Physics Problems for Nerds

Analyzing “nerd” culture through physics 101

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Introduction

It should not be a surprise that students do better when subject matter is presented via topics they care about. This effect comes from focusing their attention towards subject matter by using such topics. It is also of note that most students do not inherently care about a block sliding down a ramp, or a block on a frictionless plane. To utilize this method of focusing attention I composed physics problems presented via topics students are more likely to be invested in: Superheroes, Movies, Video Games, TV shows. What follows are a selection of such problems divided by problem type. Separately attached are solutions for each of these problems. Embrace pop culture and have fun with the physics! If we as professors cannot have fun with our subject matter, then our students are unlikely to either.

Of note, some of these problems may seem repetitive. This is a deliberate choice as I prefer to use similar problems for practice. If your own preferences differ do not feel any hesitation to utilize individual problems out of each set.

Chapter 1: Unit conversions

1. In *Star Wars: The Force Awakens* the Starkiller Base has a diameter of 660 km. What is the diameter in miles? (1 mile = 1.609 km)

2. The landmass of Sokovia lifted in the air in *Avengers: Age of Ultron* had a volume of about 2.09 km^3. What volume is that in $miles^3$? (1 mile = 1.609 km still)

3. Doc Brown's DeLorean needs to go 88.0 miles/hour to time travel. How fast is this in m/s? 1 mile = 1609 m. 1 hour = 3600 s

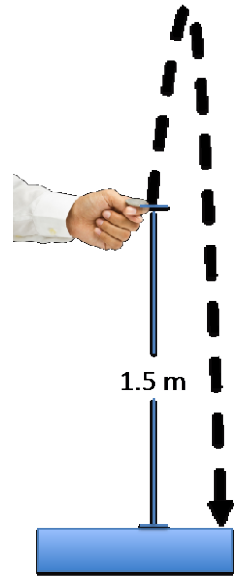
4. A sheppey, as defined by author Douglas Adams, is defined as the closest distance at which sheep remain picturesque, where 1 sheppey is 0.875 miles. Convert the distance from Delhi to Oneonta (21.2 miles) to sheppies.

5. Westeros, from *Game of Thrones*, has an area of approximately 6.89×10^6 $miles^2$. Convert the area of Westeros to km^2 where 1 mile = 1.609km.

6. Iron Man's suit is said to weigh 225 lbs. What is its mass in kilograms?
   1 kg = 2.20 lb

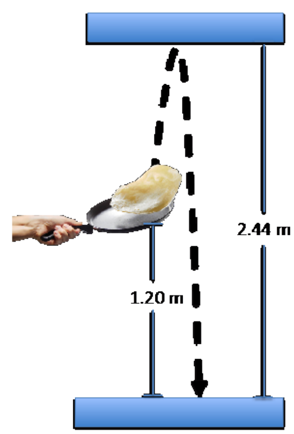
7. The play area in the video game *Red Dead Redemption 2* is 75.0 km^2. Convert this area to $miles^2$ where 1 mile = 1.609 km.

Chapter 2: One Dimensional Motion



1. For a coin toss at the beginning of a football game, a coin is flicked up in towards speed of 7.0 m/s from a height 1.5 m above the ground. It isn't caught but falls all the way to the ground. A) What is the coin's velocity when it hits the ground? B) How long is the coin in the air, from the instant it is released until it hits the ground?

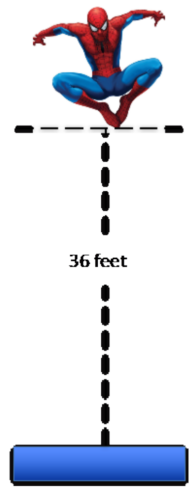
2. The record for the fastest recorded pitch in major league baseball is 105.1 mph (pitched by Aroldis Chapman in 2010). a) If Aroldis managed to pitch another ball at the same speed, what maximum height (as measured from the release point) would it reach? b) If he caught it at the same height he released it from, how long would the ball be in the air? Hint: 1 mile = 1609 m



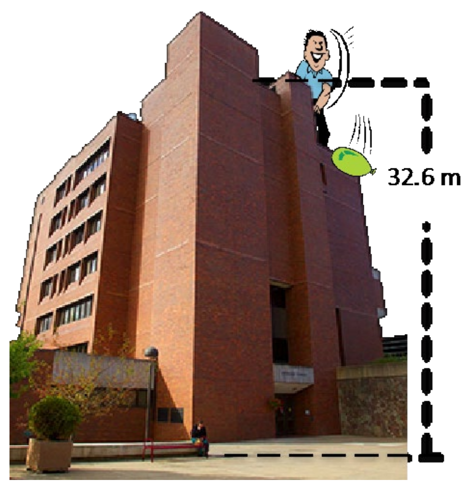
3. A person is making pancakes and tries to flip one in the pan. The person is holding the pan 1.20m above the ground when they launch the pancake. The pancake just barely touches the ceiling, which is 2.44 m above the ground. A) What must be the initial velocity of the pancake to reach that height? B) This person, shocked that they almost hit the ceiling, does not catch it on the way down and the pancake hits the floor. How long did it take from the initial flip until the pancake hit the floor ruining breakfast and this person's day?

