Chapter 5

Our longest chapter!!!!

(Some material taken from McGraw-Hill/College Physics/Giambattista, the majority from your Katz textbook)

A **force** is something that one object (also just a “thing”) exerts (initiates/creates/implies/makes) on another object that attempts to alter its motion / make it move / make it stop moving / make it change direction / etc

Long-range forces do not require the two objects to be touching. For example, gravity is a long-range force. **(Can you think of other long-range forces?)**

We call the size of the gravitational force (also called the strength, or **magnitude**, of the force) that a planet or moon exerts on a nearby object the object's **weight**.

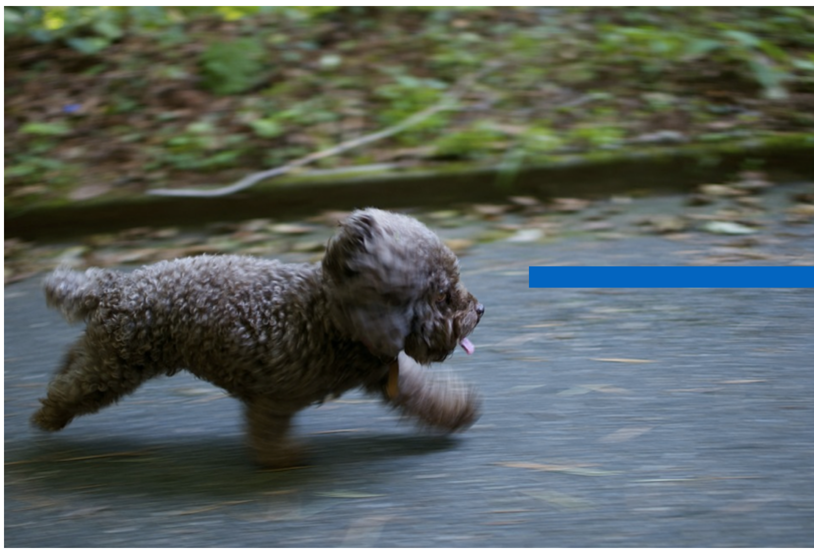
Sometimes ***mass*** and ***weight*** are used interchangeably. In physics, mass and weight are ***not*** interchangeable.

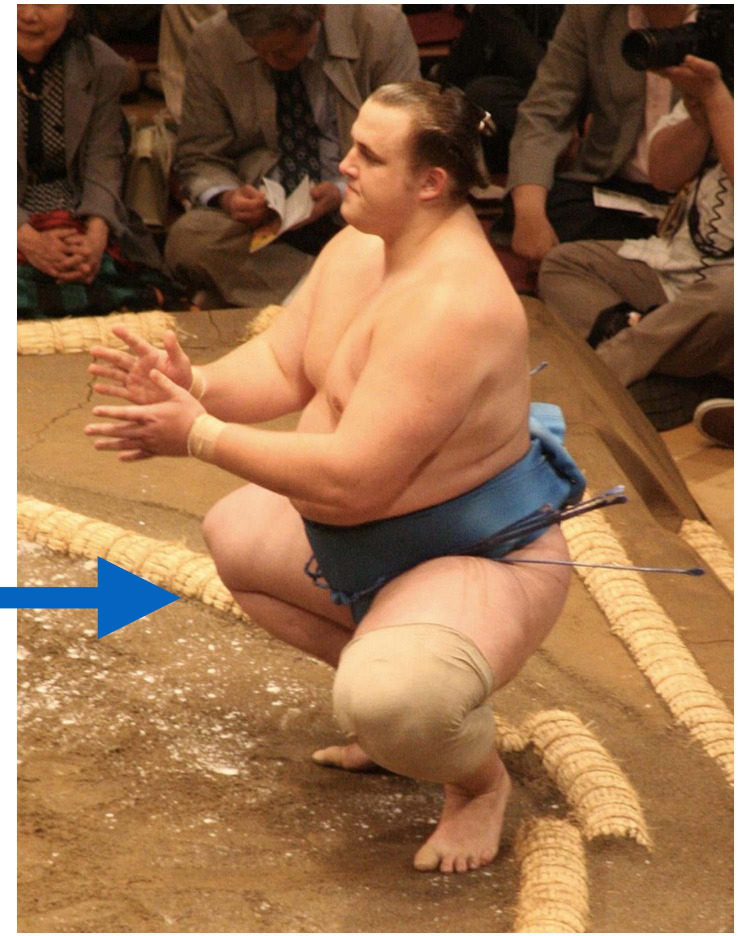
Mass is a measure of inertia—the tendency of an object at rest to remain at rest or, if moving, to continue moving with the same velocity.

Weight, on the other hand, is a measure of the gravitational pull on an object

When you see a problem involving mass and/or weight, first step back and check which one is given. We'll see that it's easy to convert between the two, but you need to make sure you use the right one at the right time

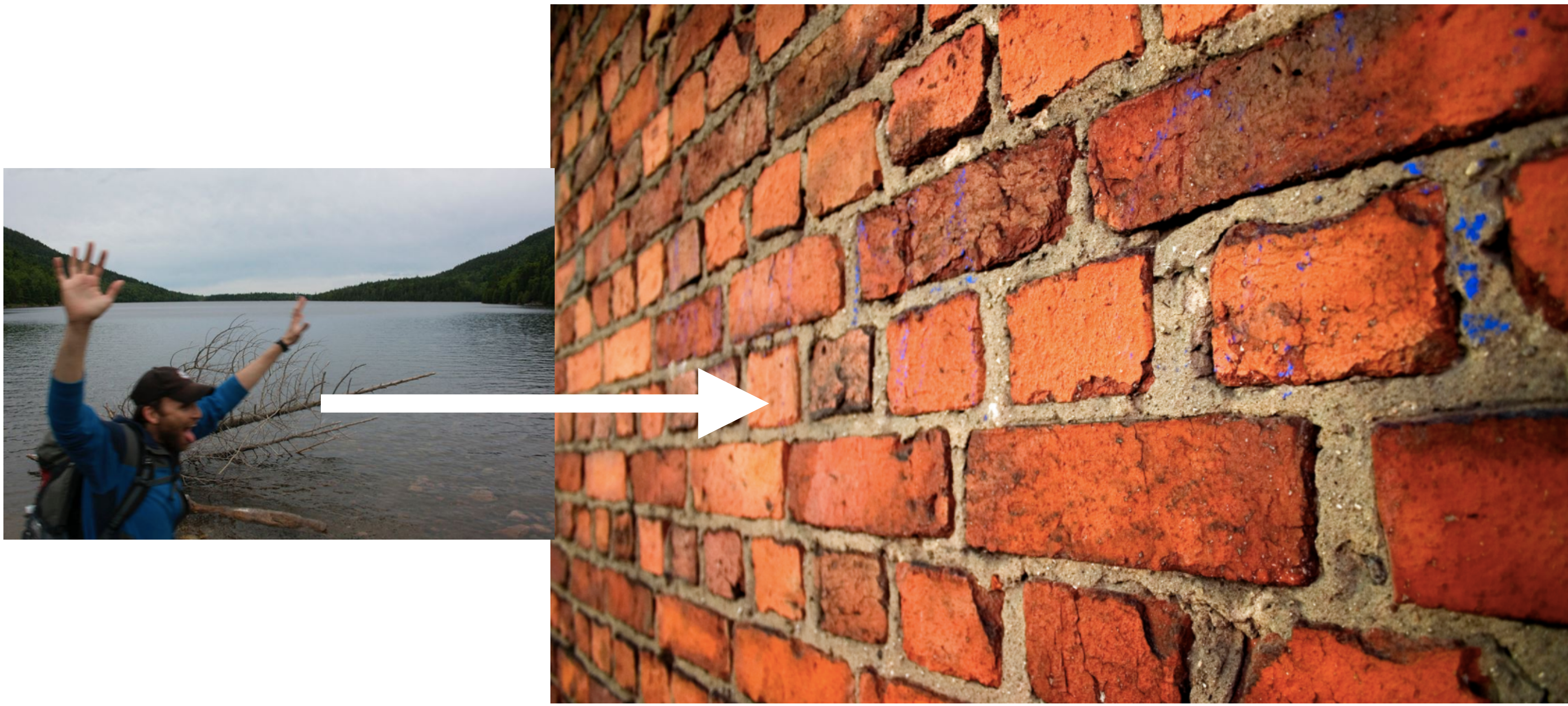
What happens when this small running dog with small mass (and thus small inertia)? hits a sumo wrestler, who has a large mass (and thus large inertia)?

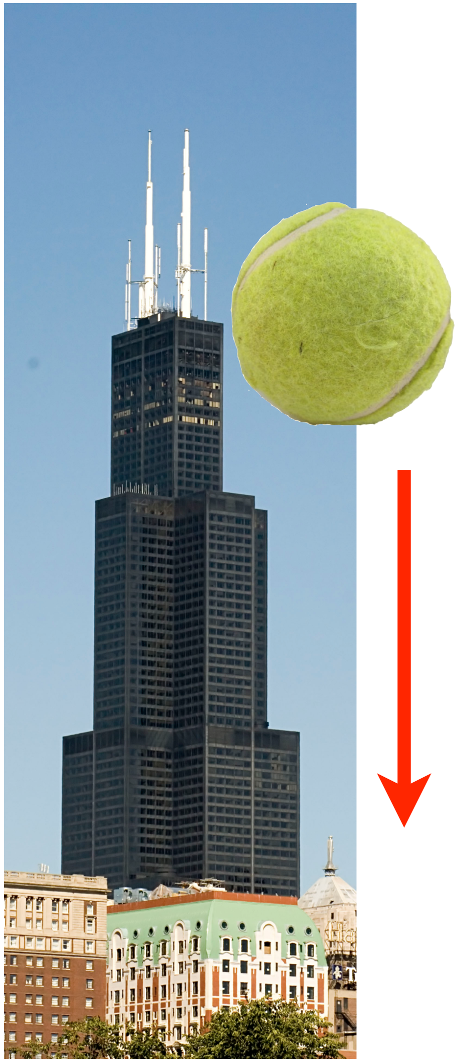




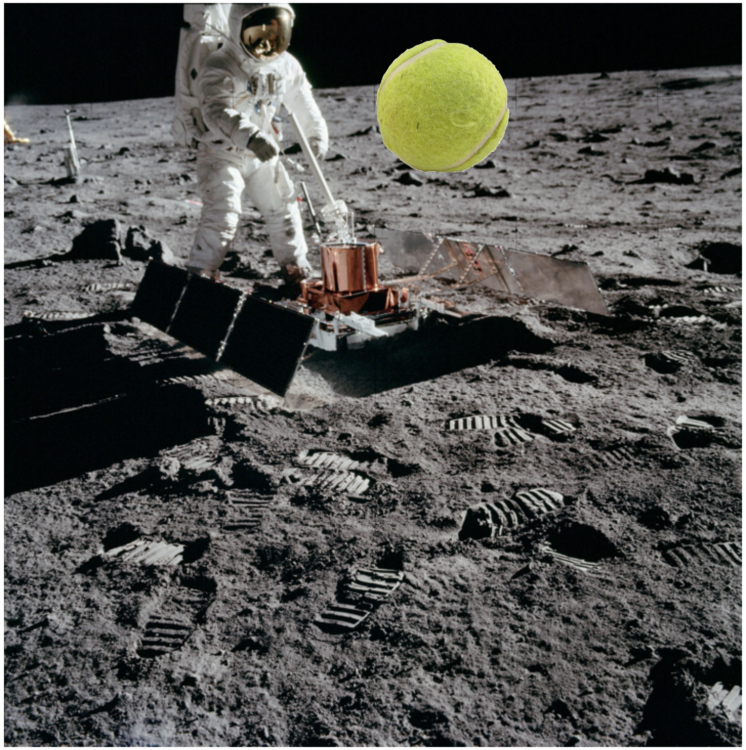
What happens when the wrecking ball (with large mass and inertia) runs into a brick wall?

What happens if I run into a brick wall instead?





If you drop a tennis ball from the Willis Tower, the weight tells us something about how much gravity pulls it down towards the earth



Tennis ball dropped on surface of the moon has the same mass but a different weight from the values on Earth (as we'll soon see)

In the United States, supermarket scales are generally calibrated to measure forces in pounds (lb).

In the SI system, the unit of force is the **newton** (N).

Don't worry about memorizing numbers like this

$$1\ \text{lb} = 4.448\ \text{N} \quad \text{or} \quad 1\ \text{N} = 0.2248\ \text{lb}$$

Note already something surprising if you hadn't already noticed - we use what you might think of as a "weight" as a **unit of force**!

Relationship between mass and weight: $W = mg$

In vector form: $\vec{\mathbf{W}} = m\vec{\mathbf{g}}$

Here $\vec{\mathbf{W}}$ stands for the gravitational force $\vec{\mathbf{g}}$ and is called the gravitational field; the direction of both is downward.

The italic (scalar) symbol *g* is the *magnitude* of a vector, so its value is *never negative.*

Average value of *g* near Earth's surface:

$$g = 9.80 \text{ N/kg}$$

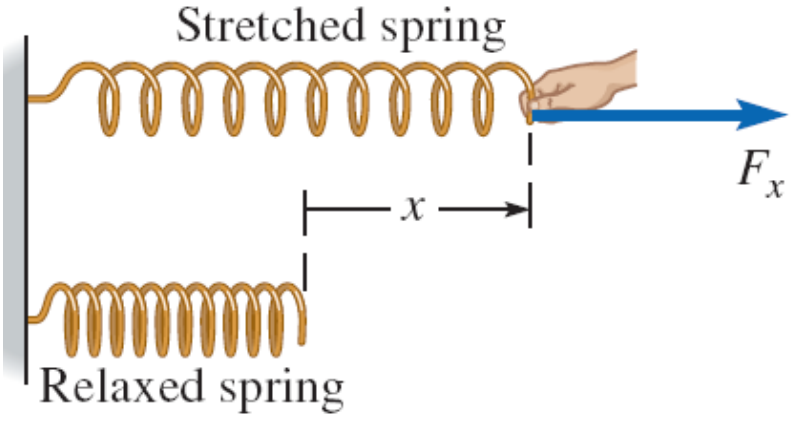
Direction of gravitational force

It is… 9.80 N / kg downward. What does that mean? Downward? What direction is that? Is that the same at different points on the Earth? If I walk across the room, does the gravitational force change?

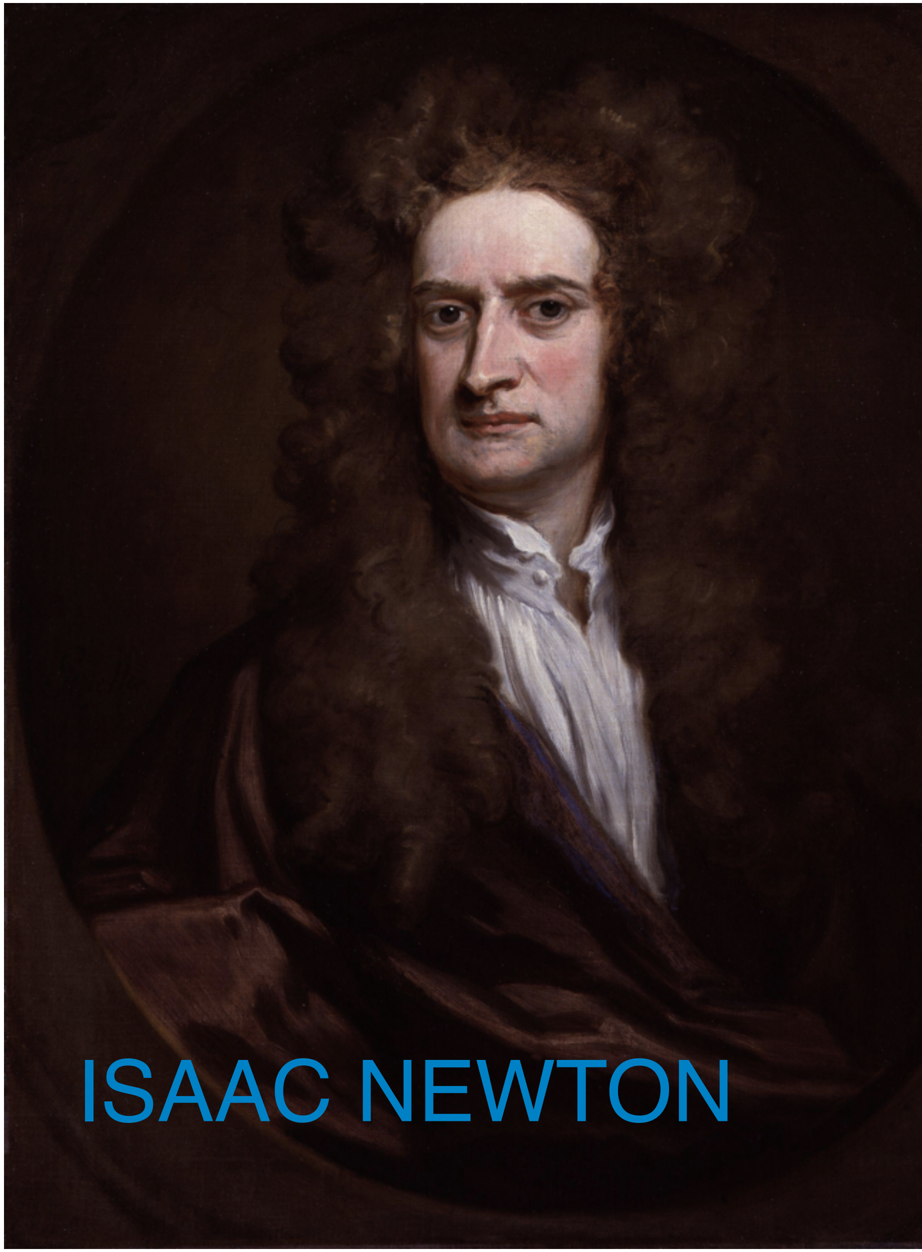
Hooke's Law and Ideal Springs

Robert Hooke (1635–1703) observed that, for many objects, the deformation— change in size or shape—of the object is proportional to the magnitude of the force that causes the deformation.

This observation, called **Hooke's law**, is an approximation and is valid only within limits.



PHYS253 Chapter 5



Newton to Hooke:

If I have seen further it is by standing on the shoulders of giants.”

Was he mocking Hooke?

