68	
Glass	Glass	0.94	
Metal	Wood	0.2–0.6	0.2 (wet)
Polythene	Steel	0.2	0.2
Steel	Steel	0.80	0.16
Steel	Teflon	0.04	0.04
Teflon	Teflon	0.04	0.04
Wood	Wood	0.25–0.5	0.2 (wet)

http://en.wikipedia.org/wiki/Friction

As a Reference, Here are Some Other Coefficients of Restitution

Balls Bounced on a Concrete Surface:

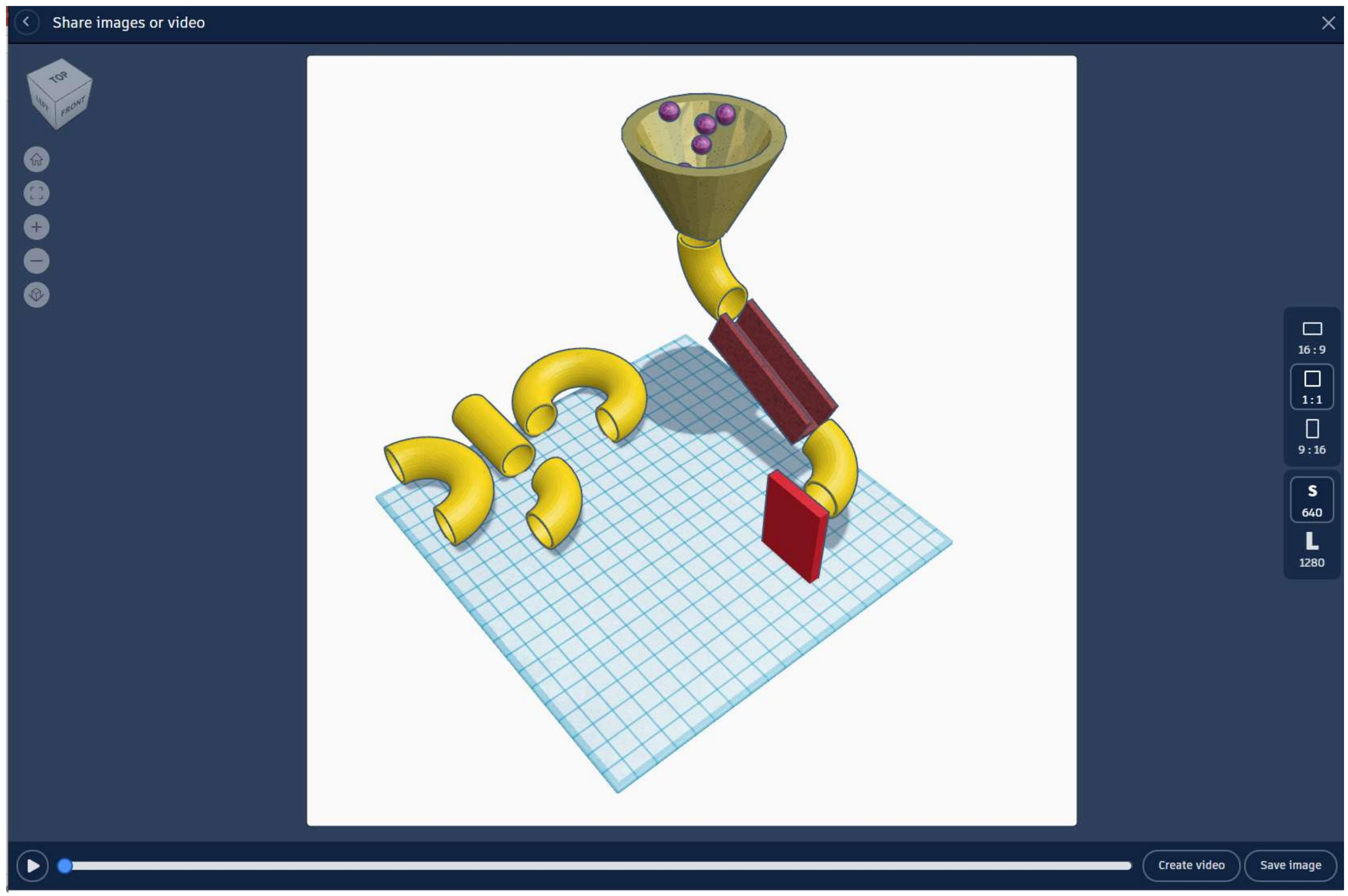
Ball Material	CoR
range golf ball	0.858
tennis ball	0.712
billiard ball	0.804
hand ball	0.752
wooden ball	0.603
steel ball bearing	0.597
glass marble	0.658
ball of rubber bands	0.828
hollow, hard plastic ball	0.688