4. Biff Hutchison and Dalton Smith are tied for the highest jump on a pogo stick world record. They both managed to get a maximum height of 10.5 feet above the ground. A) What initial velocity did they need to achieve that height? B) What was the total air time of the jump (time from leaving the ground until return to the ground) 1m = 3.28 feet

5. One of Spiderman's less discussed powers is that he can jump really high. In the comics Spider-man can jump upwards 3 stories, which is 36.0 feet. A) What initial velocity does Spider-man need to leave the ground to reach this height? B) If Spider-man jumps directly upwards with the initial velocity found in part A and then returns to the ground, what total amount of time does he spend airborn? (1m = 3.28 feet)

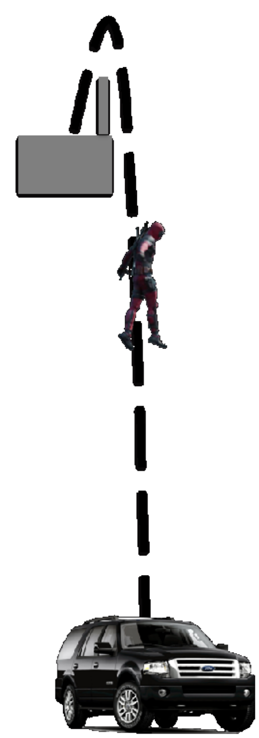


6. A student sneaks up to the roof of Evenden Tower, which is 32.6m above the ground, to throw waterbaloons at passerbys. A) If they give the water balloon an initial velocity of 32.0 miles per hour straight downward, at what velocity does the water balloon hit the pavement? B) How long will it take the balloon to hit the pavement below? (1 mile = 1609m)



7. Gollum jumps up to take the ring (and a finger) from the hobbit Frodo Baggins who is standing on a ledge overlooking the volcano called Mount Doom. A) What initial velocity does Gollum need to have a maximum height of 0.982 m above the ledge (the height of Frodo's hand)? B) Gollum grabs the ring (and finger) and without slowing or stopping misses the ledge and falls down into the lava below. It takes 6.00 s to hit the lava from the time he began his leap. What is Gollum's velocity when he hits the lava? Assume gravity in Middle Earth is the same as on Earth.

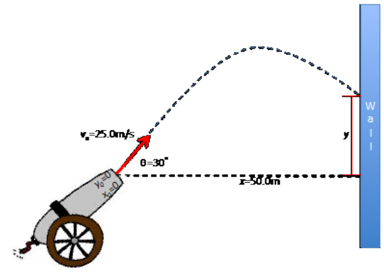
8. The first *Deadpool* movie opens with Deadpool stepping off a bridge into a car below. Deadpool's slight hop off the bridge gives him an upward initial velocity of 2.21 m/s. The bridge Deadpool starts on is 55.0 ft above the cars below. A) What is Deadpool's velocity when he hits the car at the bottom? B) How long until Deadpool hits the car below? 1m = 3.28 ft



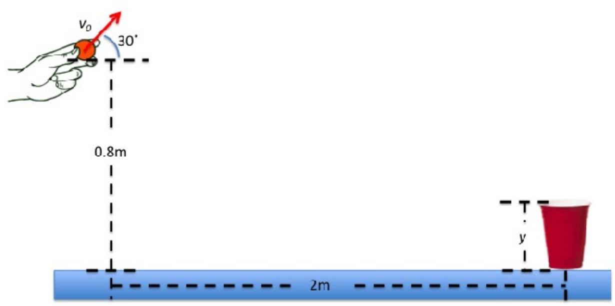
9. The launch pads in *Fortnite* can launch players straight up with an initial velocity of 39.0 mph. A) What is the maximum height, in m, of the player?) If the player goes straight up and then straight back down and hits the ground at the same place, how much total time do they spend in the air?
   1mile = 1609 m

Chapter 3: Projectile Motion

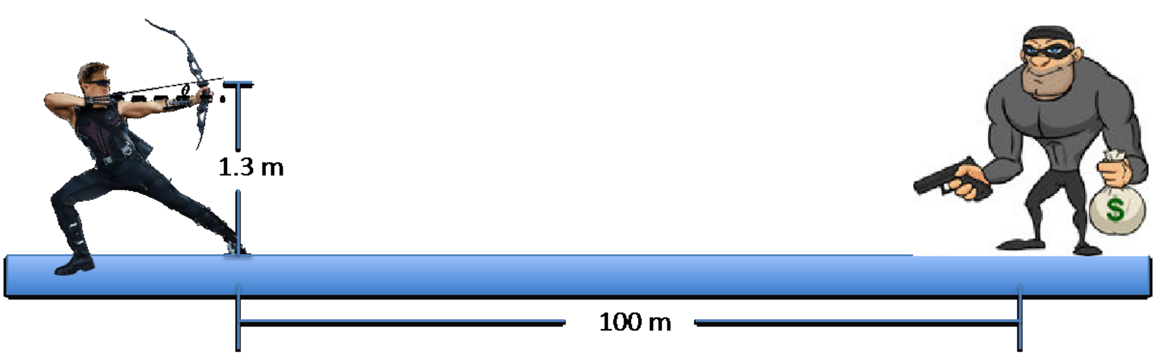
1. A student who is being punished for not studying for a physics final is shot out of a cannon at 45.0° above the horizontal with an initial speed of 25.0 m/s. A net is positioned a horizontal distance of 50.0 m from the cannon. At what height above the cannon, in yards, should the net be placed in order to catch the student? (hint: 1 yard = 0.914 meters)



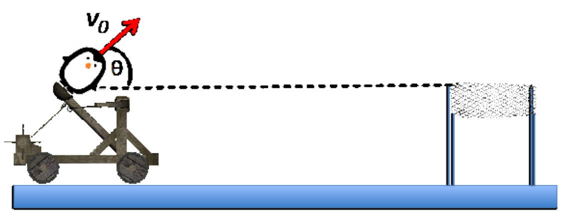
2. A student, in an effort to forget about a physics final, plays some beer pong. The student throws a Ping-Pong ball at an angle of 30.0˚ above the horizontal with an initial velocity of 3.77 m/s. They are standing 2.00 m away from the cup they are aiming at and releasing the ball 0.800 m above the top of the table. The ball goes into the cup. What must the height of the cup be in inches? (Hint, find the height *y* of the ball when it has traveled 2m in *x*.) (1 inch = 0.0254 m)