Force Is a Vector Quantity

The **magnitude (or size)** of a force is ***not*** a complete description of the force.

The ***direction*** of the force is equally important.

Force is another example of a **vector**

Force exerted *by* an ideal spring (Hooke's law):

$$F_x = -kx$$

(F_x is the force exerted ***by*** the moveable end when its position is x; the spring is relaxed at $x = 0$.)

The constant k is called the **spring constant** for a particular spring.

Let's think about the minus sign here

Net Force

When more than one force acts on an object, its motion is determined by the **net force** acting on the object.

The **net force** is the vector sum of **all** the forces acting on an object.

Definition of net force:

If $\vec{\mathbf{F}}_1, \vec{\mathbf{F}}_2, \ldots, \vec{\mathbf{F}}_n$

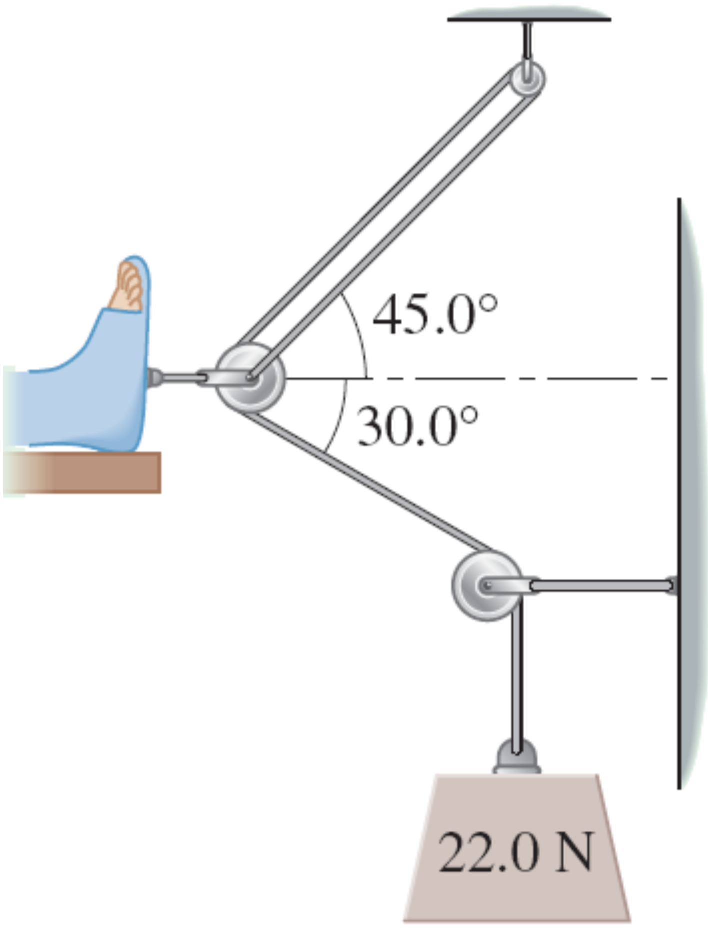
are *all* the forces acting on an object, then the net force $\vec{\mathbf{F}}_{\text{net}}$ acting on that object is the **vector sum** of those forces:

$$\vec{\mathbf{F}}_{\text{net}} = \sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \cdots + \vec{\mathbf{F}}_n$$

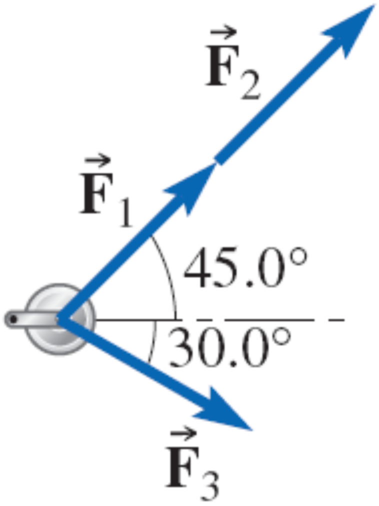
In a traction apparatus, three cords pull on the central pulley, each with magnitude 22.0 N, in the directions shown in the figure.

What is the sum of the forces exerted on the central pulley by the three cords?

Give the magnitude and direction of the sum.



Strategy Sketch the graphical addition of the three forces to get an estimate of the magnitude and direction of the sum.

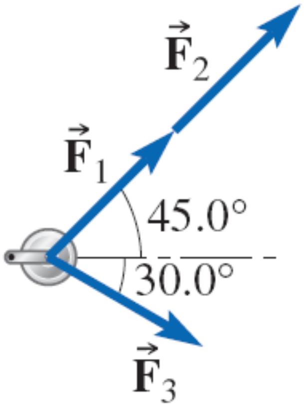


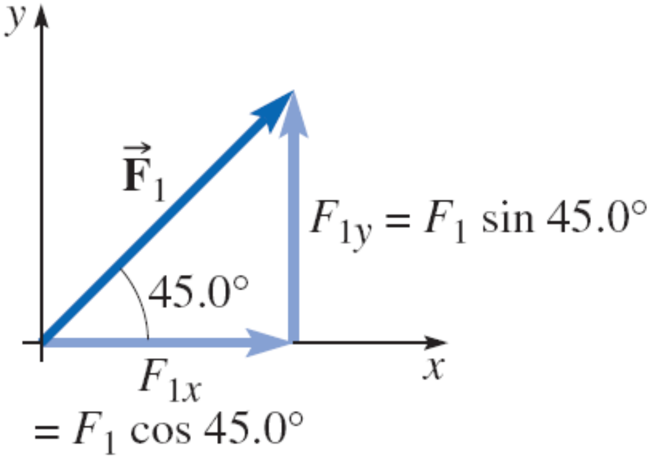
F_1 and F_2! Why?

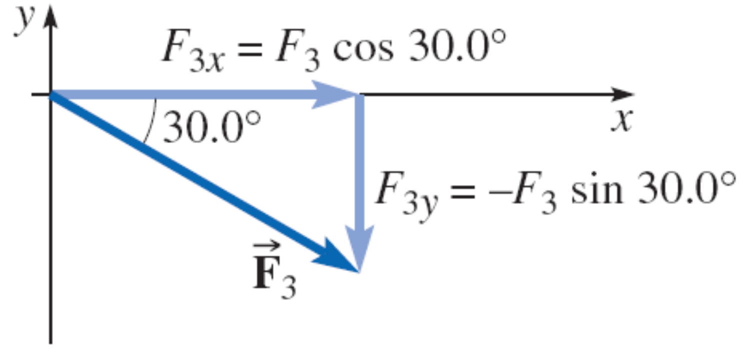
Then, to get an accurate answer, resolve the three forces into their *x*- and *y*-components, sum the components, and then calculate the magnitude and direction of the sum.

As always, it's easiest to add vectors by resolving into components

Solution







$$F_{1x} = F_{2x} = (22.0\text{ N})\cos 45.0°$$

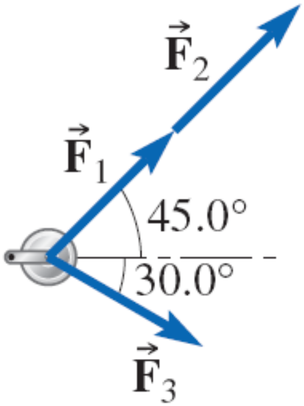
$$F_{3x} = (22.0\text{ N})\cos 30.0°$$

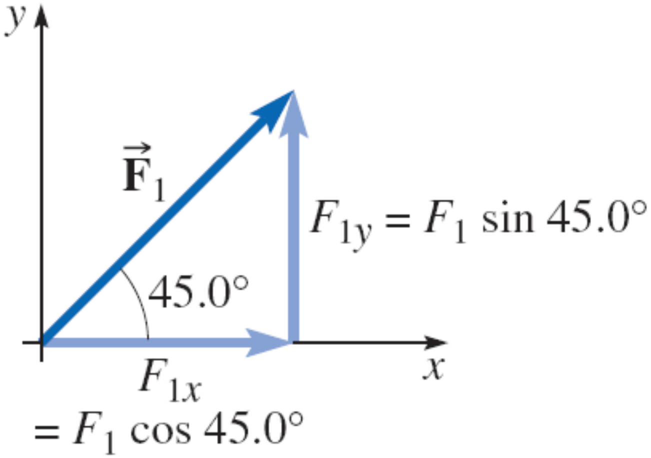
$$F_x = F_{1x} + F_{2x} + F_{3x}$$

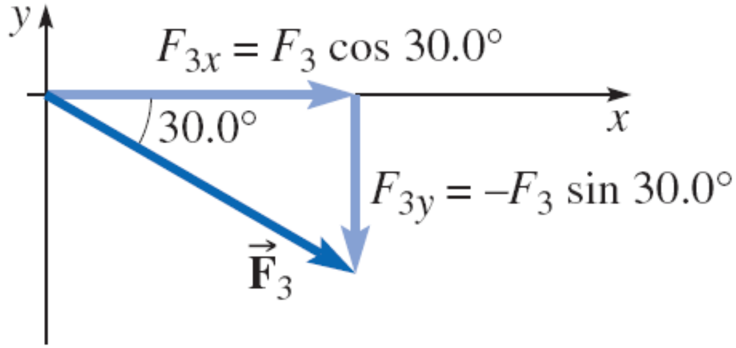
$$= 2 \times (22.0\text{ N})\cos 45.0° + (22.0\text{ N})\cos 30.0°$$

$$= 31.11\text{ N} + 19.05\text{ N} = 50.16\text{ N}$$

Solution







$$F_{1y} = F_{2y} = (22.0\text{ N}) \sin 45.0°$$

$$F_{3y} = (-22.0\text{ N}) \sin 30.0°$$

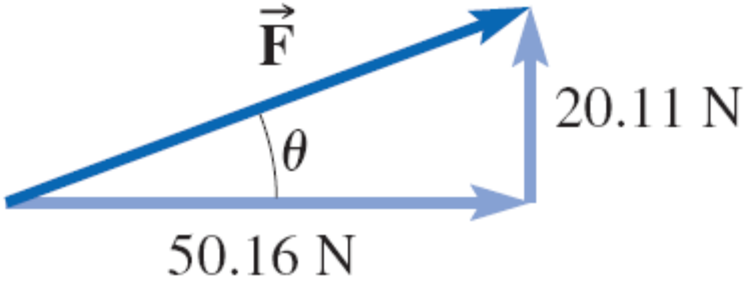
$$F_y = F_{1y} + F_{2y} + F_{3y}$$

$$= 2 \times (22.0\text{ N}) \sin 45.0° + (-22.0\text{ N}) \sin 30.0°$$

$$= 31.11\text{ N} - 11.00\text{ N} = 20.11\text{ N}$$

Solution

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(50.16\ \text{N})^2 + (20.11\ \text{N})^2} = 54.0\ \text{N}$$



$$\theta = \tan^{-1}\frac{\text{opposite}}{\text{adjacent}} = \tan^{-1}\frac{20.11\ \text{N}}{50.16\ \text{N}} = 21.8°$$

Time for Sir Isaac ...

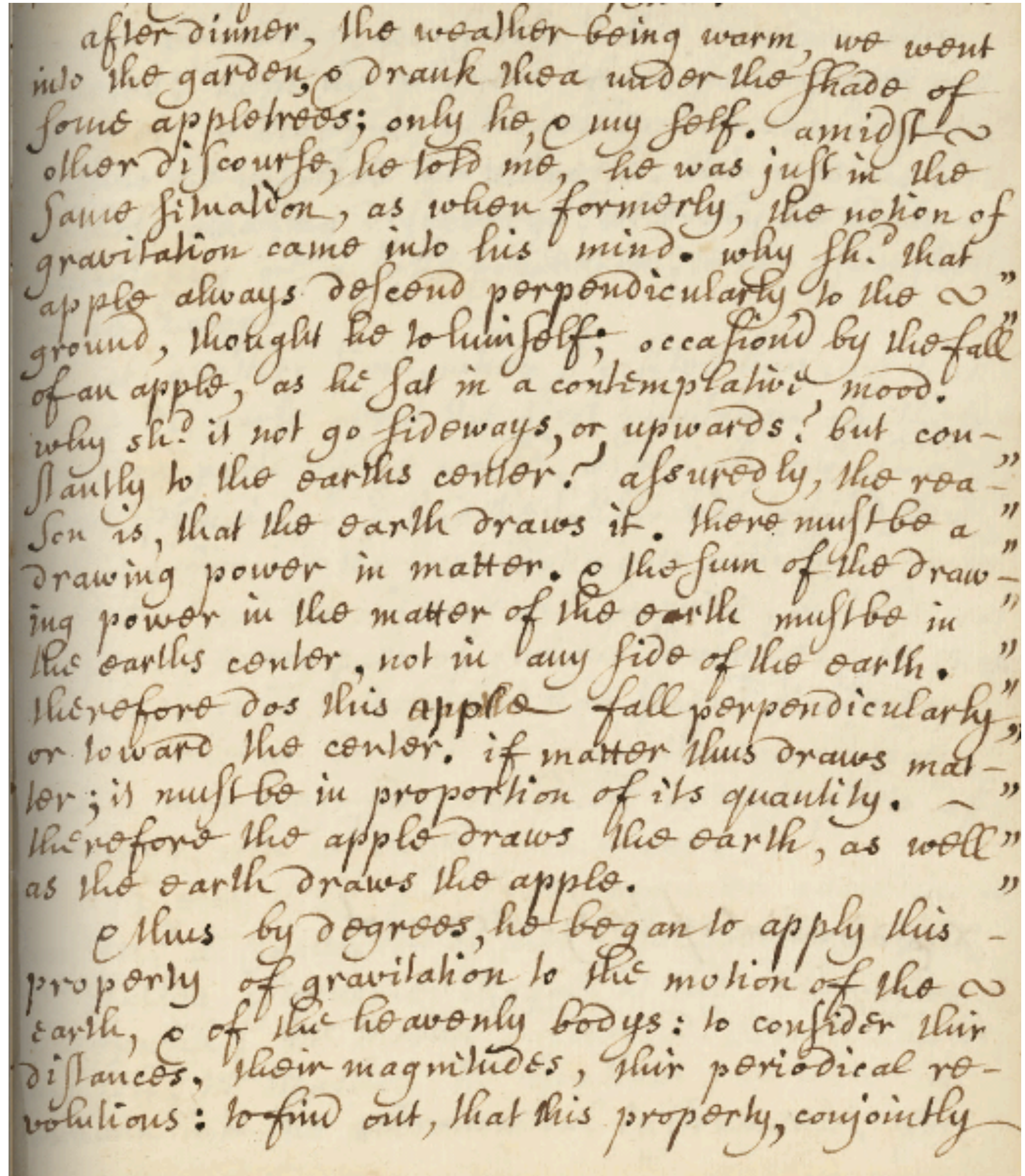
From Wikipedia

Newton himself often told the story that he was inspired to formulate his theory of gravitation by watching the fall of an apple from a tree. Although it has been said that the apple story is a myth and that he did not arrive at his theory of gravity in any single moment, acquaintances of Newton (such as William Stukeley, whose manuscript account of 1752 has been made available by the Royal Society) do in fact confirm the incident, though not the cartoon version that the apple actually hit Newton's head. Stukeley recorded in his Memoirs of Sir Isaac Newton's Life a conversation with Newton in Kensington on 15 April 1726:

we went into the garden, & drank thea under the shade of some appletrees; only he, & my self. amidst other discourse, he told me, he was just in the same situation, as when formerly, the notion of gravitation came into his mind. "why should that apple always descend perpendicularly to the ground," thought he to himself; occasion'd by the fall of an apple, as he sat in a contemplative mood. "why should it not go sideways, or upwards? but constantly to the earths center? assuredly, the reason is, that the earth draws it. there must be a drawing power in matter. & the sum of the drawing power in the matter of the earth must be in the earths center, not in any side of the earth. therefore dos this apple fall perpendicularly, or toward the center. if matter thus draws matter; it must be in proportion of its quantity. therefore the apple draws the earth, as well as the earth draws the apple.

We'll get to that later, but for now we study some of Newton's other contributions to science http://ttp.royalsociety.org/ttp/ttp.html?id=1807da00-909a-4abf-b9c1-0279a08e4bf2&type=book

My hand-writing is pretty atrocious, but maybe no worse?



after dinner, the weather being warm, we went into the garden, & drank thea under the shade of some appletrees; only he, & my self. amidst other discourse, he told me, he was just in the same situation, as when formerly, the notion of gravitation came into his mind. why sh.d that apple always descend perpendicularly to the ground, thought he to himself; occasion'd by the fall of an apple, as he sat in a contemplative mood. why sh.d it not go sideways, or upwards? but constantly to the earths center? assuredly, the reason is, that the earth draws it. there must be a drawing power in matter. & the sum of the drawing power in the matter of the earth must be in the earths center, not in any side of the earth. therefore dos this apple fall perpendicularly, or toward the center. if matter thus draws matter; it must be in proportion of its quantity. therefore the apple draws the earth, as well as the earth draws the apple.

& thus by degrees, he began to apply this property of gravitation to the motion of the earth, & of the heavenly bodys: to consider their distances, their magnitudes, their periodical revolutions: to find out, that this property, conjointly

Newton's First Law

An object's **velocity vector** remains **constant** if and only if the net force acting on the object is zero.

Sometimes: "In the absence of forces, an object in motion stays in motion, and an object at rest stays at rest"

Inertia

Newton's first law is also called the **law of inertia.**

In physics, **inertia** means resistance to ***changes*** in velocity.

It does ***not*** mean resistance to the continuation of motion (or the tendency to come to rest).