http://hypertextbook.com/facts/2006/restitution.shtml

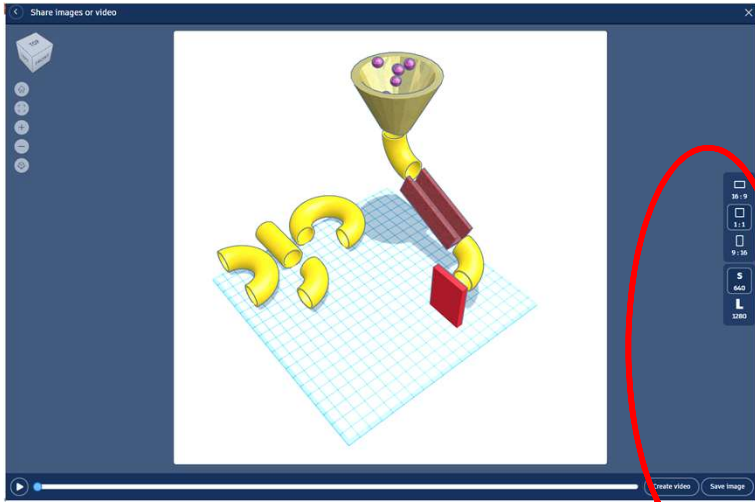
Sharing an Image or a Video

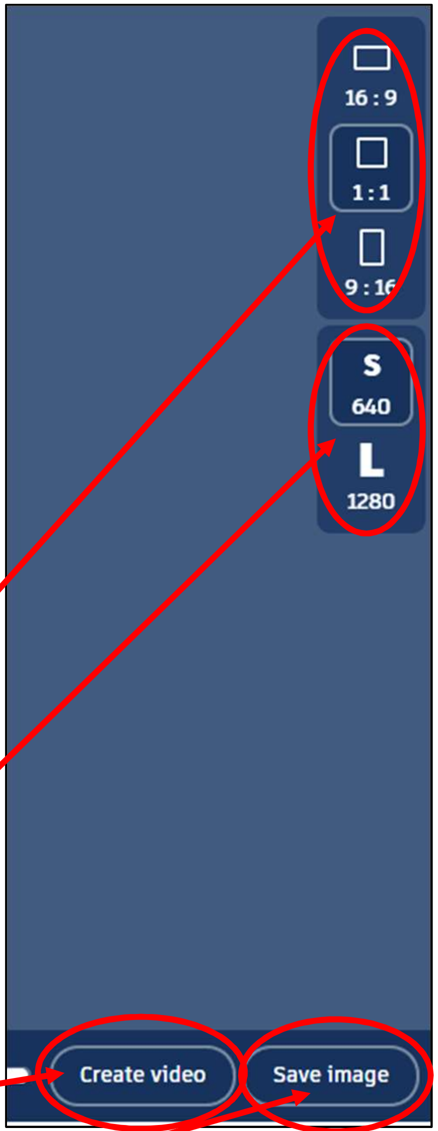
Click on the **Share** button

To reach this screen:



Sharing an Image or a Video





Aspect ratio (the one above is 1:1)