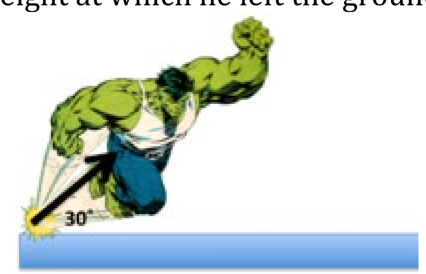
3. Hawkeye (from The Avengers) wants to shoot a distant criminal. To do this, he fires an arrow at a 3.00˚ angle to try to hit the criminal who is 100. m away from him. If he shoots the arrow from 1.30 m above the ground (approximately chest high) at an initial velocity of magnitude of 225 miles per hour at what height is the arrow when it travels the 100. m? (If the arrow is between a height of zero and 2 meters after traveling 100. m he hits the target.) (1 mile = 1609.34 meters)



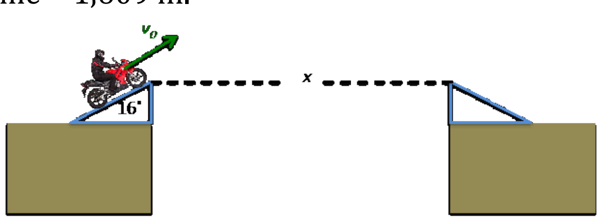
4. A rather inhumane circus show decides to shoot penguins from a catapult (because who wouldn't want to watch that). However, they don't want their penguins to die, so they set up nets. The catapult launches a penguin at 30˚ with an initial velocity of magnitude of 22 m/s. If the net catches the penguin at the same height it is launched at ($y=y_0$), how far away does the net need to be? Please put your answer in feet, since this is an American circus. 1m = 3.28 feet



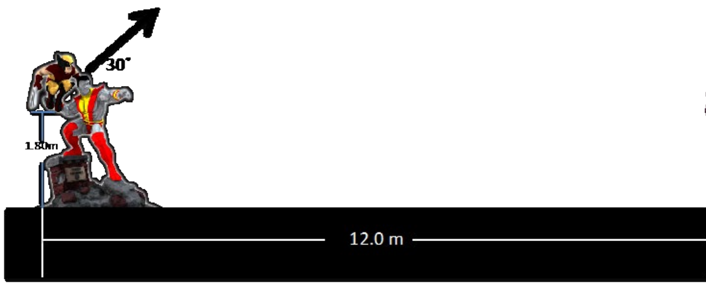
5. The Incredible Hulk travels from place to place by taking huge leaps according to the comic books. Also, according to the comic books, the Hulk can leave the ground with an initial velocity of 220 m/s. If the Hulk leaves the ground at an angle of 30˚, how far can he travel in x? Assume that he lands at the same height at which he left the ground ($y=y_0$).



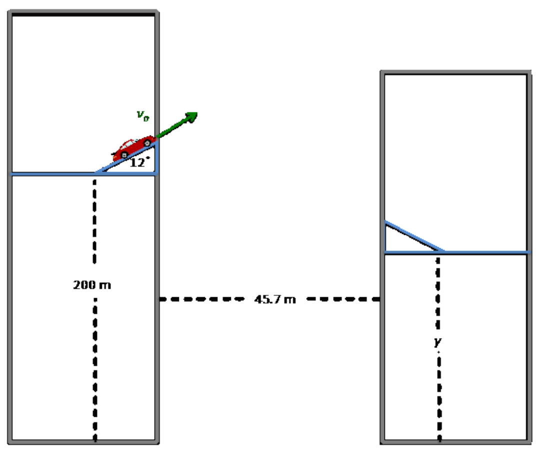
6. In 1999 Robbie Knievel, son of famous stuntman Evel Knievel, jumped the Grand Canyon on a motorcycle on live television. He was traveling at 80.0 mph when he left the take off ramp, which was at 16.0˚ from the horizontal. The ramp he landed on was at the same height as the one he left. How wide was the Grand Canyon at that point? (note, this is real numbers and did happen) 1 mile = 1,609 m.



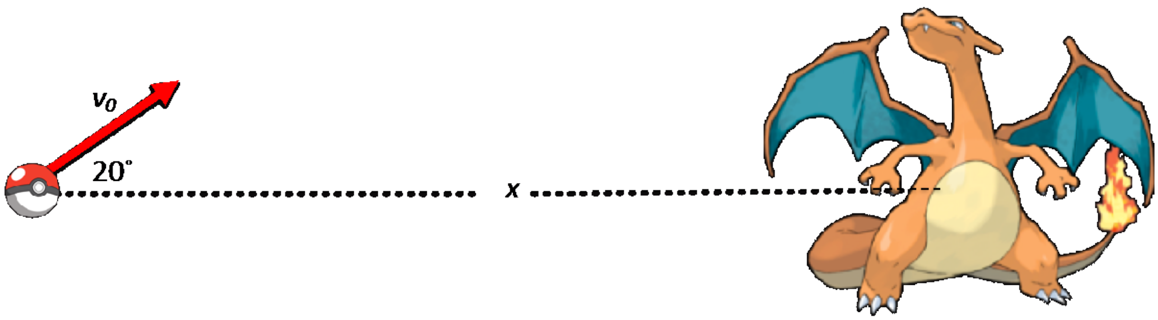
7. In X-Men comic books the mutant Colossus often picks up Wolverine and throws him (claws first) at enemies. This move is known as a "fastball special." Let's say Colossus throws Wolverine with an initial velocity of 35.6 mph at an angle of 30.0˚ from the horizontal at a Sentinel (very large bad robot) that is 12.0m away. If Colossus throws Wolverine from an initial height of 1.80m, at what height above the ground does Wolverine hit the Sentinel? (hint: 1 mile = 1609 m)