Free-Body Diagrams

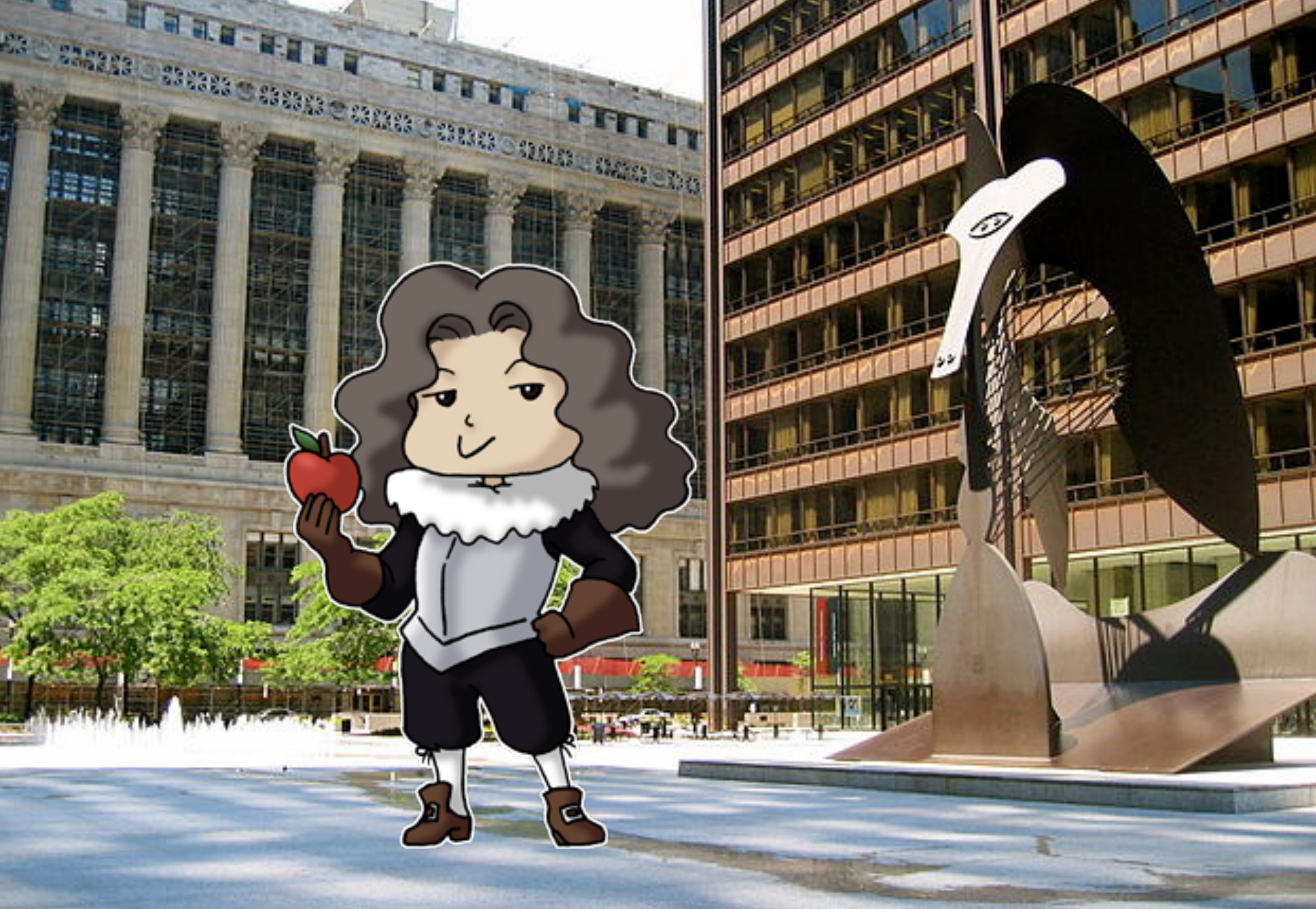
A **free-body diagram** (FBD) is a simplified sketch of a single object with force vectors drawn to represent ***every* force** acting on that object.

It must **not** include any forces that act on other objects, only the ones on the object we're looking at.

Free-Body Diagrams

To draw a free-body diagram:

- **Draw coordinate axes, carefully labeled. ALWAYS**
- Draw the object in a simplified way **(you don't have to be Picasso!), NOT on the axes**
- Identify all the forces that are exerted on the object.
- Check your list of forces to make sure that each force is exerted ***on*** the object of interest *by* some other object. Make sure you have **not** included any forces that are exerted ***on other objects***.
- Draw vector arrows representing all the forces acting on the object.



But too messy makes it difficult to follow

For an object in equilibrium (constant velocity)

Net force →

$$\sum \vec{\mathbf{F}} = 0$$

$$\sum F_x = 0 \quad \text{and} \quad \sum F_y = 0 \quad \left(\text{and} \quad \sum F_z = 0\right)$$

Who would love to be able to play “Push the Professor”?

What would happen if we had two people playing the game pushing in opposite directions on the chair? What would be the net force on me? What would be my motion?

Newton's Third Law

In an interaction between two objects, each object exerts a force on the other.

These two forces are **equal in magnitude and opposite in direction**.

Equivalently, we can write

$$\vec{\mathbf{F}}\ (\text{on } B \text{ by } A) = -\vec{\mathbf{F}}\ (\text{on } A \text{ by } B)$$

I bet some of you would prefer to play “Kick the Professor” from a second chair? What do we think would happen?

Defining a System
We call a set of particles that we are examining a **"system"** and classify all the interactions that affect the system as either **internal** or **external** to the system.

For an **internal** interaction, *both* interacting objects are part of the system. When we add up all the forces acting on the system to find the net force, every internal interaction contributes two forces that always add to zero.

WHY?!

For an **external** interaction, only one of the two forces between them is exerted on the system. The other partner is exerted on an object outside the system and does not contribute to the net force on the system.

So to find the net force on the system, we can ignore all the internal forces and just add the external forces.

As this car is rolling along the road, let's talk about some of the internal forces and external forces depending on our system

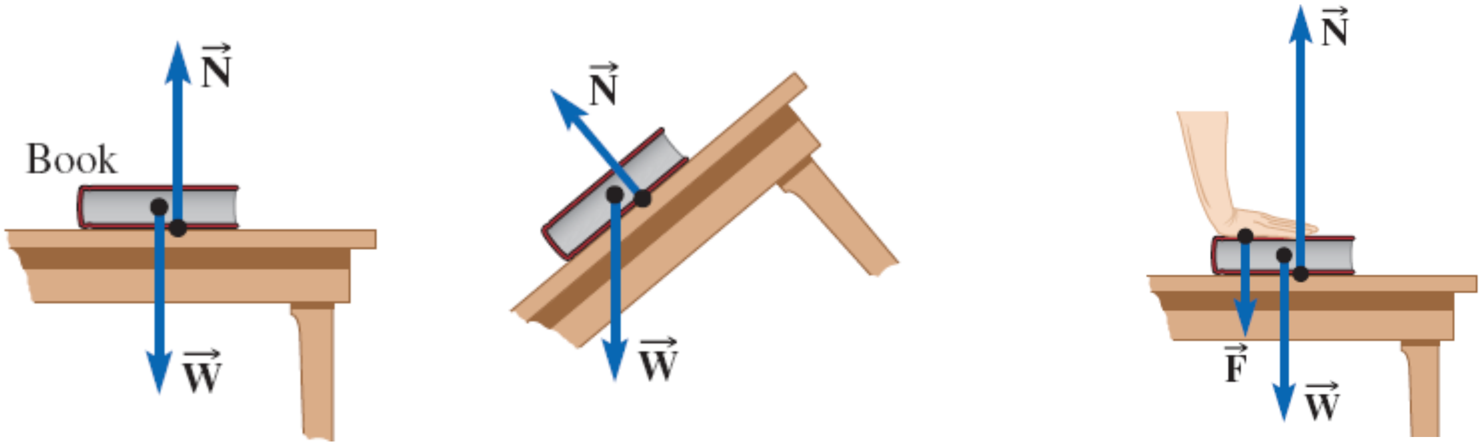
What if we put this car on a boat? Let’s reconsider

How is is that humans can walk and run? Any ideas?

The force due to two objects touching one another is called the **contact force**. It is often convenient to think of the components of a contact force as two separate but related contact forces: the ***normal force*** and the ***frictional force***.

Normal Force

A contact force perpendicular to the contact surface that prevents two solid objects from passing through one another is called the **normal force**



Friction

A contact force **parallel** to the contact surface is called **friction**.

We distinguish several types. For now, we consider only **kinetic friction**

Force of kinetic (sliding) friction:

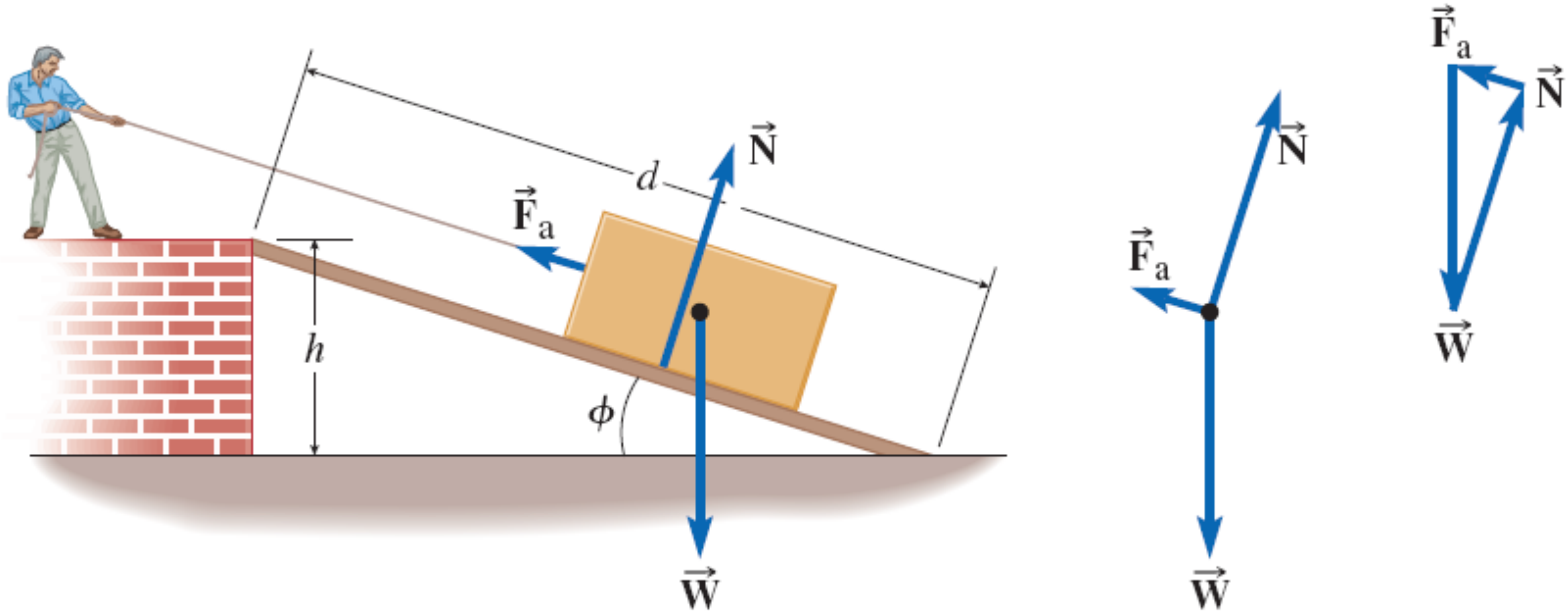
$$f_k = \mu_k N$$ ← Normal force

The constant of proportionality is called the **coefficient of kinetic friction**. Its value depends on the condition and nature of the surfaces.

Kinetic friction acts in a direction that tends to make the sliding or slipping stop.

From Newton's third law, frictional forces come in pairs. If the table exerts a frictional force on the sliding book to the right, the book exerts a frictional force on the table to the *left* with the same magnitude.

Application: Equilibrium on an Inclined Plane
Suppose we wish to pull a large box up a *frictionless* incline to a loading dock platform.



NOTE OUR CHOICE OF AXES! WHAT ARE THEY?

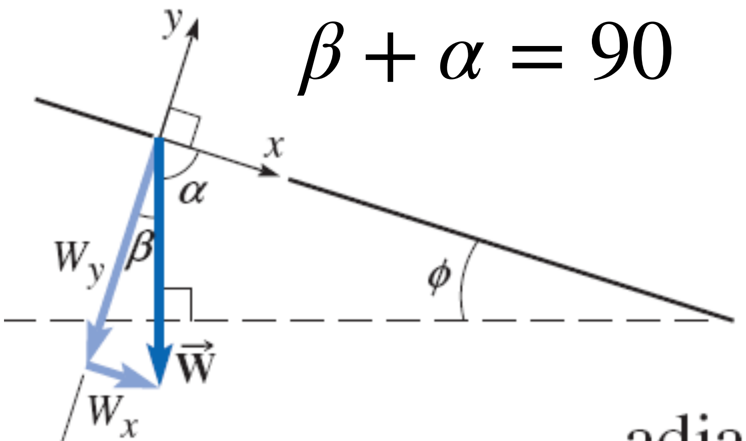
$$\beta + \alpha + 90 = 180$$

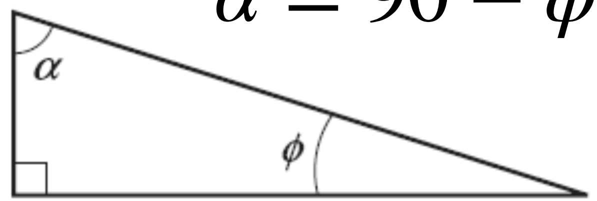
$$\beta + \alpha = 90$$

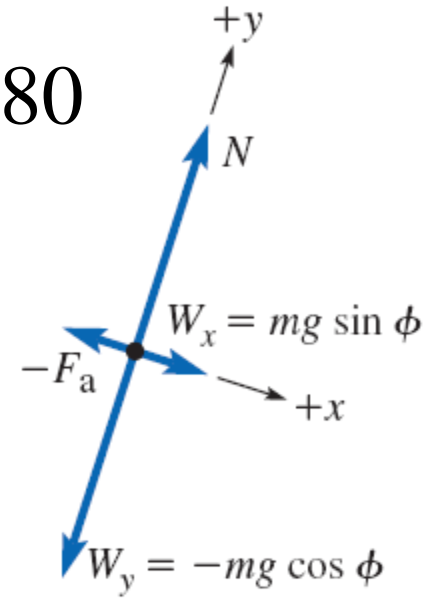
$$\alpha + \phi + 90 = 180$$

$$\alpha + \phi = 90$$

$$\alpha = 90 - \phi$$





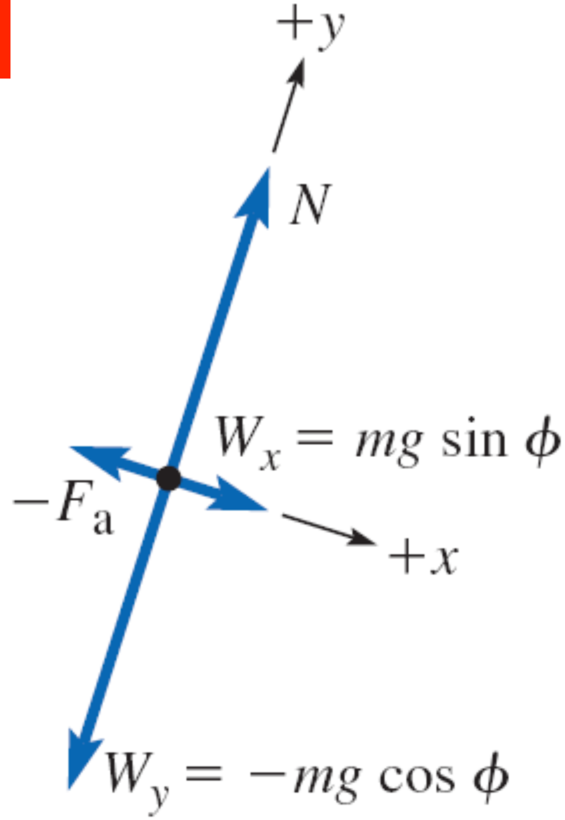


$$\cos \beta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{|W_y|}{|W|} \quad W = mg$$

Why negative? $W_y = -mg \cos \beta = -mg \cos \phi$ $(\beta = \phi)$ **WHY?**

$$W_x = +mg \sin \phi$$

Good check on whether it's cosine or sine – what happens if ϕ goes to zero? And if angle goes to 90 degrees?



If the box is in equilibrium,

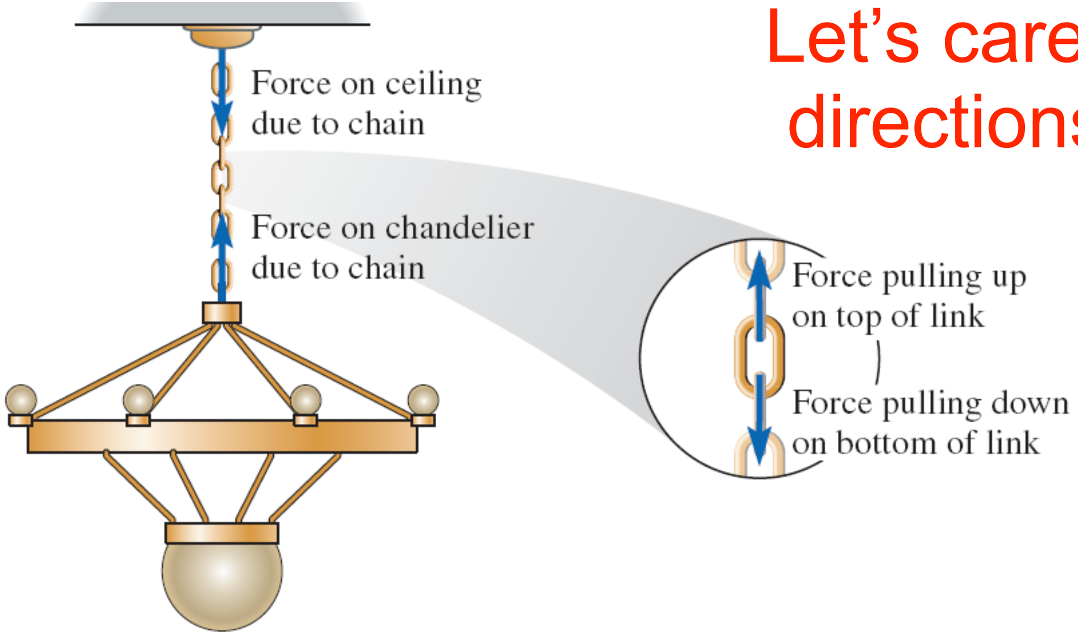
$$\sum F_x = (-F_a) + mg \sin \phi = 0$$

$$\sum F_y = N + (-mg \cos \phi) = 0$$

If the applied force has magnitude *mg* sin ϕ, we can pull the box up the incline at constant velocity.

If friction acts on the box, we must pull with a force greater than *mg* sin φ to slide the box up the incline at constant velocity.