Low resolution vs. high resolution

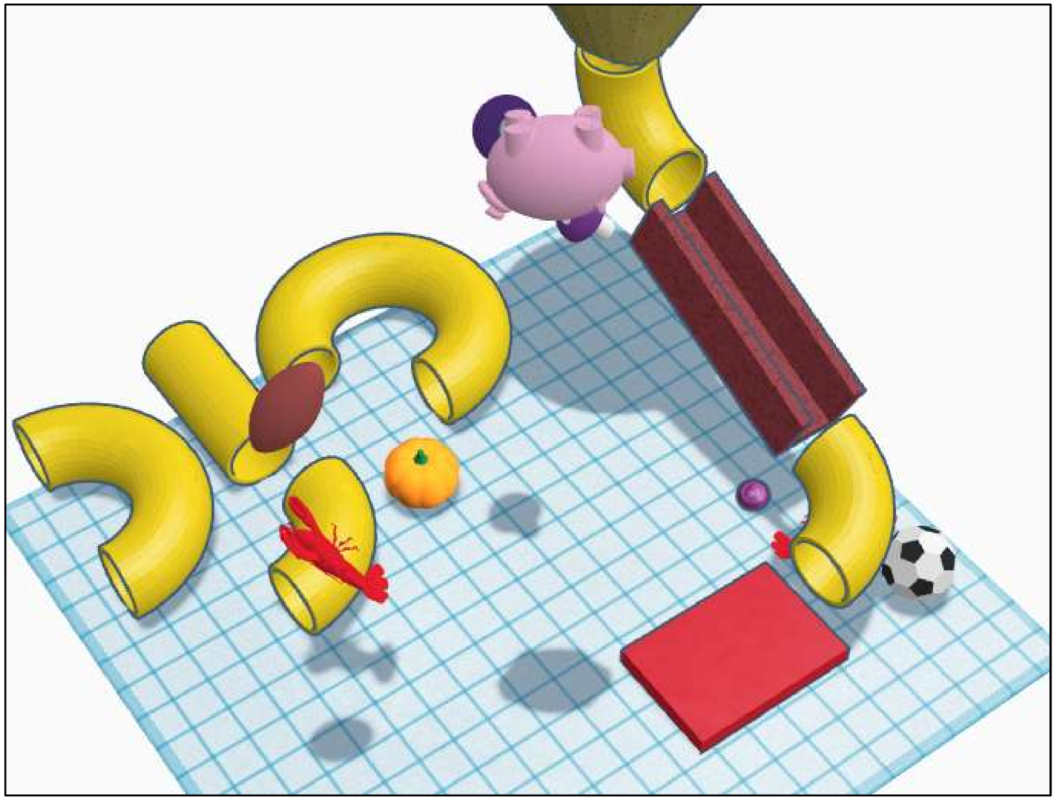
Create an MP4 video

Create a PNG image

Here's the video from the scene above:
http://cs.oregonstate.edu/~mjb/tinkercad/MikesObstacleCourse.mp4

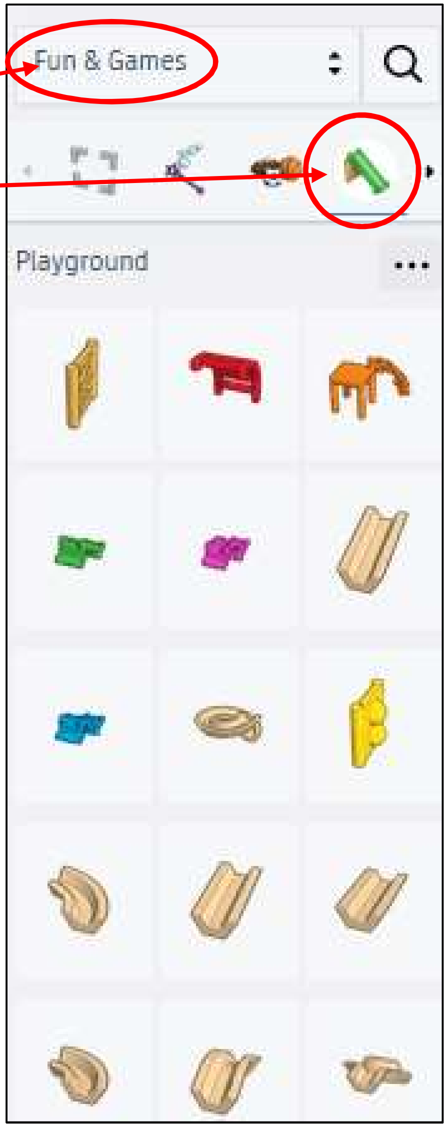
Throwing Stuff

Not sure why this feature is here, but I'm glad it is … ☺
First, select the **Reset button** to the right of the animation bar.
Second, while your animation is running, repeatedly click with the **left mouse button**.
TinkerCad will throw random 3D stuff into your scene.