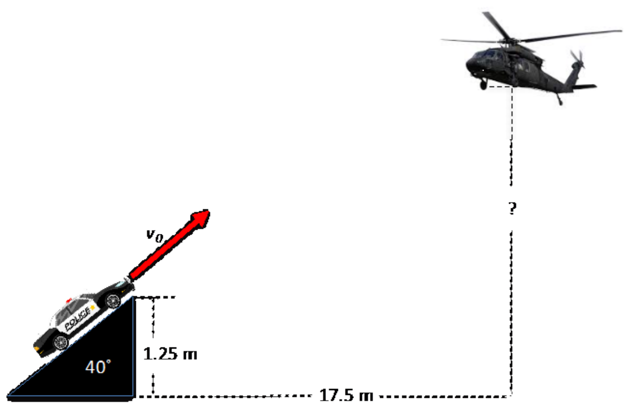
8. In the movie *Furious 7*, the heroes Dom and Brian jump a car out of one of the Etihad Towers in Abu Dhabi and land inside another of the towers a few floors lower. The buildings are 45.7m away from each other. Let's say they start about 50 stories high, which is 200.m off the ground. If the car leaves the building traveling at 26.8 m/s (only 60 mph since there is not much room to speed up) at an angle of 12.0˚, how high off the ground does the car hit the 2nd building?



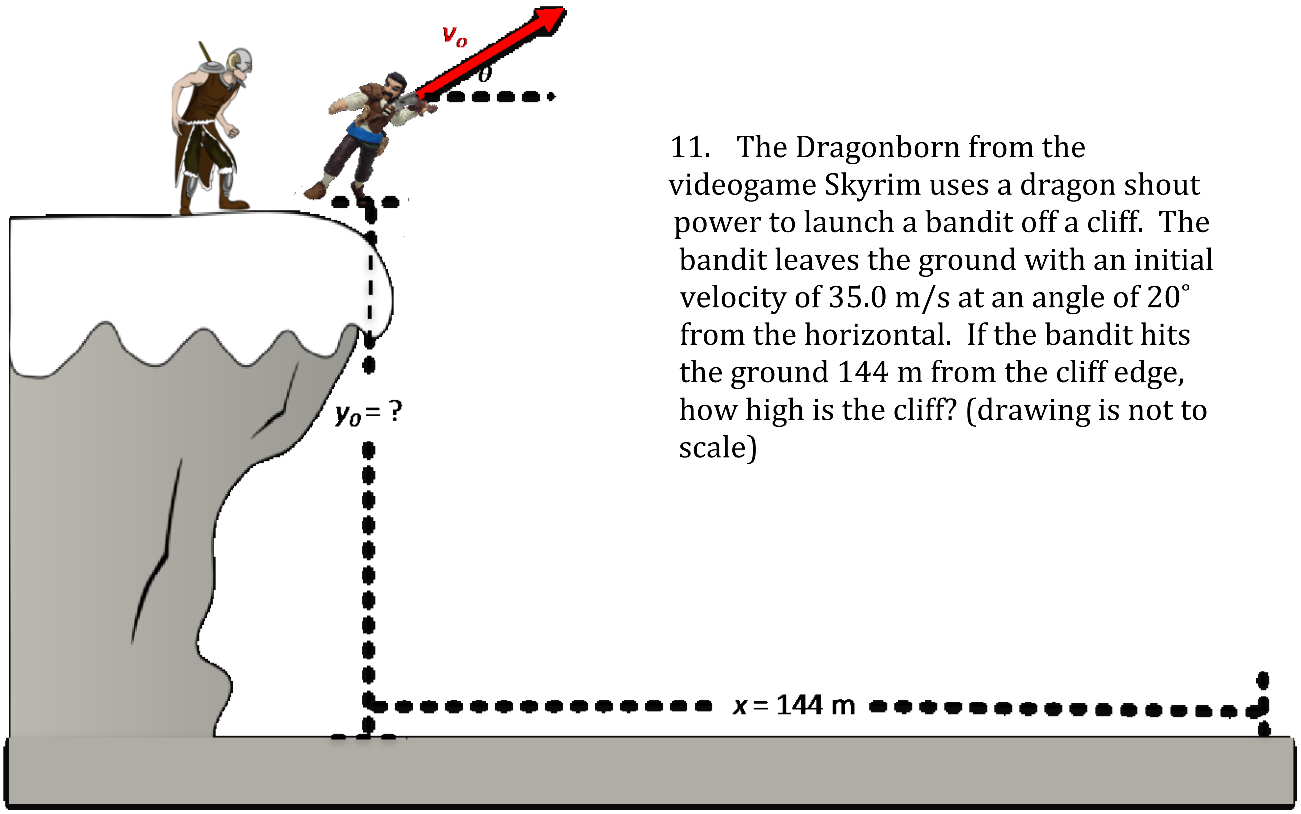
9. A wild Charizard appears! A Pokémon trainer sees a Charizard and throws a pokéball at the Charizard to catch it. The trainer throws the ball with a velocity of 15.0 m/s at an angle of 20.0˚ from the horizontal. The pokéball hits the Charizard at the same height from which it was thrown (as in $y=y_0$). How far away is the Charizard?