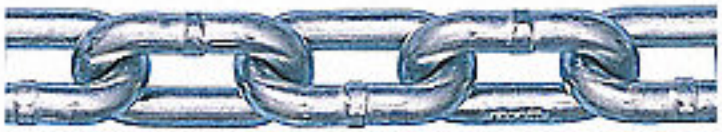
An ***ideal* cord** (rope, string, tendon, cable, or chain) pulls in the direction of the cord with forces of equal magnitude on the objects attached to its ends as long as no external force is exerted on it anywhere between the ends. An ideal cord has zero mass and zero weight.



Let's carefully check directions of forces

A single link of a chain or rope is pulled at both ends by the neighboring links. The magnitude of these forces is called the **tension** in the chain.

The tension has the same value everywhere on the chain and is equal to the force that the cord exerts on the objects attached to its ends.



Introduction to Newton's Second Law of Motion

When a **non-zero** net force acts on an object, the velocity changes.

Newton's second law of motion tells us how the net force and the object's mass determine the change in velocity.

Note: Can still have a net force of zero in one or more components or directions

The Effect of a Nonzero Net Force Acting on an Object

When a nonzero net force acts on an object, Newton's second law says that the rate of change of the velocity is proportional to the net force and inversely proportional to the mass of the object:

VECTORS!

$$\frac{\Delta \vec{\mathbf{v}}}{\Delta t} = \frac{1}{m} \sum \vec{\mathbf{F}}$$

Note sum over all forces, ie the NET force

$$\Delta \vec{\mathbf{v}} = \vec{\mathbf{v}}_{\mathrm{f}} - \vec{\mathbf{v}}_{\mathrm{i}}$$

$$\Delta t = t_{\mathrm{f}} - t_{\mathrm{i}}$$

$$\vec{\mathbf{a}} = \frac{1}{m}\sum\vec{\mathbf{F}} \quad \text{or} \quad \sum\vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

$$\sum F_x = ma_x \quad \text{and} \quad \sum F_y = ma_y$$

Let's discuss as derivatives!

What happens when Δt→0?

$$a_x = \frac{\Delta v_x}{\Delta t} \quad \text{and} \quad a_y = \frac{\Delta v_y}{\Delta t}$$

The SI units of acceleration are (m/s)/s = m/s^2.

The SI unit of force, the newton, is *defined* so that a net force of 1 N gives a 1-kg mass an acceleration of 1 m/s^2:

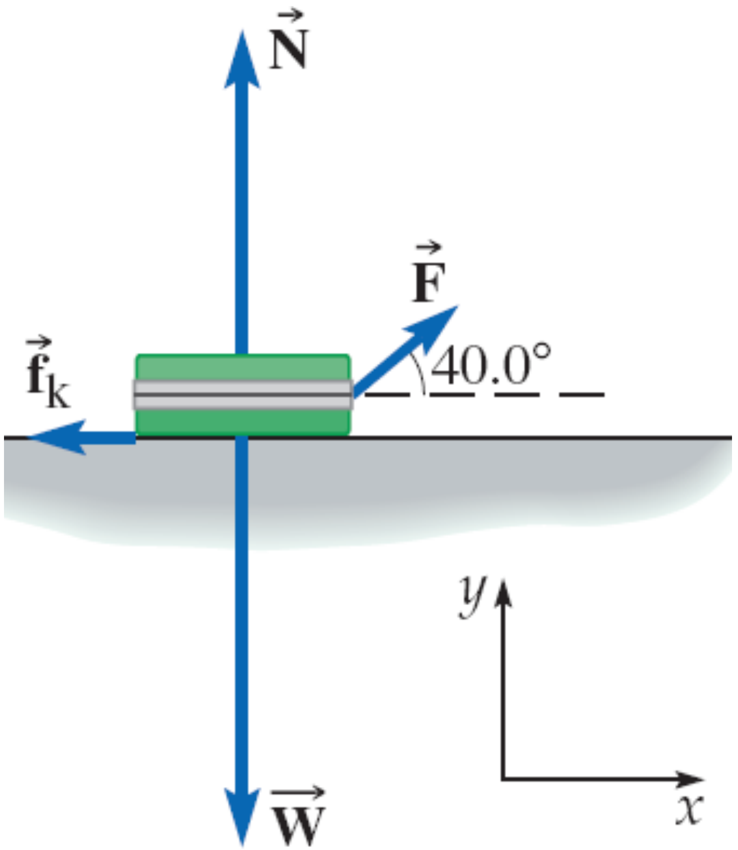
$$1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$$

The wheels fall off Beatrice's suitcase, so she ties a rope to it and drags it along the floor of the airport terminal. The rope makes a 40.0° angle with the horizontal. The suitcase has a mass of 36.0 kg and Beatrice pulls on the rope with a force of 65.0 N. **Poor Beatrice!**

(a) What is the magnitude of the normal force acting on the suitcase due to the floor?
(b) If the coefficient of kinetic friction between the suitcase and the marble floor is $\mu_k = 0.13$, find the frictional force acting on the suitcase.
(c) What is the acceleration of the suitcase ?
(d) Starting from rest, for how long a time must she pull with this force until the suitcase reaches a comfortable walking speed of 0.5 m/s?

Start as always by defining our axes and by drawing our Free Body Diagram. We're not dealing with a ramp, so it makes sense to use standard axis coordinates. There are 4 forces acting on the suitcase

Our FBD



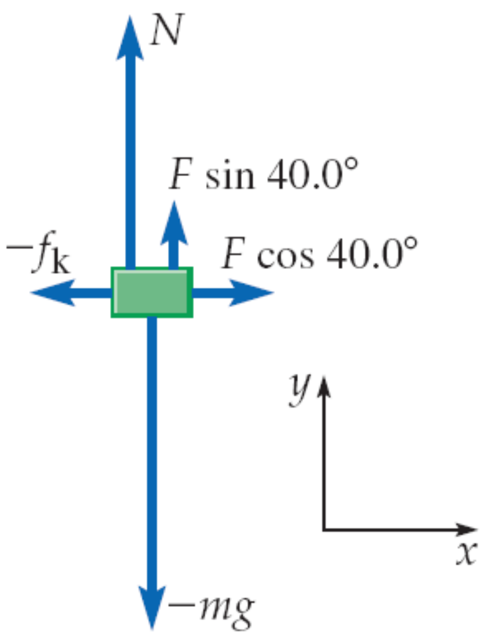
Solution

(a)

$$F_x = F\cos 40.0° = 65.0\text{ N} \times 0.766 = 49.8\text{ N}$$

$$F_y = F\sin 40.0° = 65.0\text{ N} \times 0.643 = 41.8\text{ N}$$

FBD with F broken up into components



$$\sum F_y = ma_y = 0$$ **Why!?**

$$N + F\sin 40.0° - \text{mg} = 0$$

$$N = mg - F\sin 40°$$ **Are units correct?**

$$= (36.0\text{ kg} \times 9.80\text{ N/kg}) - (65.0\text{ N} \times \sin 40.0°)$$

$$= 352.8\text{ N} - 41.8\text{ N} = 311\text{ N}$$

Solution

(b) $f_k = \mu_k N = 0.13 \times 311\ \text{N} = 40.43\ \text{N}$

Need normal force to find frictional force!

(c)
$$\sum F_x = +F\cos 40.0° + (-f_k)$$
$$= 49.79\ \text{N} - 40.43\ \text{N} = 9.36\ \text{N}$$

Newton's 2nd law!

$$a_x = \frac{\sum F_x}{m} = \frac{9.36\ \text{N}}{36.0\ \text{kg}} = 0.260\ \text{m/s}^2$$

The acceleration is 0.3 m/s² in the (+*x*)-direction.

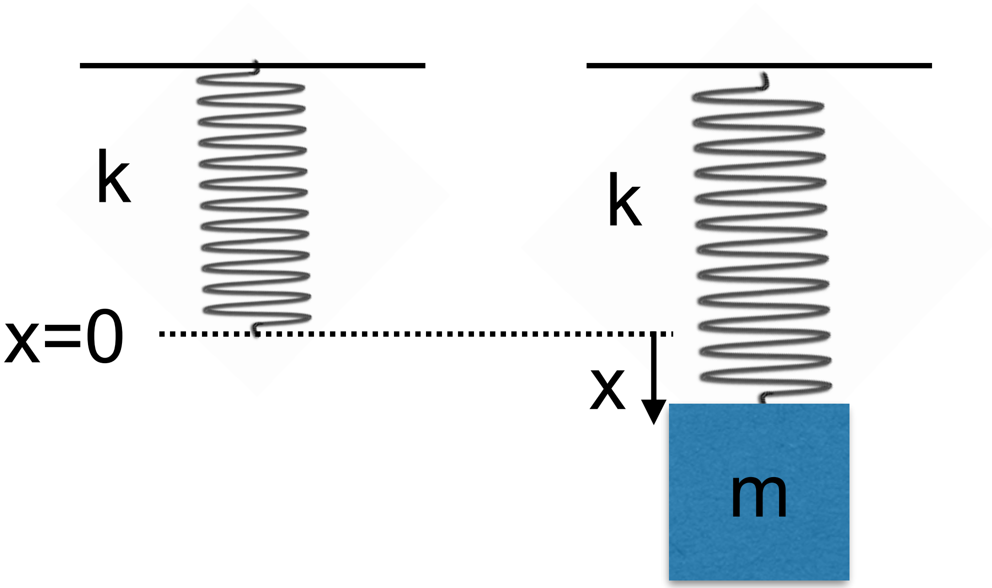
(d)
$$\Delta v_x = a_x \Delta t$$

Why is this true?

$$v_{ix} = 0 \text{ and } \Delta v_x = v_{fx} - v_{ix} = v_{fx}$$

$$\Delta t = \frac{v_{fx}}{a_x} = \frac{0.5\ \text{m/s}}{0.260\ \text{m/s}^2} = 2\ \text{s}$$

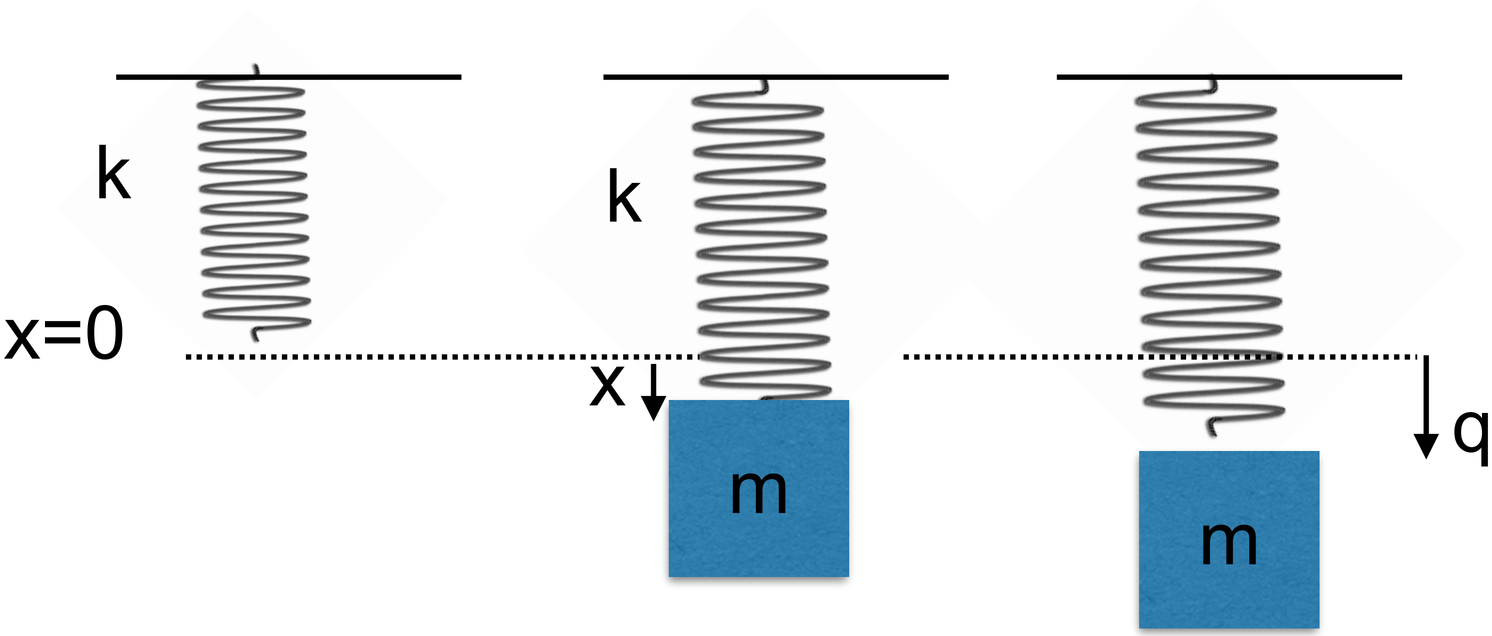
Back to simple harmonic motion



Hanging a mass m on a spring will cause it to be pulled down from its equilibrium position. What is the new equilibrium position? There is a restoring force upwards = -kx and the gravitational weight downwards = mg. At equilibrium, these balance and

mg-kx = 0, or $x = \dfrac{mg}{k}$

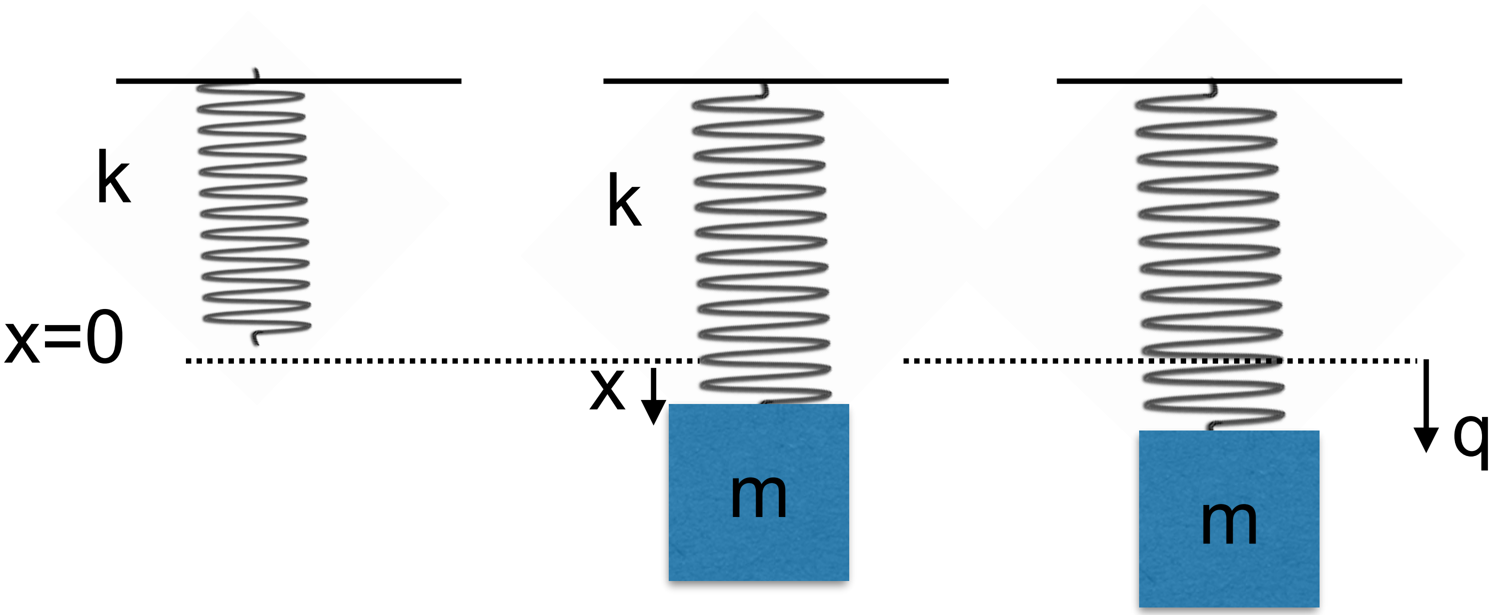
What if we disturb the spring?



Put the spring not at equilibrium position x, but new position q. Then we have a net force on the spring! The restoring force is -kq, and gravity pulls it down with a force mg. Newton's 2nd Law:

$$\sum F = mg - kq = ma = m\frac{d^2q}{dt^2}$$

What if we disturb the spring?

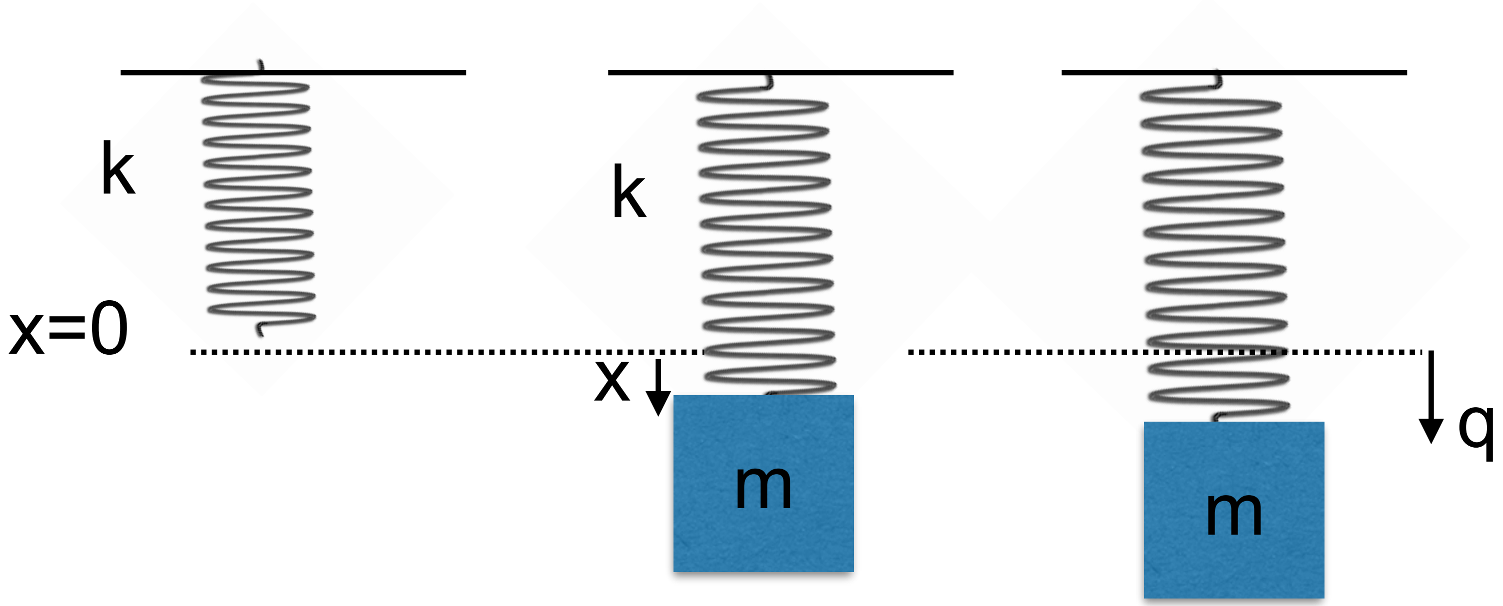


$$\sum F = mg - kq = ma = m\frac{d^2q}{dt^2}$$, so $\frac{mg}{k} - q = \frac{m}{k}\frac{d^2q}{dt^2}$ but

$x = \frac{mg}{k}$ so $x - q = \frac{m}{k}\frac{d^2q}{dt^2}$. What is a solution to this equation?