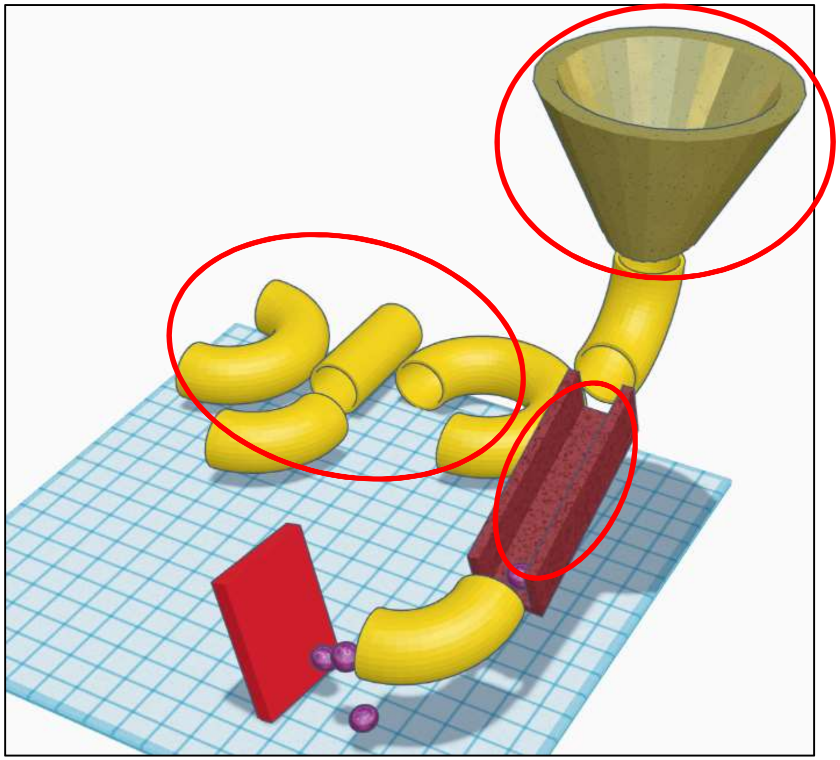


Hints on Building a Physics-Cool Scene

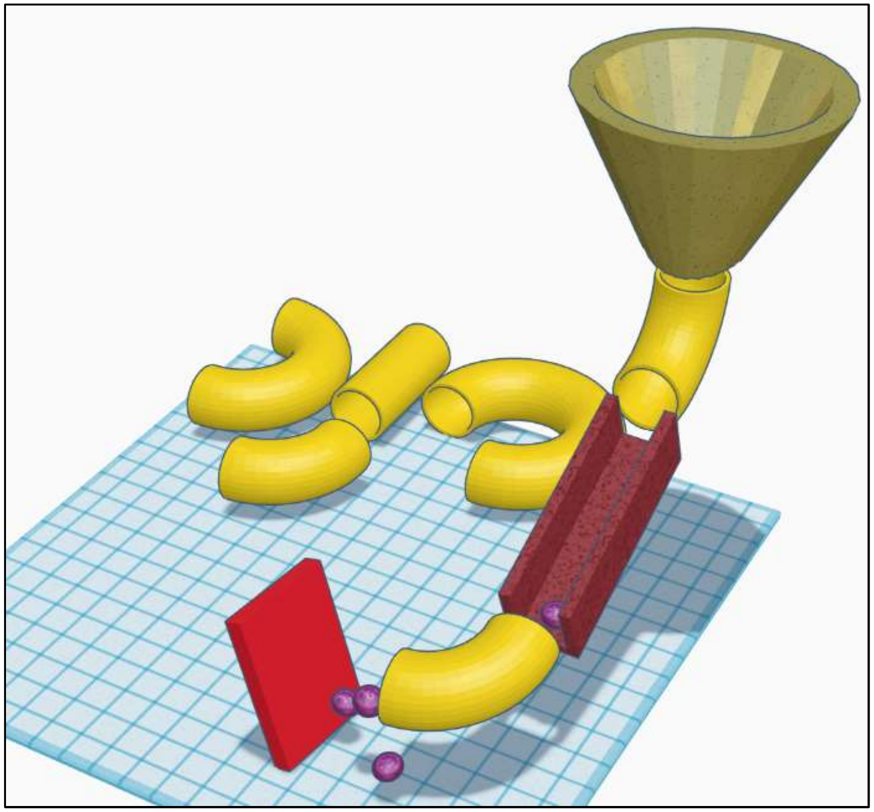
You can use *any* TinkerCad objects. But, there are some great ones under the **Fun & Games tab**. Then select the **Playground icon**.