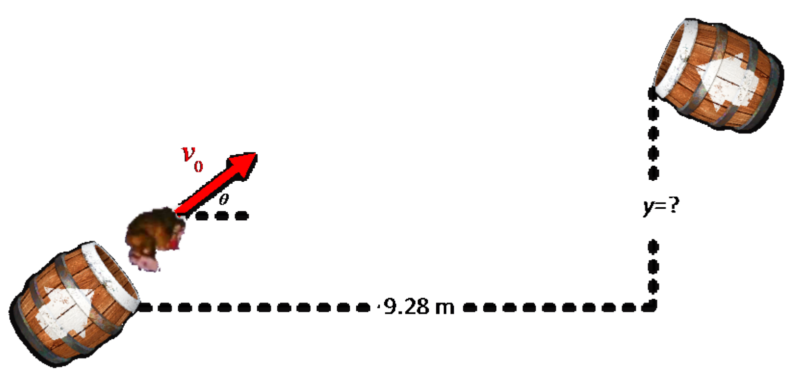
10. In the movie *Live Free or Die Hard* (also known as *Die Hard 4*) the character John McClane knocks a helicopter out of the sky by launching a police car off a ramp and into the helicopter. Let's say the car is traveling 70.0 mph when it hits the end of a 40.0˚ ramp. The car leaves the ramp at a height of 1.25m above the ground. If the helicopter is 17.5 m away, how high above the ground is the helicopter when the police car hits it? (1 mile = 1609 m)



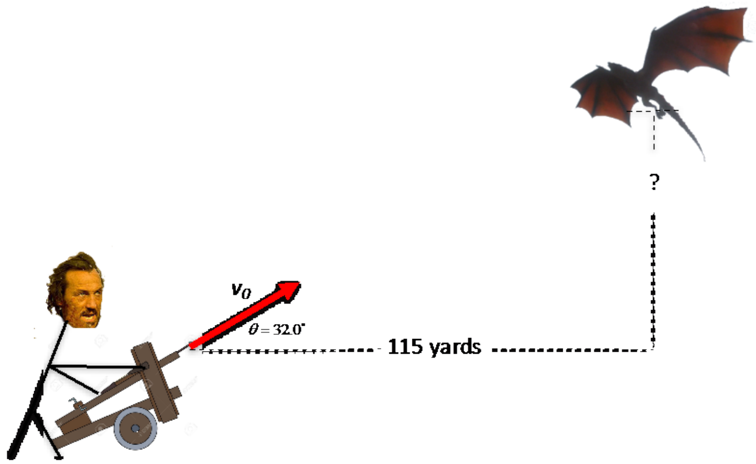
11. The Dragonborn from the videogame Skyrim uses a dragon shout power to launch a bandit off a cliff. The bandit leaves the ground with an initial velocity of 35.0 m/s at an angle of 20˚ from the horizontal. If the bandit hits the ground 144 m from the cliff edge, how high is the cliff? (drawing is not to scale)



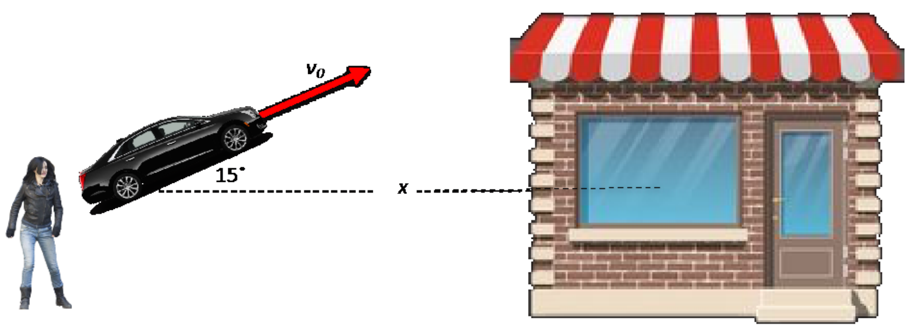
12. In the *Donkey Kong Country* video games you often get around by shooting yourself out of barrel cannons. Donkey Kong wants to launch out of one barrel and land in a different one that is a distance in x of 9.28 m away. To do so he launches himself at a velocity of 15.0 m/s at an angle of 30˚. At what height does the 2nd barrel need to be for Donkey Kong to land in it? (measure from the height of barrel 1, aka y_0=0)



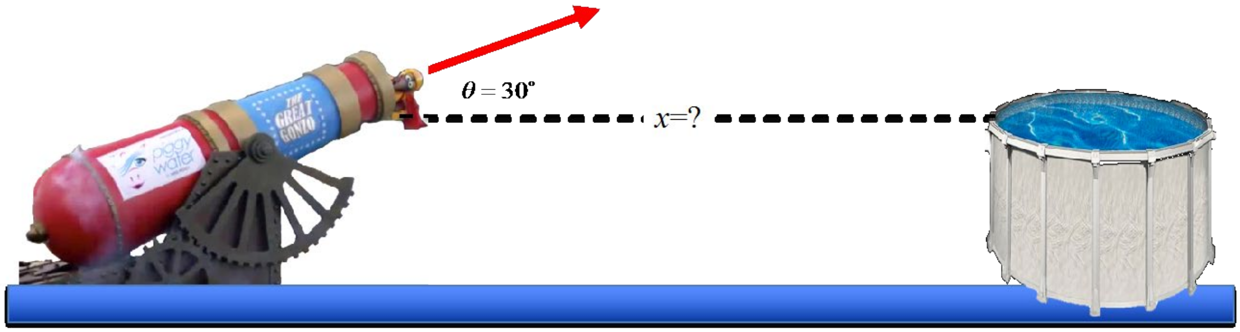
13. Bronn, from *Game of Thrones*, tries to hit a flying dragon with a ballista (picture a giant crossbow). He launches a bolt from the ballista at 67.7 m/s at an angle of 32.0° when the dragon is 115 yards away, as shown below. He hits the dragon, clipping its side. How high above the ballista must the dragon have been? (1 m = 1.09 yards)