Try $q = A\cos\omega t + B\sin\omega t + C$

What if we disturb the spring?

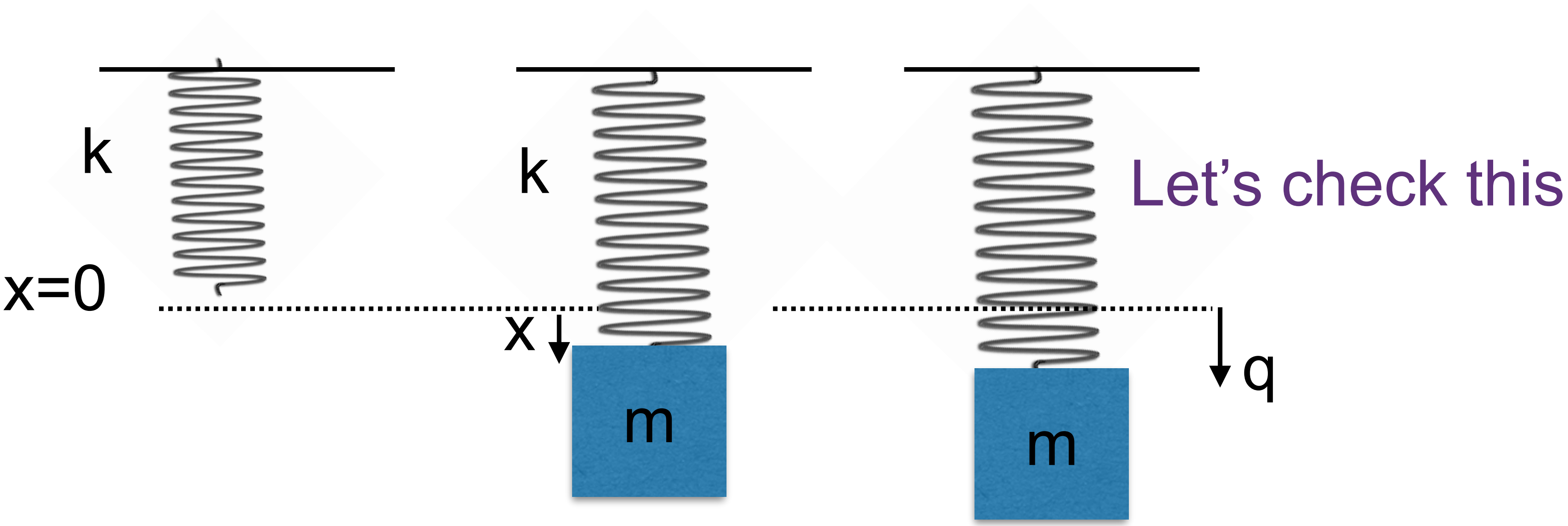


Let’s check this!

$$x - q = \frac{m}{k}\frac{d^2q}{dt^2},\ q = A\cos\omega t + B\sin\omega t + C.$$ Then

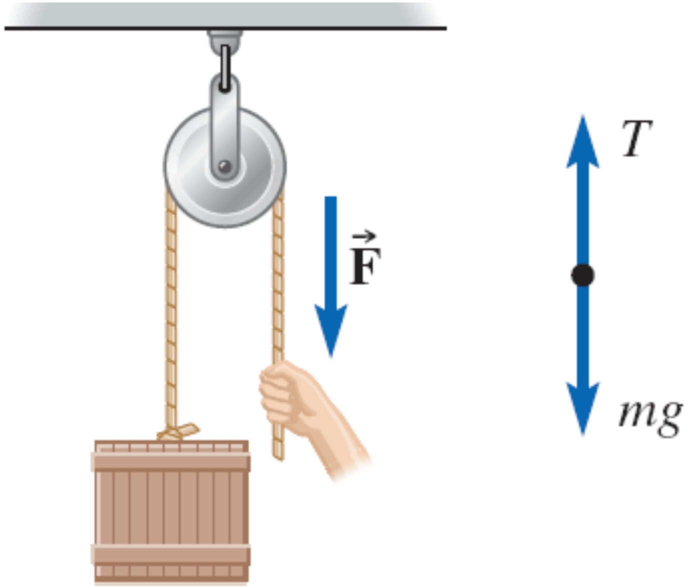
$$x - (A\cos\omega t + B\sin\omega t + C) = \frac{-m\omega^2}{k}(A\cos\omega t + B\sin\omega t)$$

What if we disturb the spring?



$$x - (A\cos\omega t + B\sin\omega t + C) = \frac{-m\omega^2}{k}(A\cos\omega t + B\sin\omega t)$$

So….C = x, $\omega^2 = \frac{k}{m}$. This is **simple harmonic oscillation**, moving around our new equilibrium position! And the speed of the oscillation (ω) depends on m and the spring constant!



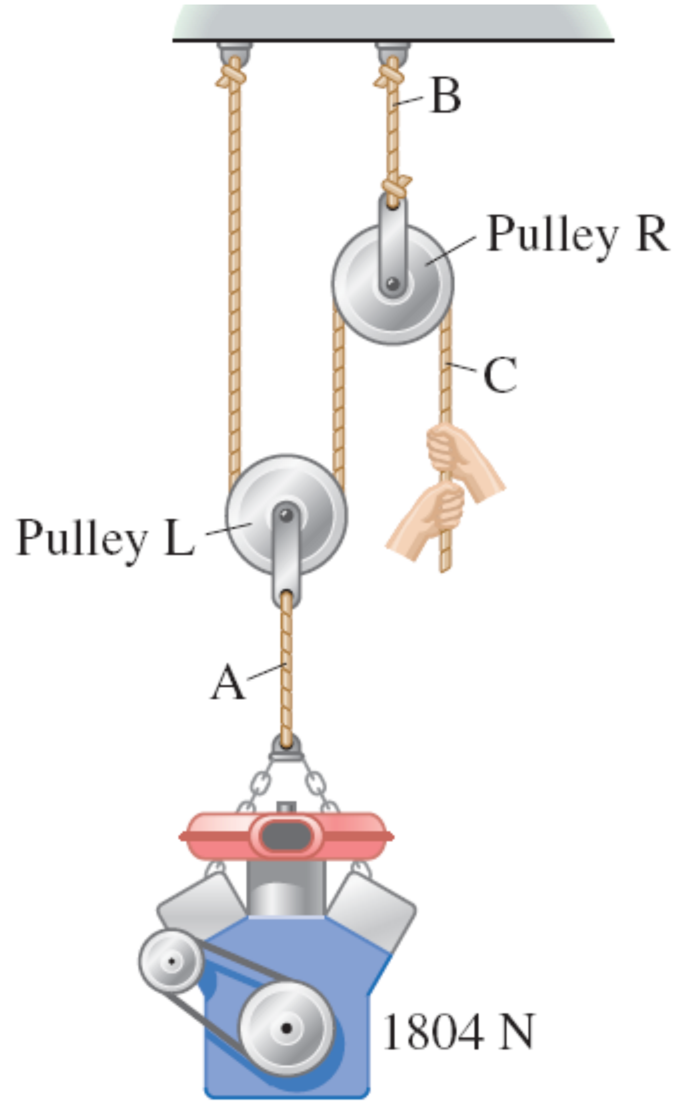
A pulley can change the direction of the force exerted by a cord under tension.

An *ideal* pulley has no mass and no friction. An ideal pulley exerts no forces on the cord that are *tangent* to the cord—it is not pulling in either direction along the cord. As a result, the tension of an ideal cord that runs through an ideal pulley is the same on both sides of the pulley.

An engine that weighs 1804-N is hauled upward at constant speed.

What are the tensions in the three ropes labeled A, B, and C?

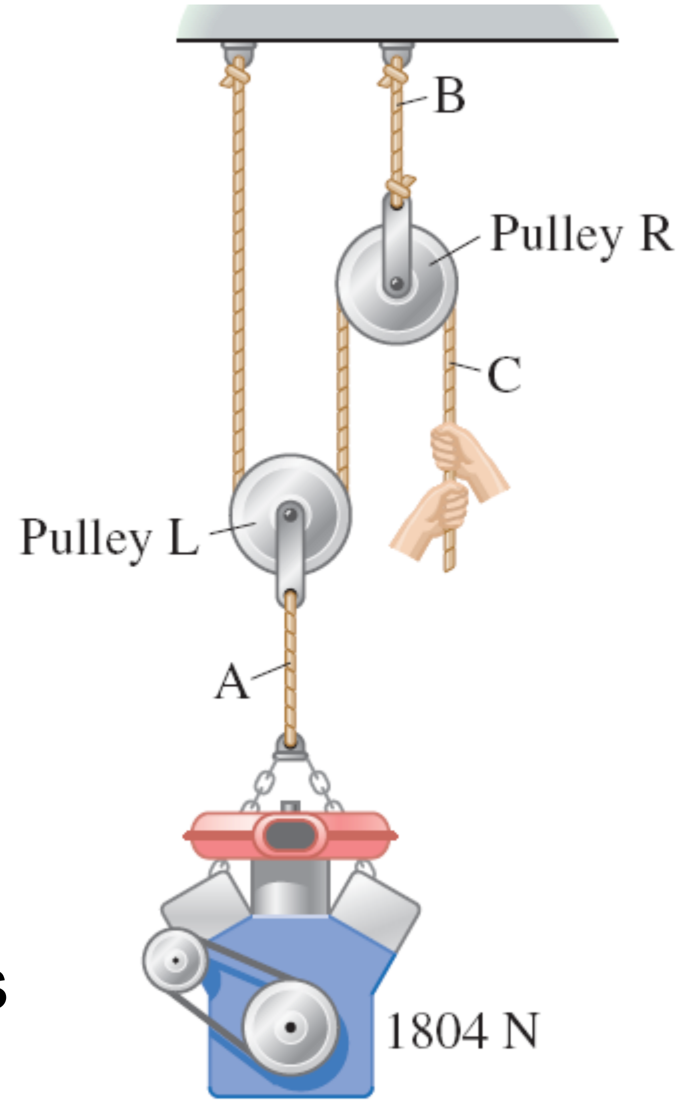
Assume the ropes and the pulleys labeled L and R are ideal.



Strategy The engine and pulley L move up at constant speed, so the net force on each of them is zero. Pulley R is at rest, so the net force on it is also zero.

If the pulleys are ideal, the tension in the rope is the same on both sides of the pulley.

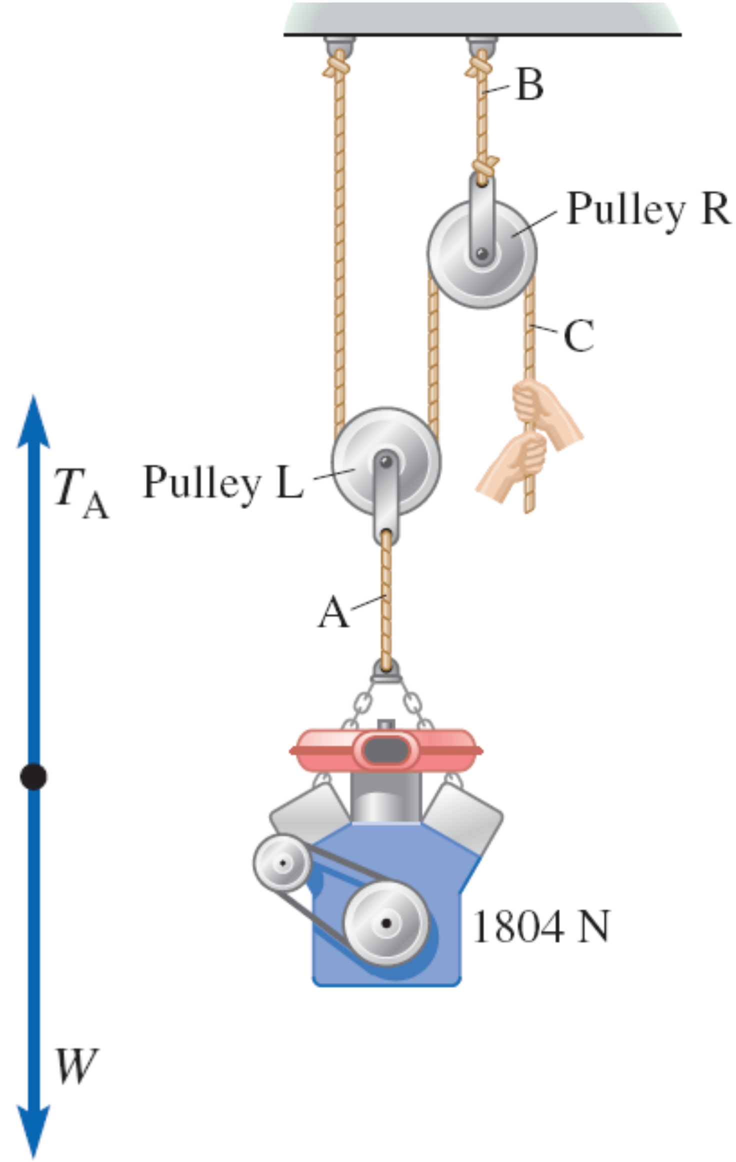
Call the tensions in the three ropes T_A , T_B , and T_C .



Solution There are two forces acting on the engine: the gravitational force (1804 N, downward) and the upward pull of rope A.

These must be equal and opposite, since the net force is zero.

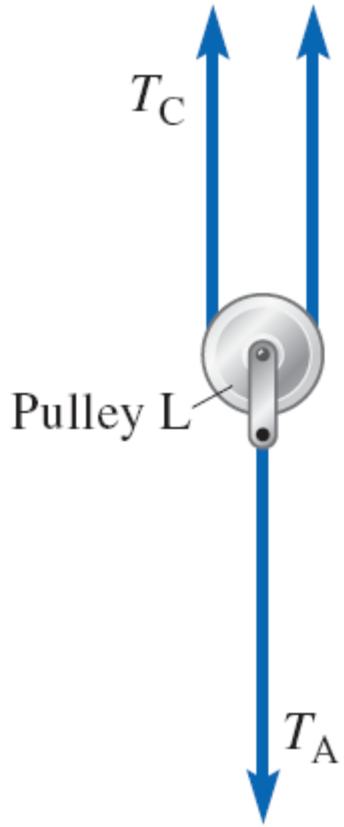
Therefore T_A = 1804 N.

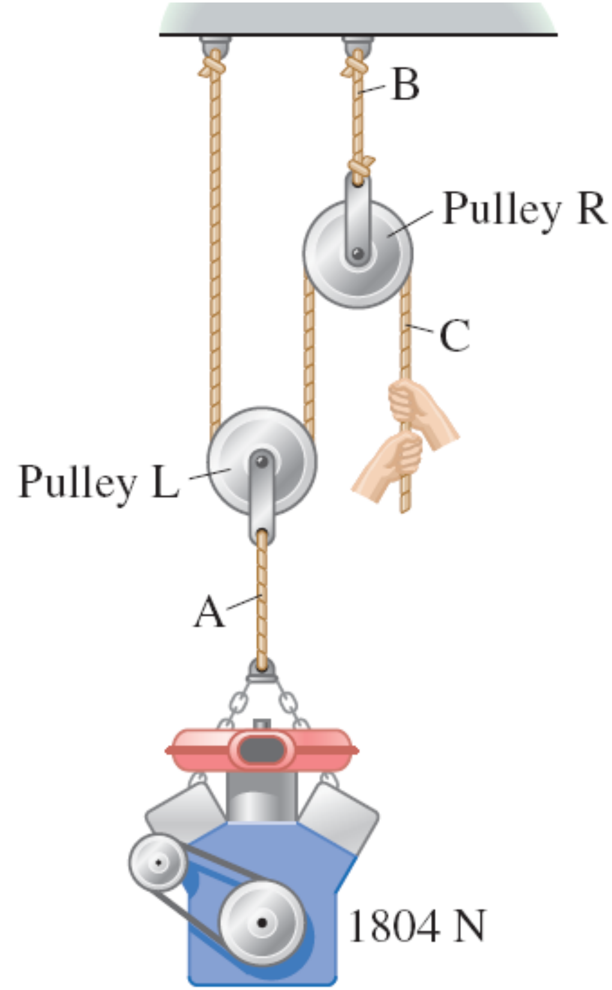


Solution

$$2T_C = T_A$$

$$T_C = \frac{1}{2}T_A = 902.0\ \text{N}$$

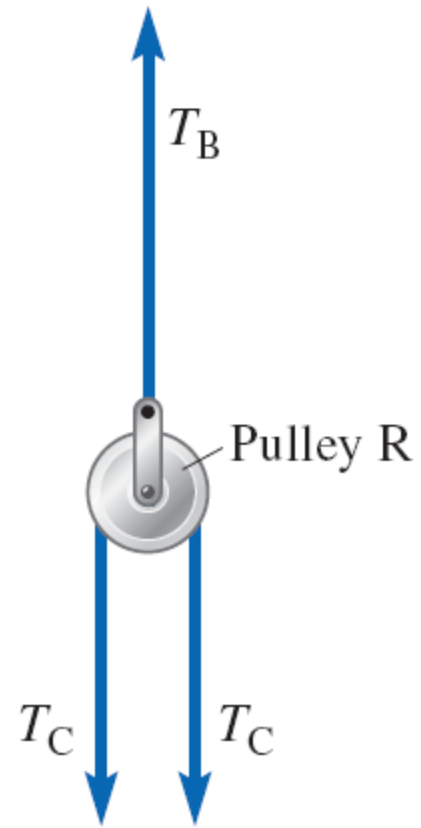


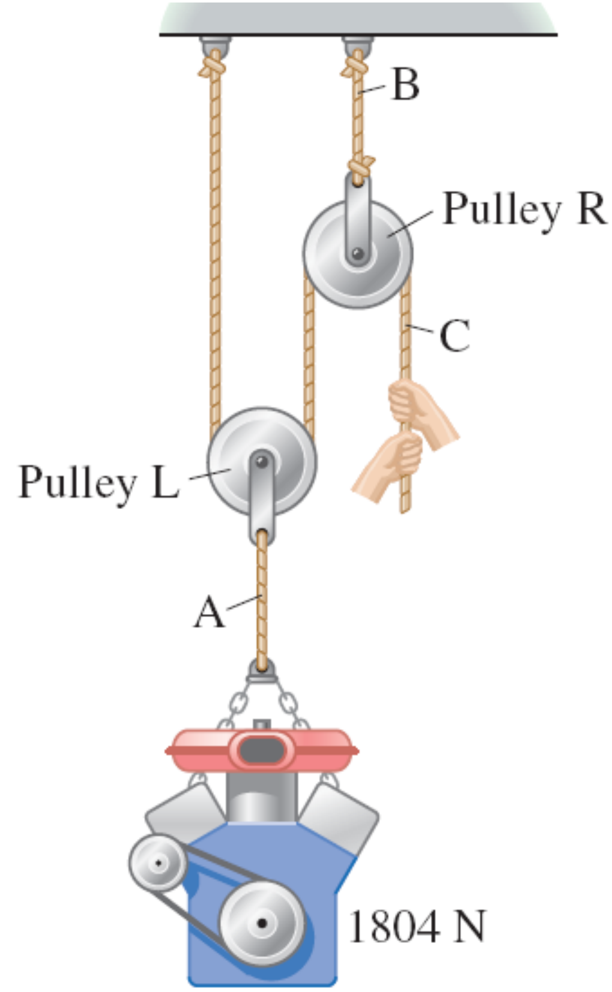


This is very useful! Imagine repeating this (not just two ropes but more than two)....