Or you can build your own.



An Example of a Student Challenge



What can you find to change about the red "domino" such that it resists being tipped over? (height, width, depth, material, add supports, etc.)

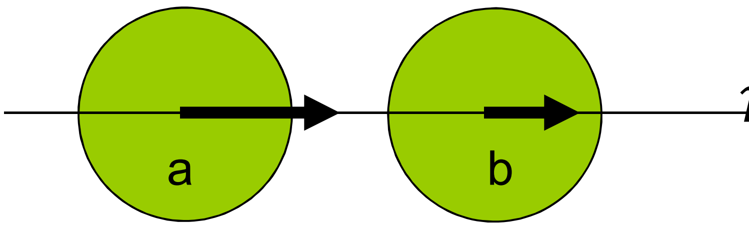
What can you find to change about the balls such that they tip the "domino" over more easily?

What happens if you add more "dominos" behind the first one?

What happens if the "domino" is something other than rectangular?

What's Really Going On:
The Physics of Collisions – Conservation of Momentum

In a collision, the total momentum after the impact is equal to the total momentum before the impact. Always.



$$m_a v_a + m_b v_b = m_a v'_a + m_b v'_b$$

where the primes ′ refer to velocities after the impact

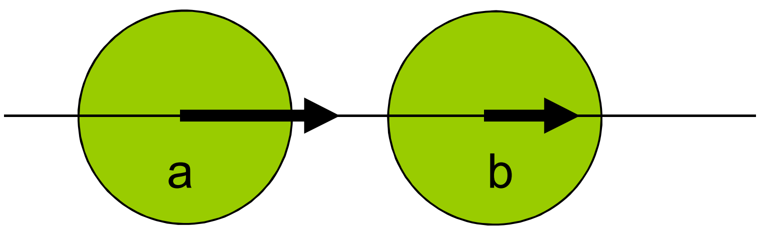
This is referred to as the ***Conservation of Momentum Law***

Momentum is ***always*** conserved through ***any*** collision

What's Really Going On:
The Physics of Collisions – Coefficient of Restitution

In a collision, energy is conserved in the *entire system*, but not necessarily in the form of velocities. (It can become heat, light, permanent deformation, etc.)

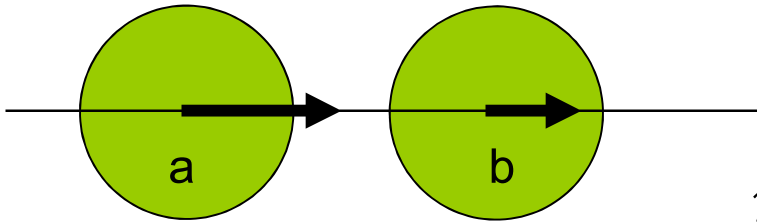
This loss of velocity is expressed as the ***Coefficient of Restitution*** (COR). The COR, e, is how much less the relative velocities of the objects are after impact than they were before impact:



$$v'_b - v'_a = -e(v_b - v_a)$$

(the negative sign is there to indicate the "bounce")

What's Really Going On: The Physics of Collisions – Combining Momentum and Restitution Laws



Starting with these two equations:

$$m_a v_a + m_b v_b = m_a v'_a + m_b v'_b$$

$$v'_b - v'_a = -e(v_b - v_a)$$

We then treat the two initial velocities as inputs and solve for the two resulting velocities. This gives:

$$v'_a = \frac{m_a v_a + m_b v_b + e m_b (v_b - v_a)}{m_a + m_b}$$

$$v'_b = \frac{m_a v_a + m_b v_b - e m_a (v_b - v_a)}{m_a + m_b}$$

What's Really Going On: The Physics of Collisions with Immoveable Objects

To treat the case of mass b being an *immoveable object*, such as the ground or a solid wall, treat b as if its mass was infinite. Then solve for the resulting velocities:

$$\lim_{m_b \to \infty} v'_a = \frac{m_a v_a + m_b v_b + e m_b (v_b - v_a)}{m_a + m_b}$$

$$= \lim_{m_b \to \infty} \left[\frac{m_a v_a}{m_a + m_b} + \frac{m_b v_b}{m_a + m_b} + \frac{e m_b (v_b - v_a)}{m_a + m_b} \right]$$

$$= [0 + v_b + e(v_b - v_a)]$$

Since mass b is immoveable, its velocity must be zero, so that a's post-collision velocity is:

$$v'_a = [0 + 0 + e(0 - v_a)] = -e v_a$$

What's Really Going On:
Collisions – Experimentally Determining the Coefficient of Restitution

Velocities are hard to measure live, but distances are not.

So, drop the object from a height ***h***, and measure its bounce to a height **h'** :

Energy before the bounce:

$$v^2 = 0^2 + 2gh$$

$$v = \sqrt{2gh}$$

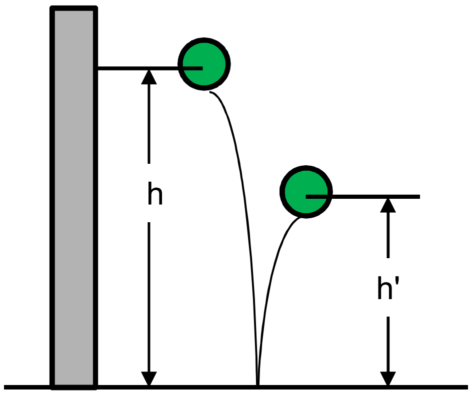
Energy after the bounce:

$$0^2 = v'^2 - 2gh'$$

$$v' = \sqrt{2gh'}$$

$$|v'| = e|v|$$

$$e = \frac{v'}{v} = \frac{\sqrt{2gh'}}{\sqrt{2gh}} = \sqrt{\frac{h'}{h}}$$

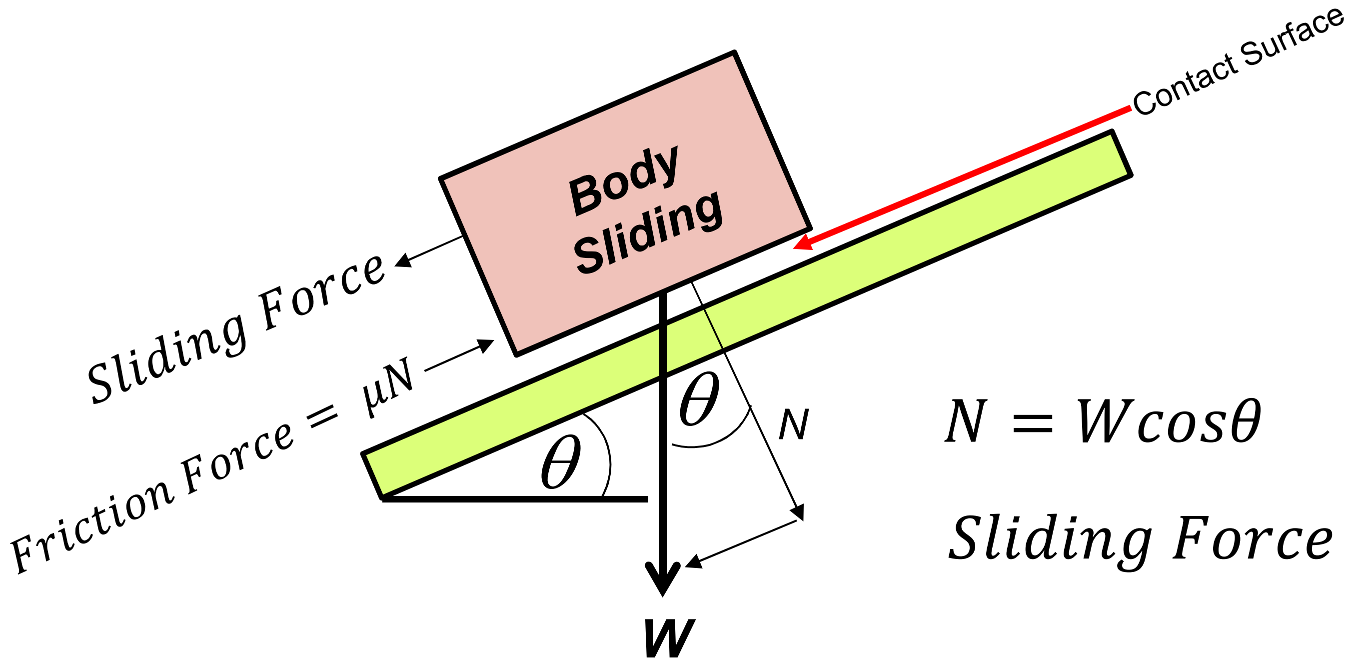


What's Really Going On: Friction Force

$$F_{friction} = \mu N$$

Normal force (i.e., amount of force that is perpendicular to the contact surface)

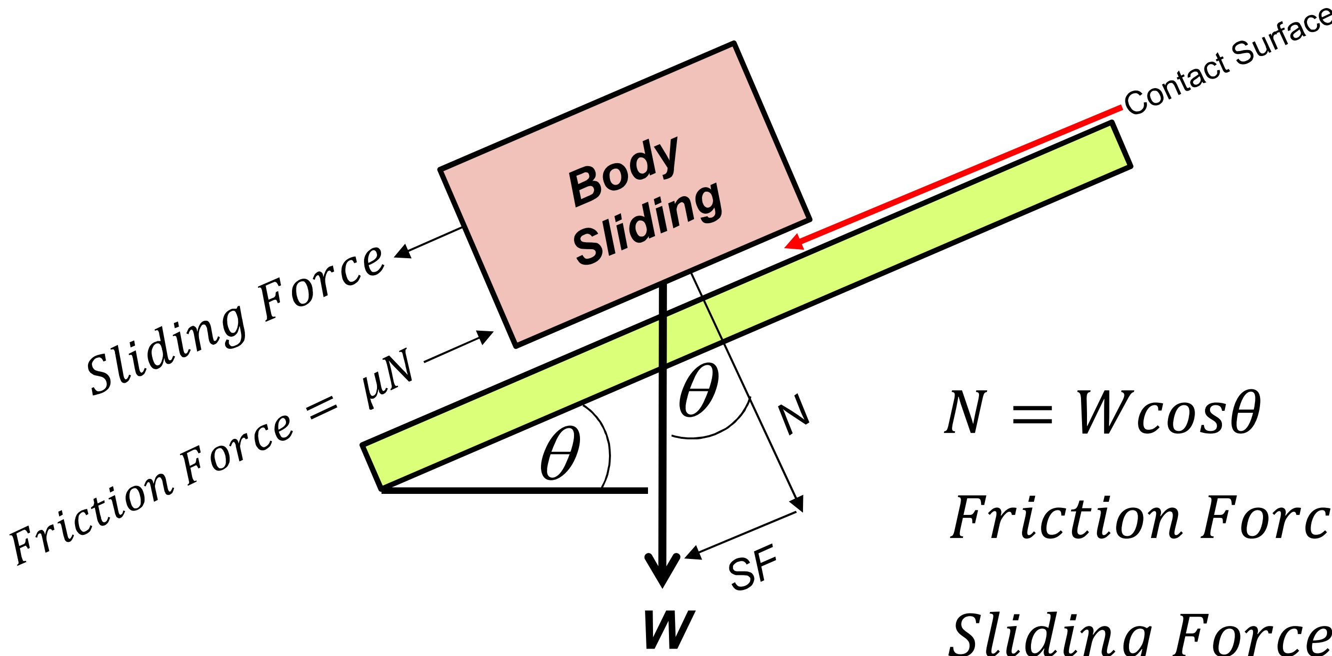
Coefficient of Friction



$$N = W\cos\theta$$

$$Sliding\ Force = W\sin\theta$$

What's Really Going On: Determining the Coefficient of Friction Experimentally



$$N = W\cos\theta$$

$$Friction\ Force = \mu W\cos\theta$$

$$Sliding\ Force = W\sin\theta$$

At what angle, Θ, does the block *just* begin to slide?
It begins to slide when the sliding force just equals the friction force:

$$W\sin\theta = \mu W\cos\theta$$

$$\mu = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

Thus, if you raise the board just enough that the block starts to slide, the coefficient of friction is the tangent of that angle.

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