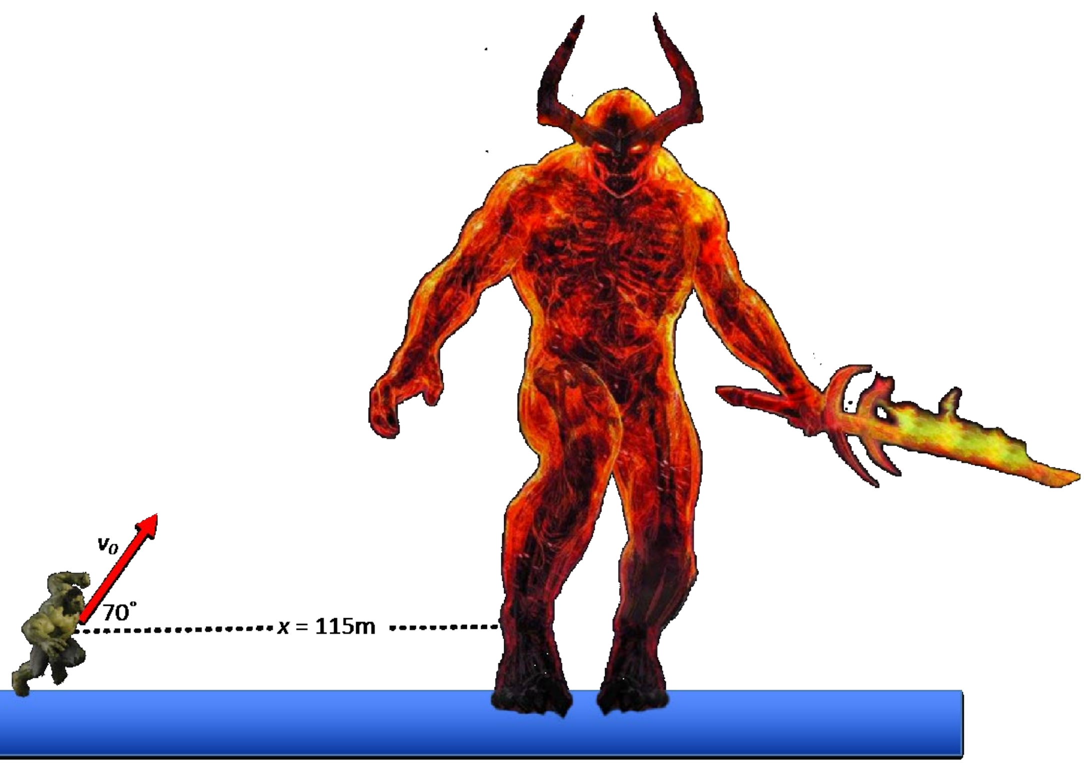
14. Jessica Jones, in an effort to defend her fellow Defenders, throws a car through a plate glass window of a restaurant. She launches the car with an initial velocity of 9.00 m/s at an angle of 15.0°. The car hits the window at the same height she threw it from. How far away was she from the window before throwing the car?



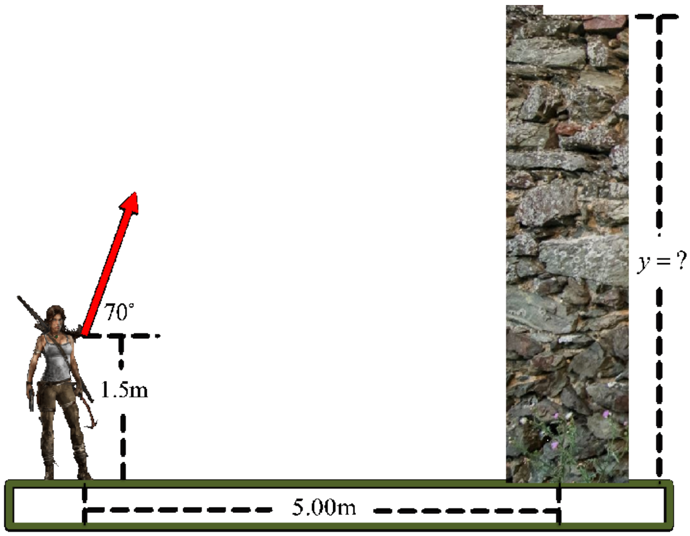
15. The Great Gonzo, of *Muppets* fame, shoots himself out of a cannon into a pool of water. Gonzo hits the pool at the exact same height he leaves the canon. ($y=y_0$) If the Gonzo leaves the canon with an initial velocity of 80.0 mph at 30.0˚, how far away must the pool be to hit it? 1mile = 1609 m