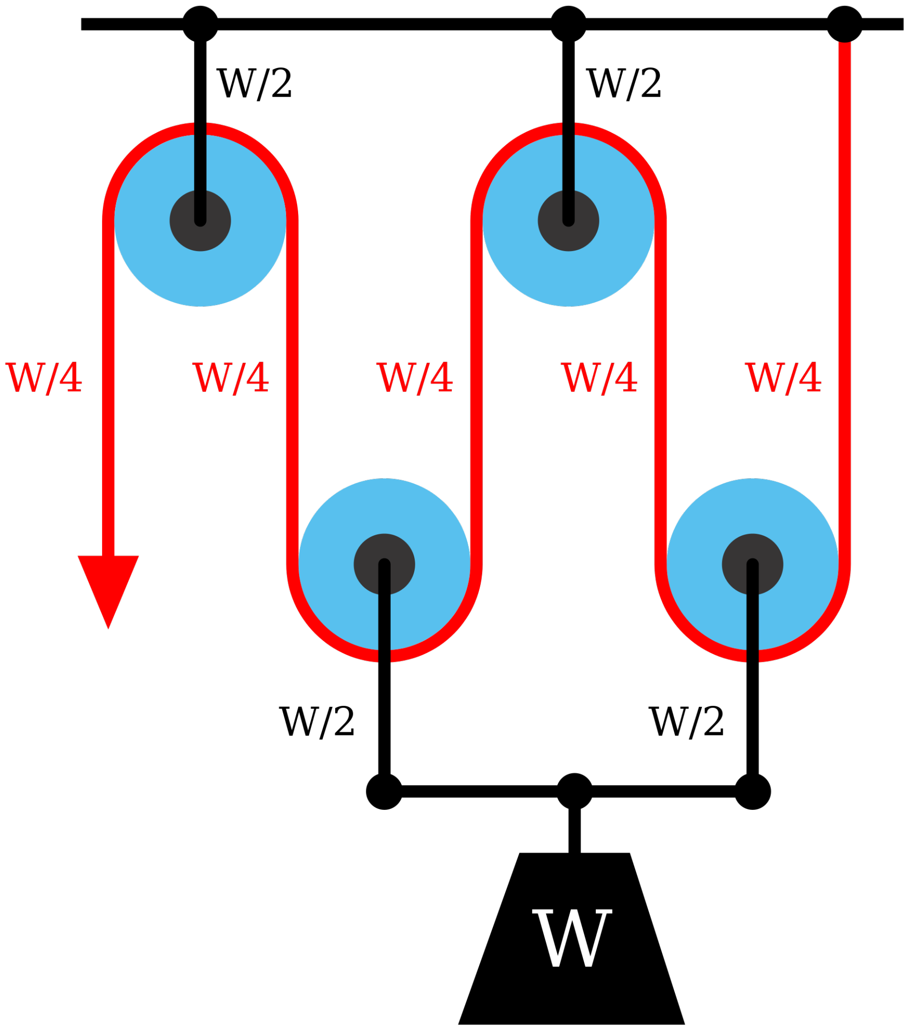
Solution

$$T_B = 2T_C = 1804\ \text{N}$$





Extending this (via Wikipedia)



Pull with W/4 to lift an object with weight W!

Connected Objects

Sometimes two or more objects are constrained to have the same acceleration by the way they are connected.

On the next slide, we look at a train engine pulling five freight cars. The couplings maintain a fixed distance between the cars, so at any instant the cars move with the same velocity; if they didn’t, the distance between them would change.

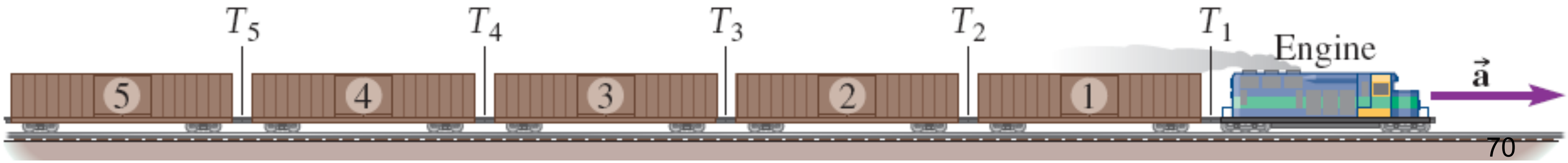
The velocities don’t have to be constant, they just have to change in exactly the same way, which implies that the accelerations must also be the same at any instant.

A train engine pulls out of a station along a straight horizontal track with five identical freight cars behind it, each of which weighs 90.0 kN. The train reaches a speed of 15.0 m/s after 5.00 min of starting its motion.

Assuming the engine pulls with a constant force during this interval, with what magnitude of force does the coupling between cars pull forward on the first and last of the freight cars?

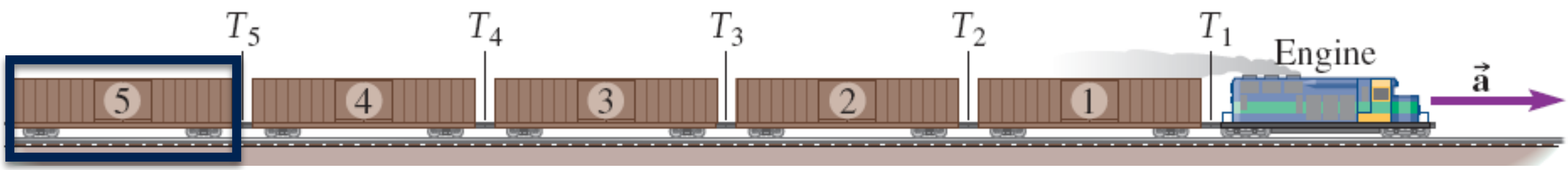
Ignore air resistance and friction on the freight cars.

Can you see why accelerations for all cars must be the same?

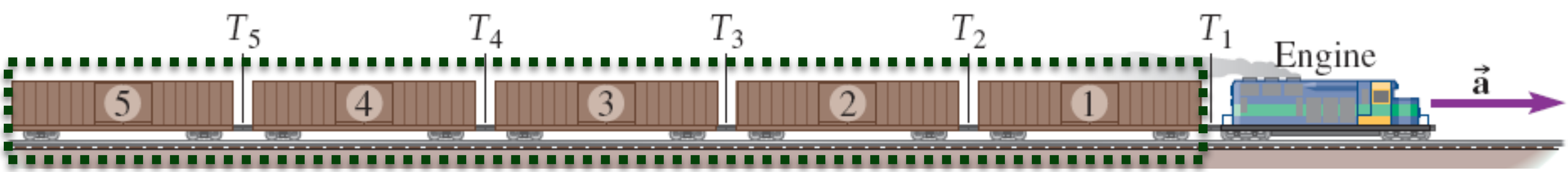


Strategy

Think back to our definition of "system" - we can make multiple choices for different questions in the same problem! Recall internal vs external forces…

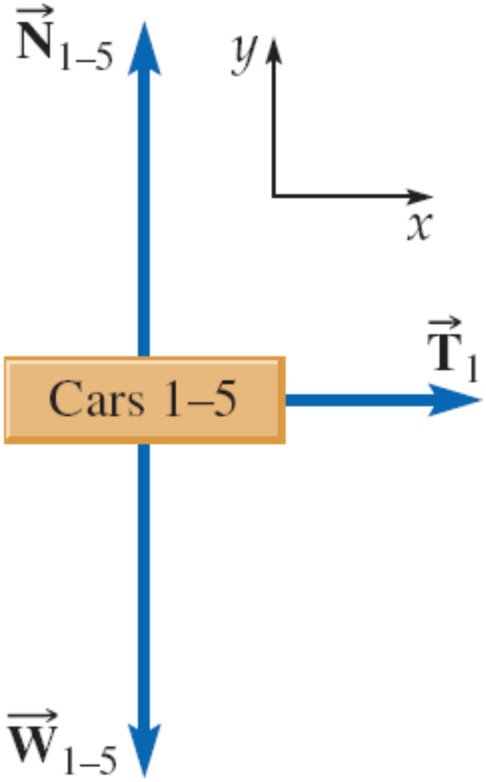


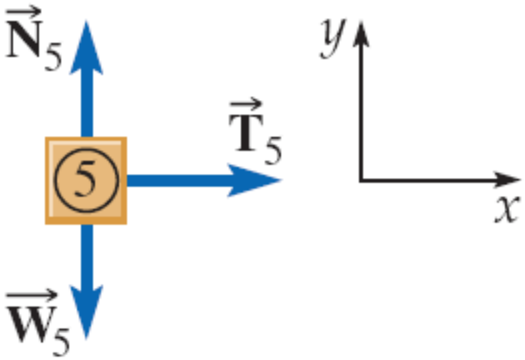
One system



Another system

Two different systems!





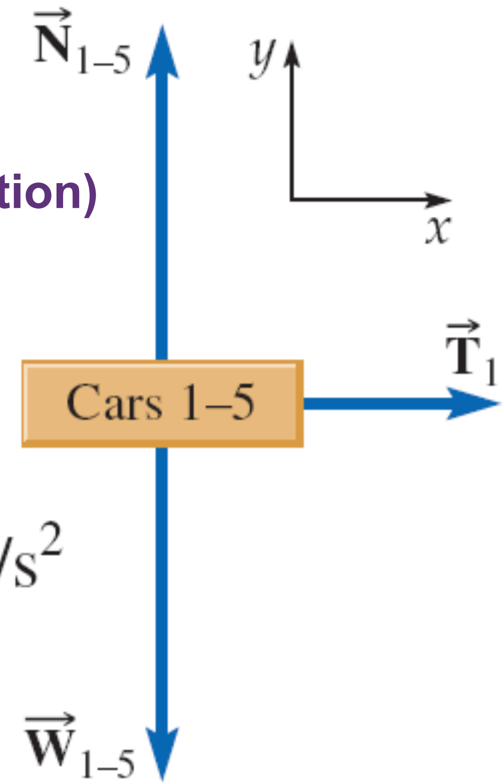
Solution

$$\sum F_y = Ma_y = N_{1-5} - W_{1-5} = 0$$

Not needed! (No friction)

$$\sum F_x = T_1 = Ma_x \qquad M = 5W/g$$

MASS VS WEIGHT!



$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{v_{fx} - v_{ix}}{t_f - t_i} = \frac{15.0\ \text{m/s} - 0}{300\ \text{s} - 0} = 0.0500\ \text{m/s}^2$$

5 min = 300 seconds

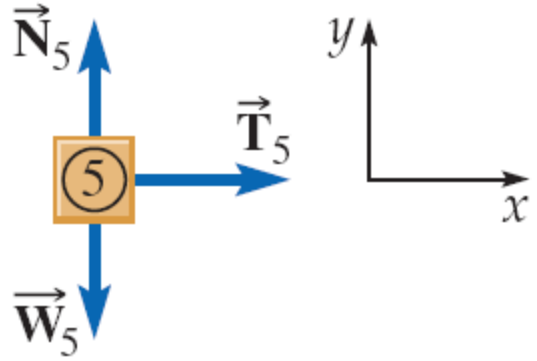
90 kN

$$T_1 = Ma_x = \frac{5W}{g} \times \frac{\Delta v_x}{\Delta t} = \frac{5 \times 9.00 \times 10^4\ \text{N}}{9.80\ \text{m/s}^2} \times \frac{15.0\ \text{m/s}}{300\ \text{s}} = 2.30\ \text{kN}$$

Solution

MASS VS WEIGHT!

$$\sum F_x = T_5 = ma_x = \frac{W}{g} a_x$$

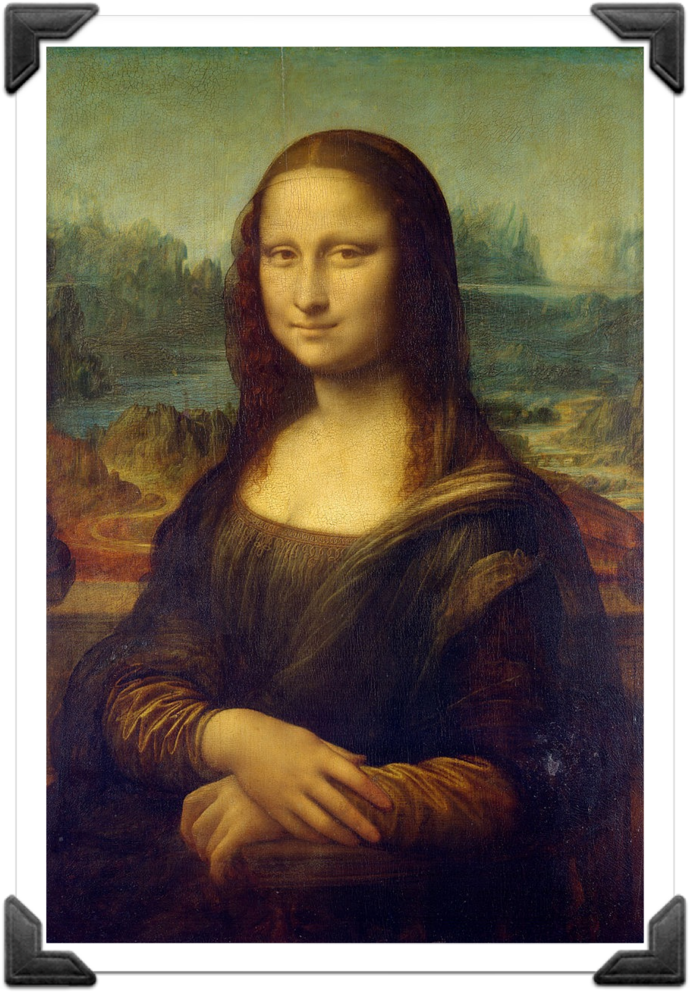


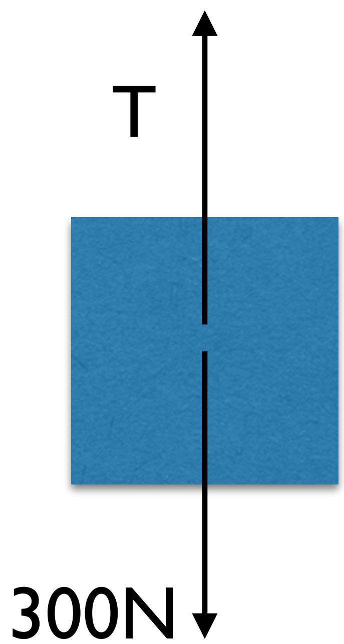
$$T_5 = \frac{W}{g} \times \frac{\Delta v_x}{\Delta t} = \frac{9.00 \times 10^4 \text{ N}}{9.80 \text{ m/s}^2} \times \frac{15.0 \text{ m/s}}{300 \text{ s}} = 459 \text{ N}$$

Big difference in the tension in the train couplings! One in the front has to "pull on more" than the one in the rear

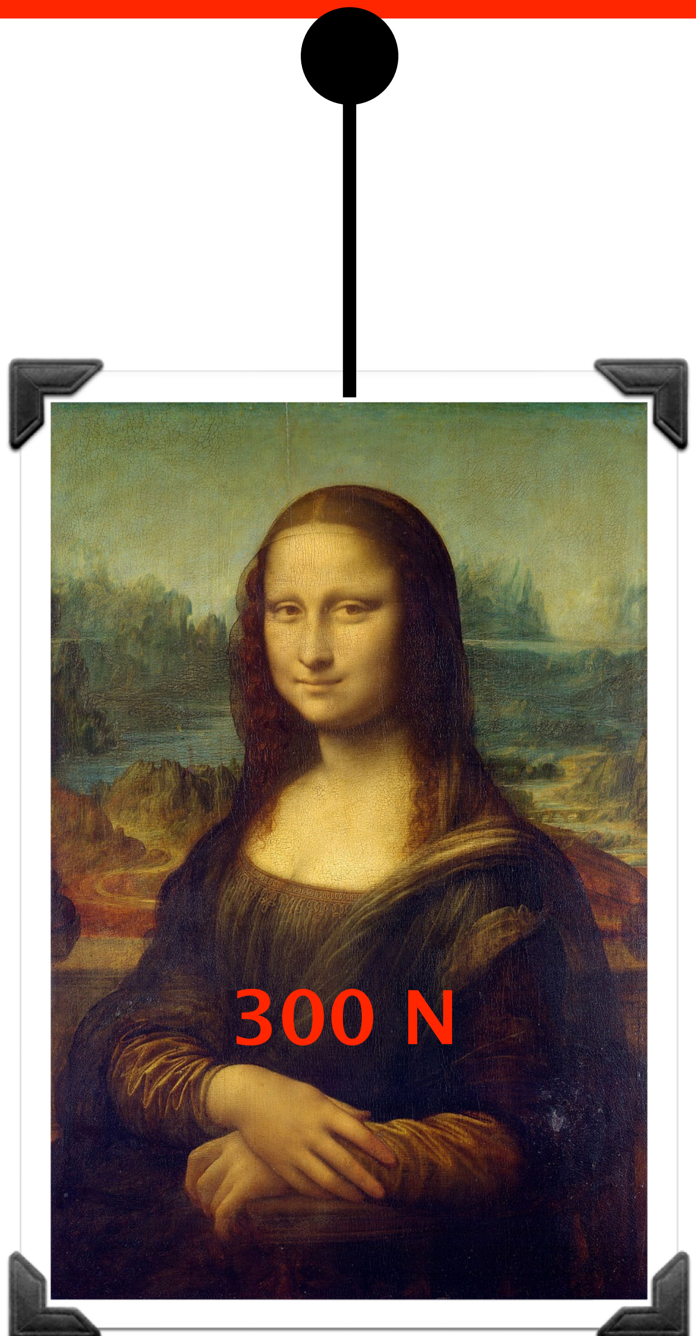
Let's imagine that we want to hang the Mona Lisa, and the picture plus frame weighs 300 N

Let's start with the simplest possibility:

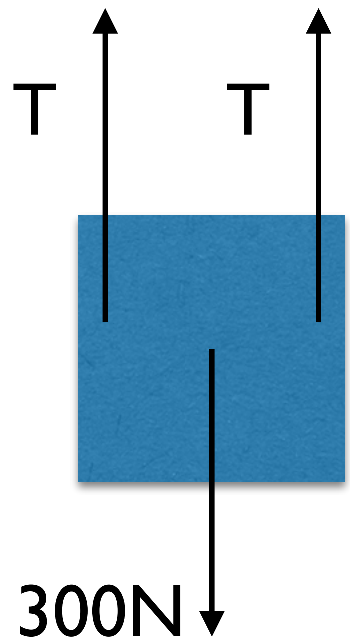


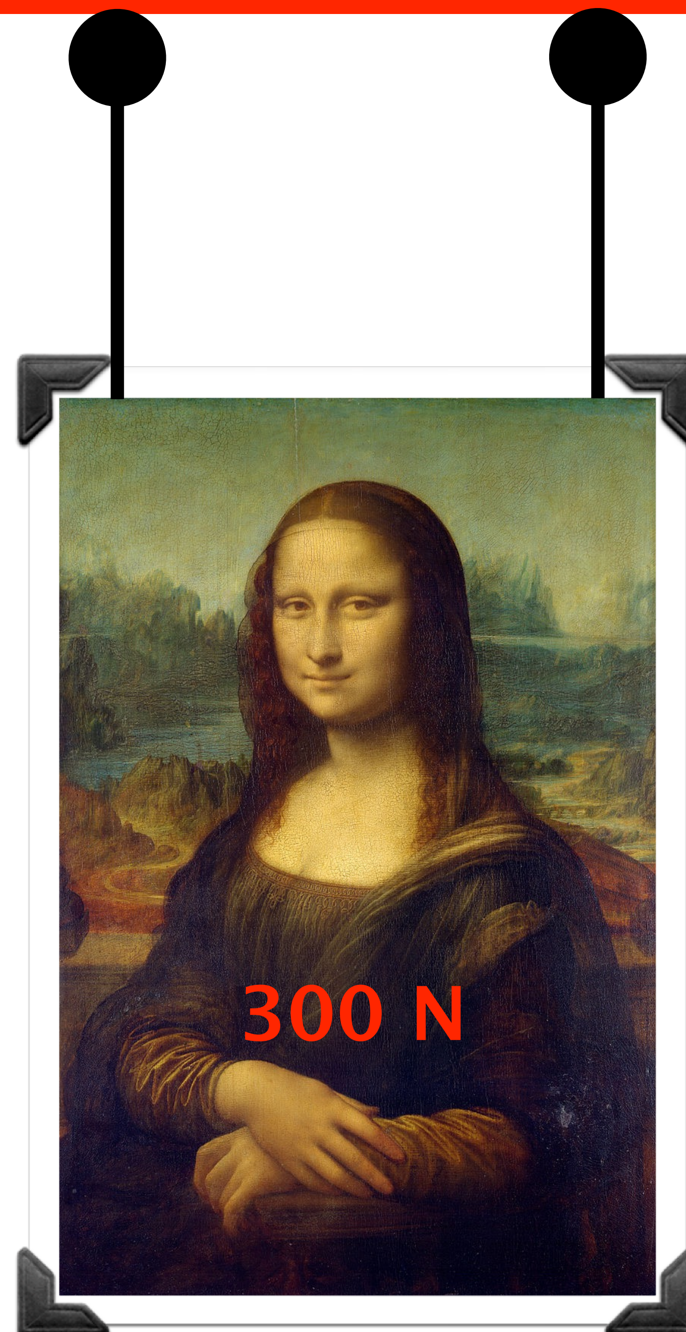


What must be the tension in the single string? Let's figure it out together

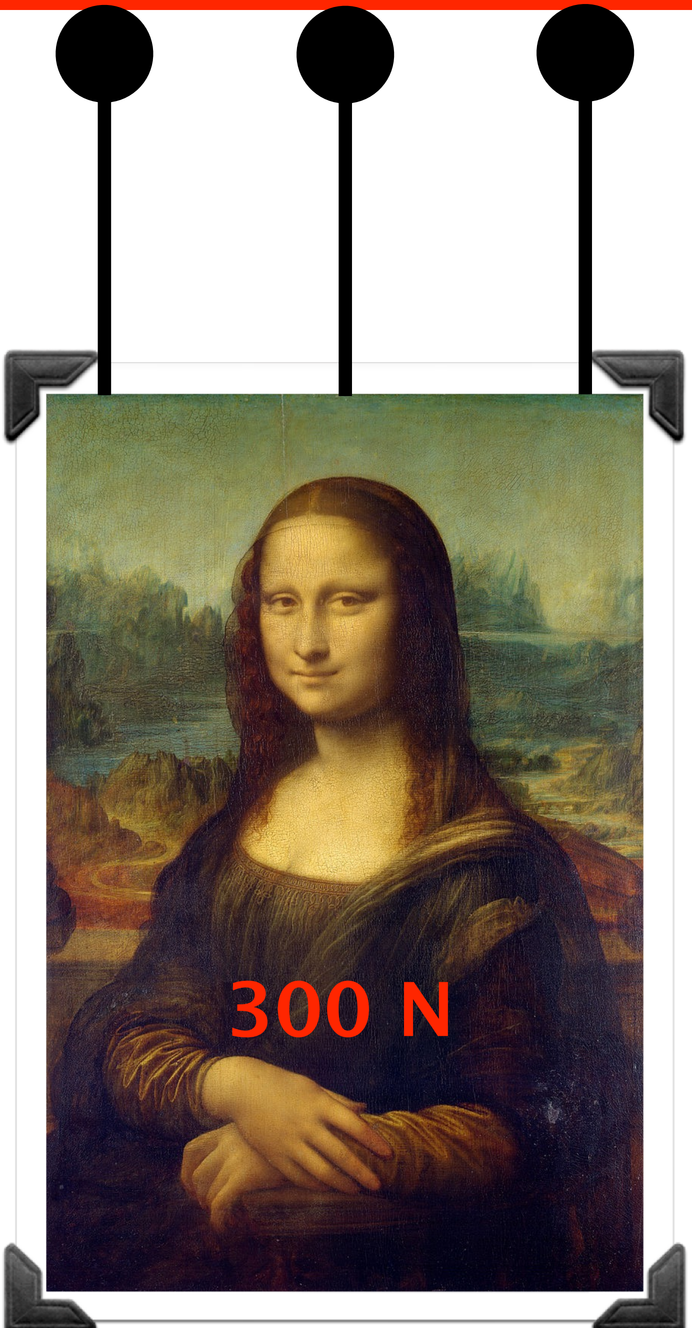


If the two cables are identical and equally spaced from the edges (we'll see why that is important in a few weeks), what must the tension be now in each cable?



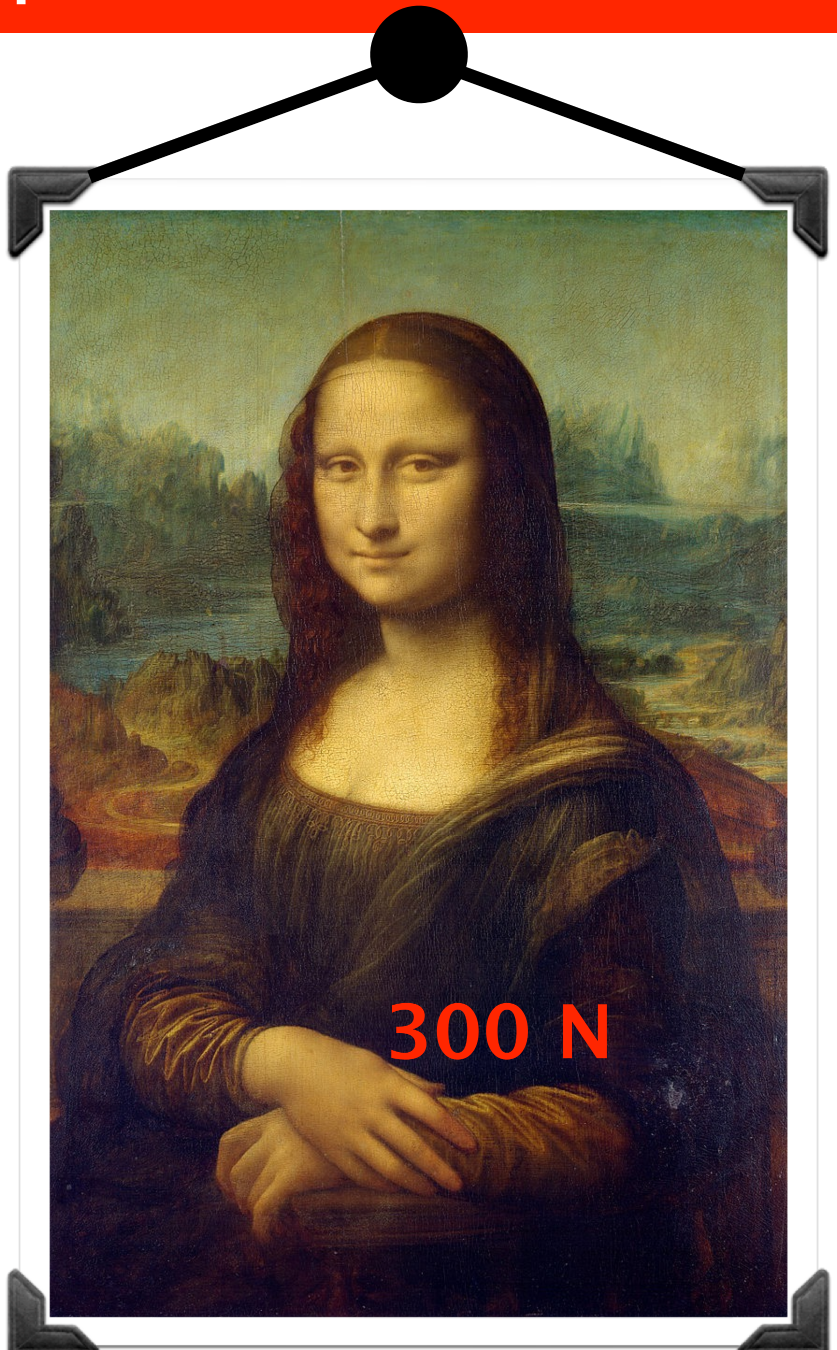


What about now? This is important if you don't have particularly strong cables



What about this?
Let’s first just think about it qualitatively. If we make things symmetric and strings are identical, what must be true about their tensions?

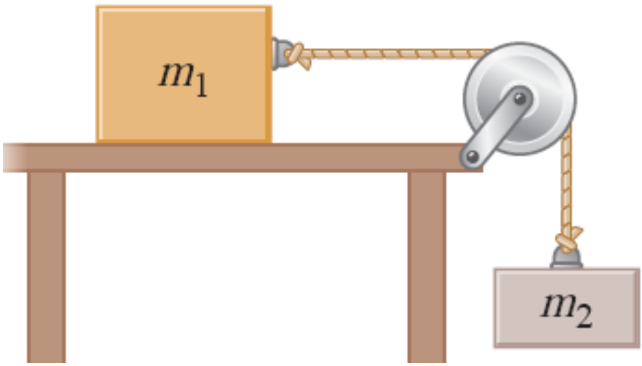
An extreme case - what do we expect here? Remember, the net force is zero so the components of the net force must also be zero!



Group work!
https://forms.gle/nWaMbn8rXKSycHNV8

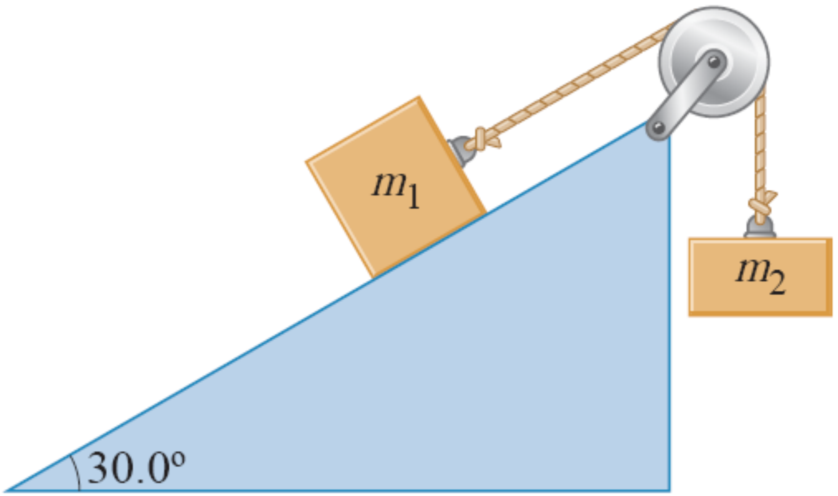
To slide a chest that weighs 750 N across the floor at constant velocity, you must push it horizontally with a force of 450 N. Find the **contact force** that the floor exerts on the chest

A block of mass m_1 = 3.0 kg rests on a frictionless horizontal surface. A second block of mass m_2 = 2.0 kg hangs from an ideal cord of negligible mass, which runs over an ideal pulley and then is connected to the first block. The blocks are released from rest.



(a) Find the accelerations of the two blocks after they are released.
(b) What is the velocity of the first block 1.2 s after the release of the blocks, assuming the first block does not run out of room on the table and the second block does not land on the floor?
(c) How far has block 1 moved during the 1.2-s interval?

A block of mass m_1 = 2.6 kg rests on an incline that is angled at 30.0° above the horizontal.

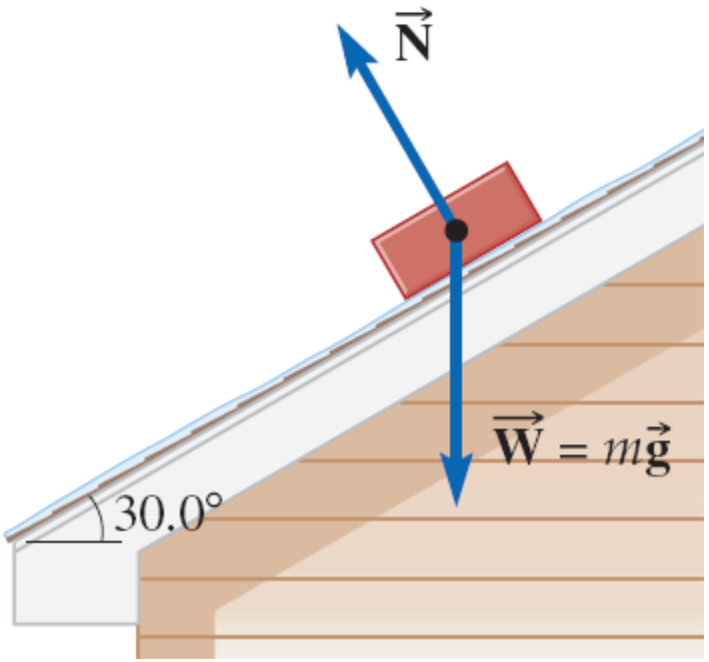


An ideal cord is connected from block 1 over an ideal, frictionless pulley to another block of mass m_2 = 2.2 kg that is hanging 2.0 m above the ground. The coefficient of kinetic friction between the incline and block 1 is 0.18. The blocks are initially at rest.

Question: How long does it take for block 2 to reach the ground?

A brick of mass 1.0 kg slides down an icy roof inclined at 30.0° with respect to the horizontal.

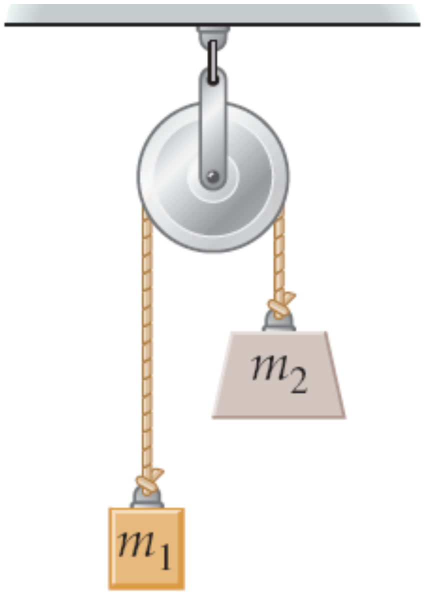
If the brick starts from rest, how fast is it moving when it reaches the edge of the roof 0.90 s later? Ignore friction.



How do we want to define our axes?

In the figure below, two blocks are connected by an ideal cord that does not stretch; the cord passes over an ideal pulley.

If the masses are m_1 = 26 kg and m_2 = 42 kg, what are the accelerations of each block and the tension in the cord?