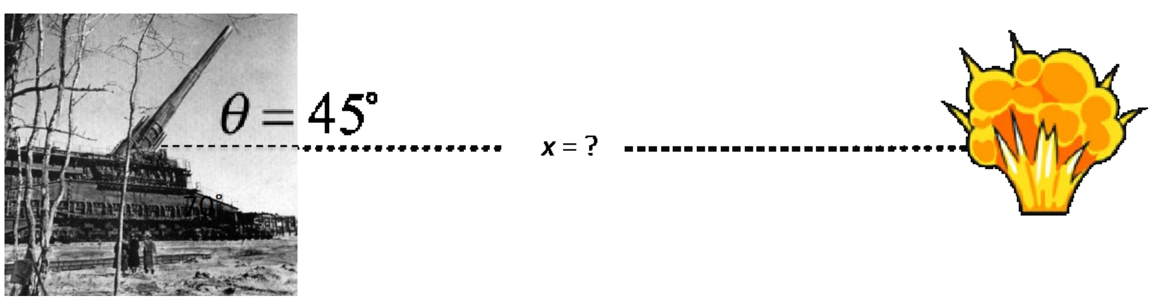
16. In the movie *Thor: Ragnarok* the incredible Hulk jumps from the ground up to the face of Surtur, a rather large fire demon (it's not a spoiler if it is in the trailers). Hulk leaves the ground at 220 m/s at an angle of 70˚ from the horizontal and hits Surtur right in his face. If Hulk started 115 m away from Surtur's feet (as shown below), how high is Surtur's face?



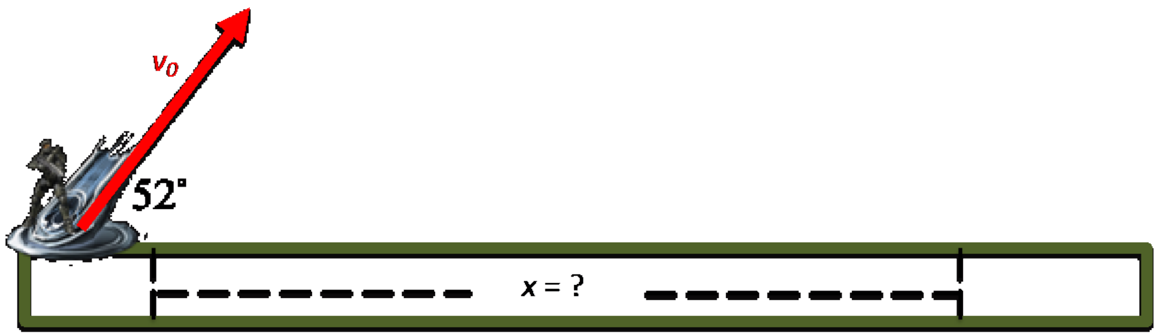
17. Lara Croft, of *Tomb Raider* fame, is trying to get to the stop of a stone wall so she throws a grappling hook to the top. The hook leaves Lara's hand at 14.0 m/s at an angle of 70˚ and hits the top of the wall 5.00 m away. If she released the hook 1.5 m above the ground, how high is the wall?



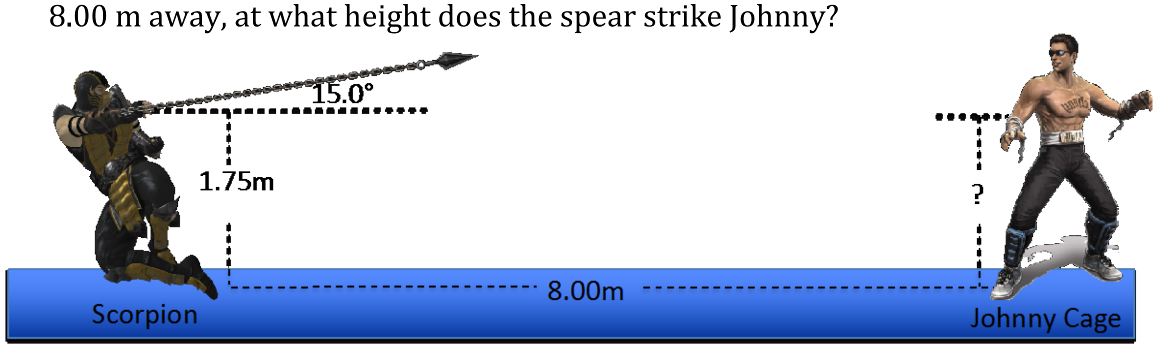
18. During World War 2, the German army constructed the V-3 cannon which was the longest ranged projectile launcher ever made which does not utilize self-propelled projectiles - luckily, it was destroyed before its first firing! The Germans had hoped to bombard London from France. This cannon could launch projectiles with a muzzle velocity of 1.50 x 10^3 m/s. If a projectile was fired from this gun at 45.0˚, what is the total horizontal distance the projectile would travel assuming it landed at the same height it left the cannon? (Hint: $y=y_0$)



19. The *Halo* franchise has jump pads that launch you out at an angle. Let's say a *Halo* jump pad launches the Master Chief with an initial velocity of 18.8 m/s at an angle of 52.0˚. If he hits the ground at the same height he was launched at ($y = y_0$), how far does he travel horizontally?

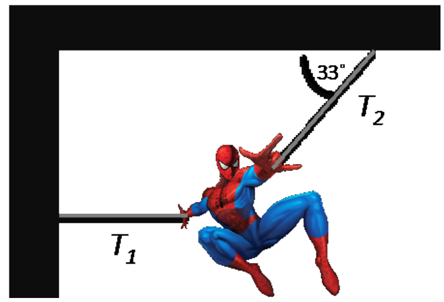


20. Scorpion, from *Mortal Kombat*, throws a spear attached to a chain at Johnny Cage while yelling "Get over here!" The spear leaves Scorpion's hand at 11.0 m/s at an angle of 15.0° and from 1.75 m above the ground. If Johnny Cage is 8.00 m away, at what height does the spear strike Johnny?