A passenger weighing 598 N rides in an elevator. What is the apparent weight of the passenger in each of the following situations? In each case, the magnitude of the elevator's acceleration is 0.500 m/s^2.

(a) The passenger is on the first floor and has pushed the button for the fifteenth floor; the elevator is beginning to move upward.
(b) The elevator is slowing down as it nears the fifteenth floor.

Measuring the mass of astronauts is important, particularly on long space missions in outer space.

a) Stepping on a scale does not work for this. Why not?
b) How might NASA measure the mass of astronauts if not using a standard scale?

You pull a suitcase at a constant speed by exerting a force of 25.0 N at angle 30.0 degrees from the vertical.

a) Draw a free body diagram
b) What is the force of friction acting on the suitcase?

A hummingbird is hovering motionless besides a flower. The blur of its wings shows that they are rapidly beating up and down. If the air pushes upward on the bird with a force of 0.30 N, what is the force exerted on the air by the hummingbird?

Find in SI units the weight of a man who on Earth has weight 140 lb when he is on:

a) Mars ($g = 3.7$ N/kg)
b) Venus ($g = 8.9$ N/kg)
c) the moon ($g = 1.6$ N/kg)

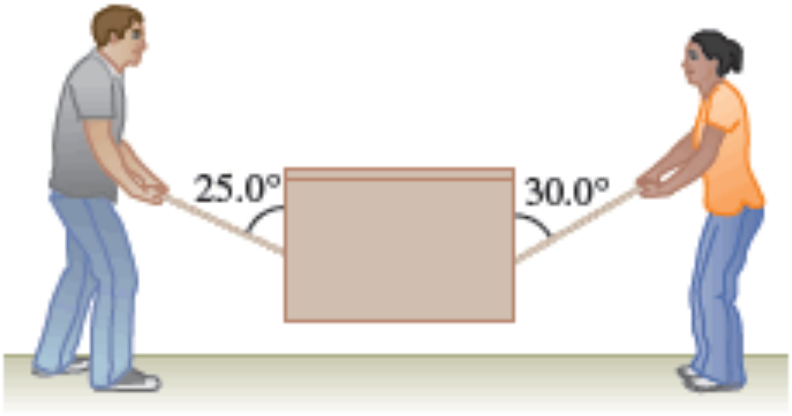
If a car (mass 1200 kg) traveling at 28 m/s is brought to a full stop in 4.0 s after the brakes are applied, find the average frictional force exerted on the car

A man lifts a 2.0 kg stone vertically with his hand at a constant upward acceleration of 1.5 m/s^2. What is the magnitude of the total force of the stone on the man's hand?

An 1100-kg airplane starts from rest and, with a constant acceleration of magnitude 4.0 m/s^2, reaches its takeoff speed in 8.0 s

(a) What is the magnitude of the net force on the airplane during this time?
(b) Sketch a FBD and label the magnitudes of the forces. Ignore friction
(c) What is its takeoff speed?

Jamal and Dayo are lifting a chest, weighting 207 lb, by using the two rope handles attached to each side. As they lift and hold it up so that it is motionless, each handles make a different angle with respect to the vertical side of the chest, as in the figure. What are the tensions in each handle?



Three crates with masses m1 = 5.45 kg, m2 = 7.88 kg and m3 = 4.89 kg are in contact on a frictionless surface. A horizontal force F=205 N is applied to the third crate as shown in the figure.

a) What is the magnitude of the contact force between crates 1 and 2?
b) What is the magnitude of the contact force between crates 2 and 3?

The forces on a small airplane (mass 1160 kg) in horizontal flight heading eastward are:

1) Gravity = 16.0 kN down
2) Lift = 16.0 kN up
3) Thrust = 1.8 kN eastward
4) drag = 1.4 kN westward

At t = 0 the plane's speed is 60.0 m/s. If the forces remain constant, how far does the plane travel in the next 60.0 s?

Yolanda, whose mass is 64.2 kg, is riding in an elevator that has an upward acceleration of 2.13 m/s^2. What force does she exert on the floor of the elevator?

A black widow spider hangs motionless from a web that extends vertically from the ceiling above. If the spider has a mass of 1.5 g, what is the tension in the web?

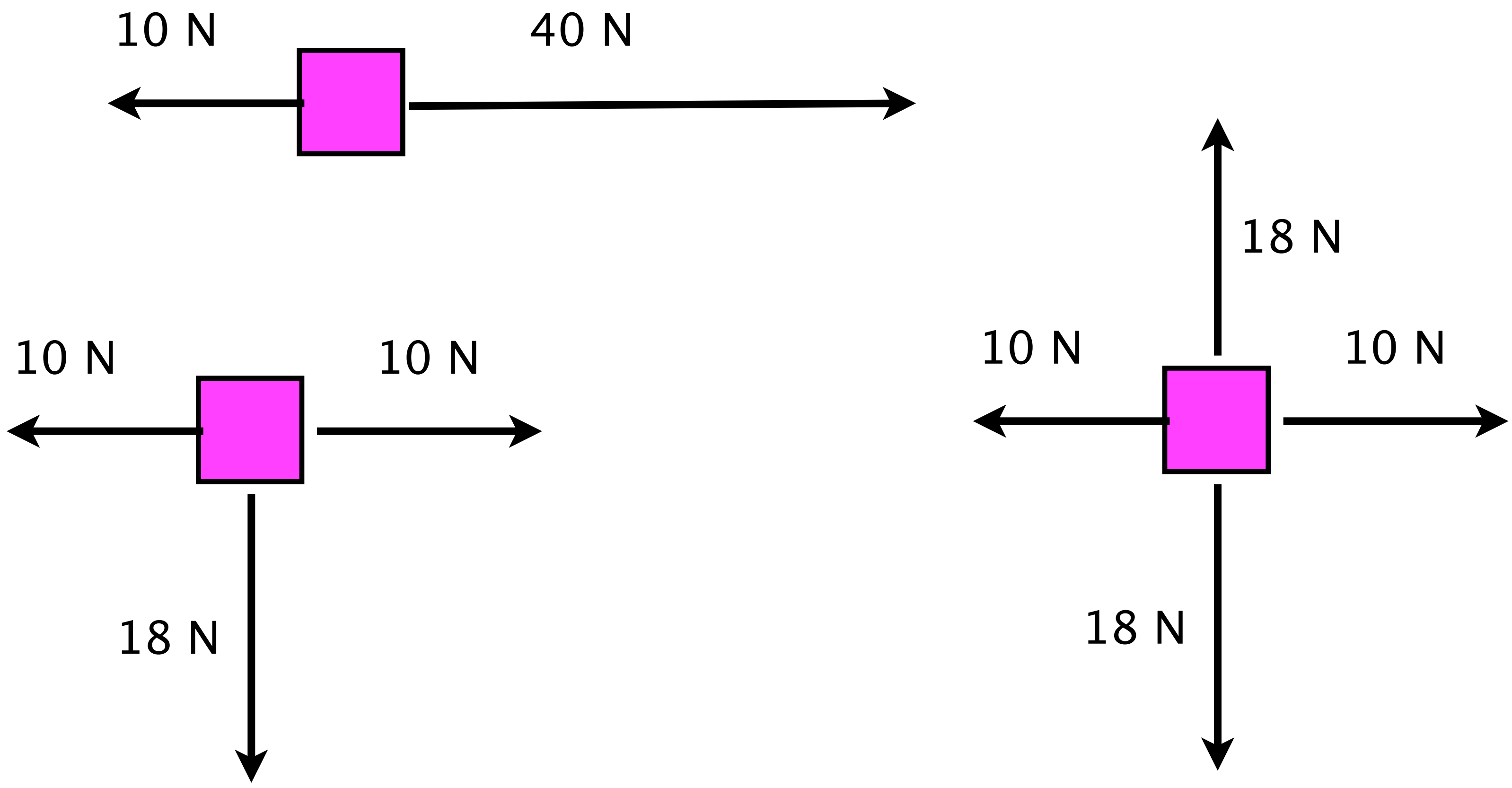
You place tomatoes in the pan of a hanging spring scale and find that they weight 2.5 lb. You measure the downward displacement of the scale's pan to be 1.5 inches. What is the spring constant? Give your answer in lb/in. and also in SI units

A student working on a school project modeled a trampoline as a spring obeying Hooke's law and measured the spring constant of a certain trampoline as 4617 N/m. A child of mass 27.0 kg compresses the spring vertically by a maximum of 0.25 m while bouncing up and down.

a) Draw a FBD for the child
b) What is the child's acceleration at the moment of maximum compression?

A 75 g arrow, fired at a speed of 110 m/s to the left, impacts a tree, which it penetrates to a depth of 12.5 cm before coming to a stop. Assuming the force of friction exerted by the tree is constant, what are the magnitude and direction of the frictional force acting on the arrow?

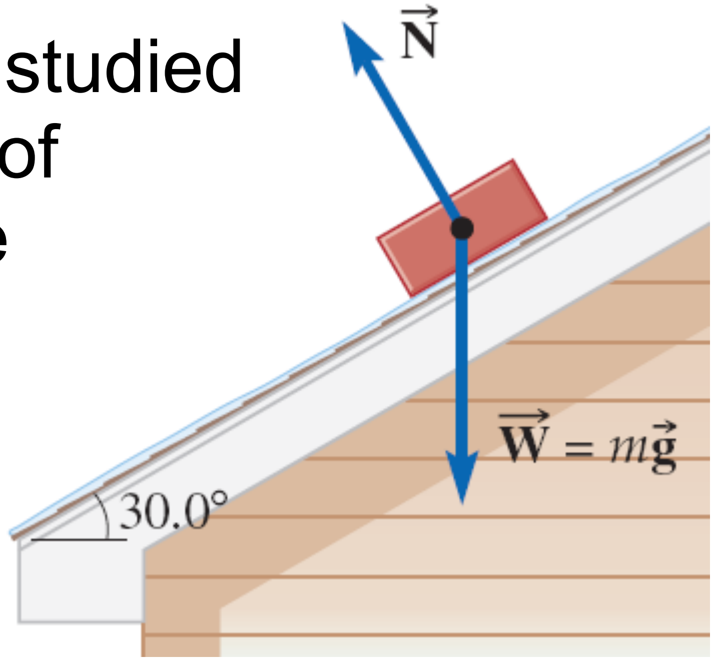
Find the magnitude and direction of the net force on the object in each of the free body diagrams:



You pull on a box with a rope at an angle of 60° with the horizontal, applying a constant force. The box has a mass of 23.0 kg. The coefficient of kinetic friction between the box and the floor is $\mu_k = 0.10$. Starting from rest, it takes 1.1 seconds for the box to reach a speed of 0.9 m/s.

What is the force that you are pulling with on the rope?

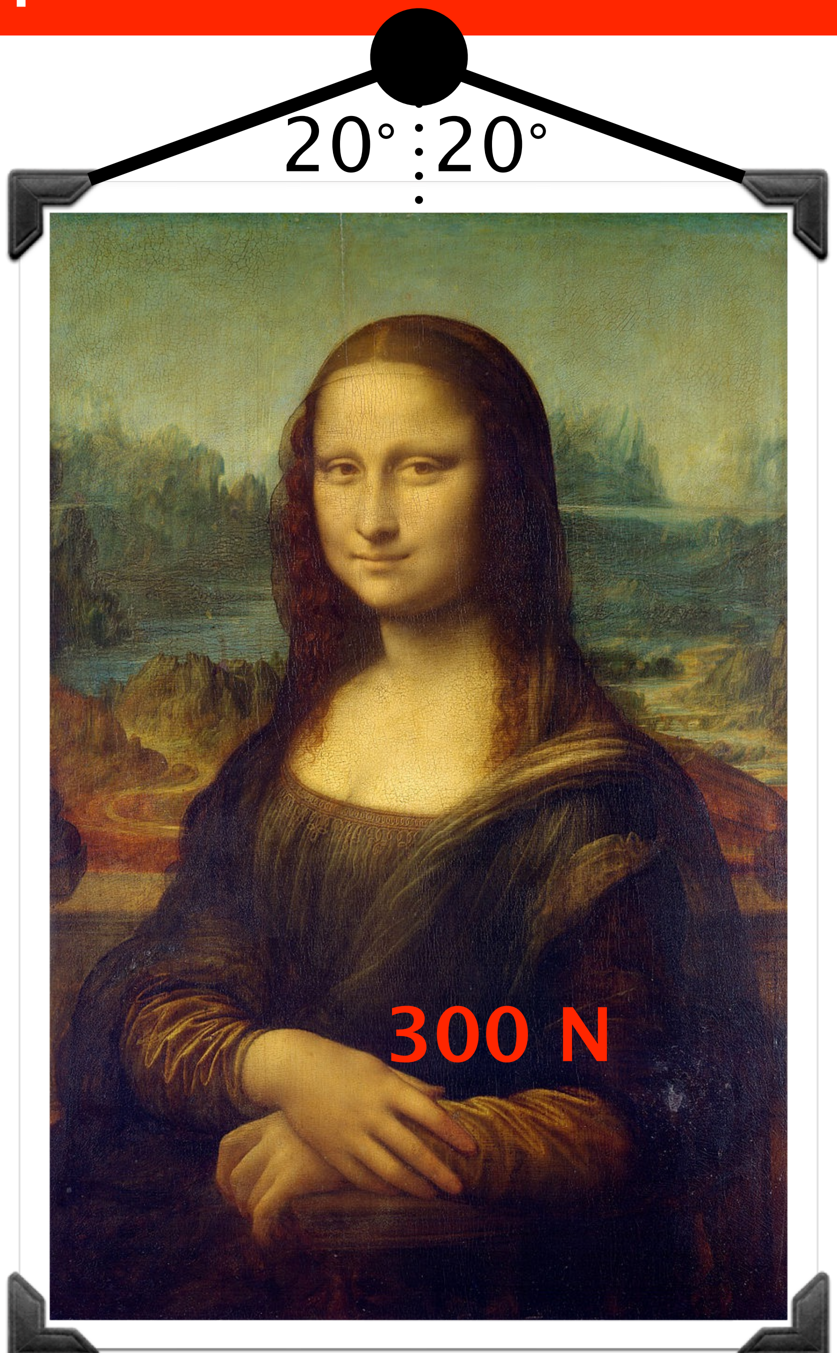
The same brick of mass 1.0 kg we studied earlier slides down the same icy roof inclined at 30.0° with respect to the horizontal.



Now assume the coefficient of kinetic friction is 0.05

What is the difference in speed after 0.90 s? By what fraction is the speed reduced? (Due to friction, the brick will now no longer be at the edge of the roof after 0.90 s)

Two identical cords are holding the Mona Lisa. What is the tension in each of them?



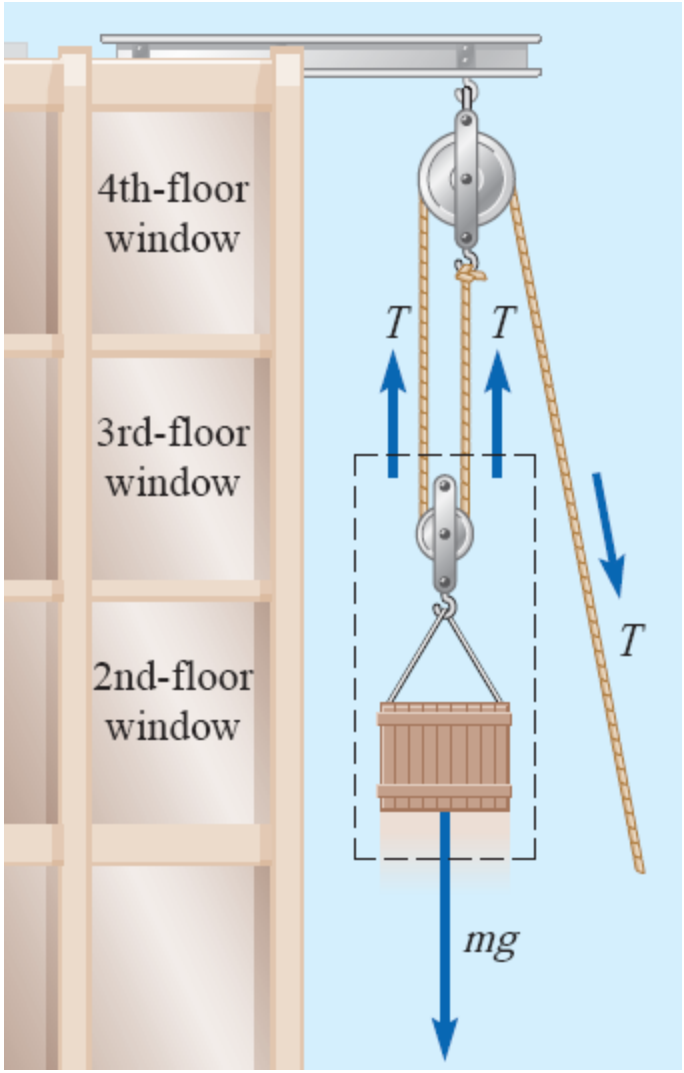
A small plane of mass 760 kg requires 120 m of runway to take off by itself. (120 m is the horizontal displacement of the plane just before it lifts off the runway, not the entire length of the runway.)

As a simplified model, ignore friction and drag forces and assume the plane's engine exerts a constant forward force on the plane.

(a) When the plane is towing a 330-kg glider, how much runway does it need?
(b) If the final speed of the plane just before it lifts off the runway is 28 m/s, what is the tension in the tow cable while the plane and glider are moving along the runway?

A student is moving into a dorm room on the third floor, and he decides to use a block and tackle arrangement to move a crate of mass 91 kg from the ground up to his window.

If the breaking strength of the available rope is 550 N, what is the minimum time required to haul the crate to the level of the window, 30.0 m above the ground, without breaking the rope?



A safe is to be moved up a ramp to a height of 1.5 m above the floor.

The mass of the safe is 510 kg, the coefficient of kinetic friction along the incline is $\mu_k = 0.33$. The ramp forms an angle $\theta = 15°$ above the horizontal.

To slide the safe up at a constant speed, with what magnitude force must the movers push?

Here's an interesting question: You pull on your suitcase via a strap that makes an angle θ with the horizontal. As the suitcase moves on the floor, it is subject to a frictional force due to a coefficient of kinetic friction μ_k. What angle θ should be chosen to provide the largest acceleration to the suitcase if $\mu_k = 0.1$? 0.3? Other values? Discuss your answer