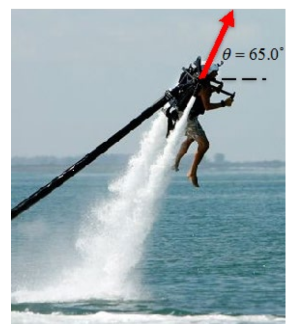


Chapter 4a: Forces (without Friction)

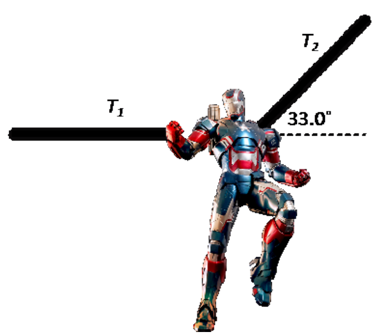
1. Spider-man holds himself up in the corner of a building by two strands of webbing, one completely horizontal and one at 33.0˚ as shown in the figure below. What tensions are needed in the horizontal web strand (T_1) and the angled web strand (T_2) to hold Spider-man still if Spider-man has a mass of 75.7 kg?



2. A recent invention is a type of jetpack that uses water to lift you. By shooting a concentrated stream of water down and behind you, the jetpack can create a force up and to the right, as shown in the figure below (note, this is not a completed free body diagram). A) What force must the jetpack be exerting at 65.0˚ (as shown below) to keep a 90.0 kg person at a set height, neither rising nor lowering? B) When the force found in A is applied, what is the person's acceleration, both magnitude and direction?

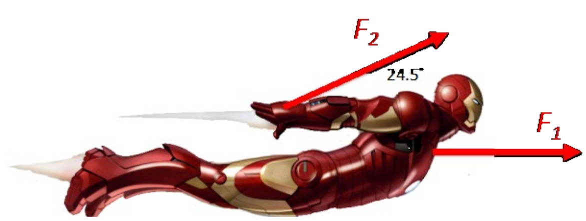


3. At the end of *Iron Man 3* (spoilers for a 3.5-year-old movie) the president of the United States of America is hung at rest from two cables while in the Iron Patriot suit. The cables holding the president are at the angles shown below, one horizontally and one at 33.0˚. What are the tensions, T_1 and T_2, of the two cables? The total weight of the president in the Iron Patriot suit is 700. lbs. (1 lb = 0.454 kg)

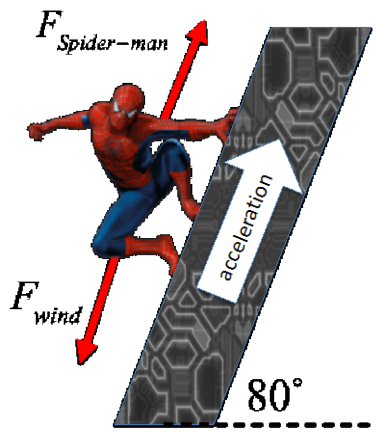


4. One scene from *Spider-Man: Homecoming* involved Spider-Man holding two halves of the Staten Island Ferry together using webbing (not a spoiler since this scene was in the trailer). Assume Spider-Man holds the two halves as shown in the figure below, with $\theta_1 = 6.00^\circ$, and he is presently in equilibrium. If the tension in the web strand labeled T_1 is 4490 N, what tension, magnitude and direction, is needed in T_2? Spider-man's mass is 76.0 kg.

5. Iron Man flies due to forces created by both his boots and his gauntlets. His boots will apply a force F_1 which has a magnitude of 6.00×10^3 N and is in the horizontal direction, as soon below. The gauntlets apply a force F_2 which is at an angle of 24.5° with the horizontal, as also shown below. A) If Iron Man has a weight of 500. lbs, what force F_2 is needed for him to travel at a set height, neither rising nor lowering? B) When the force found in part A is applied, what is Iron Man's acceleration? (Hint 1: 1 lb = 0.453 kg)

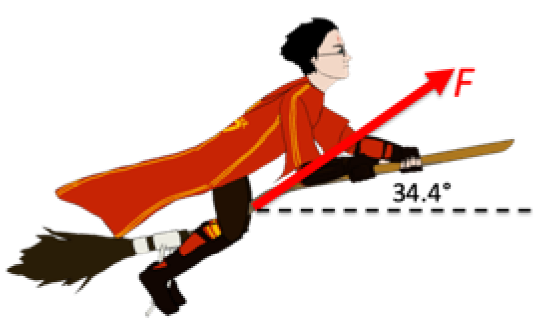


6. A scene from *Infinity War* (no spoilers) involves Spider-Man (who has a mass of 75.7 kg) clinging to a spaceship leaving Earth's atmosphere. The ships accelerates at 29.4 m/s^2 upwards at an angle of 80˚ with respect to the Earth's ground. Spider-Man is being pushed by winds which run parallel to the surface of the ship that apply a force of 1550 N, as shown below. However, Spider-Man's ability to cling to surfaces applies a force counteracting the winds. A) How much force must Spider-Man's hands be applying to stay on? B) What is his normal force? (Hint: align your *x*-axis with the ship.)



7. Doctor Strange's cloak allows him to levitate, and glide forward. Dr. Strange's cloak does this by applying a *F* at an angle of 70˚, as shown below. A) What force must the cloak be exerting to keep a Dr. Strange at a set height, neither lowering nor rising? Dr. Strange has a weight of 180. Lbs. B) When the force found in part A is applied, what is Dr. Strange's acceleration? (2.20 lb = 1 kg)

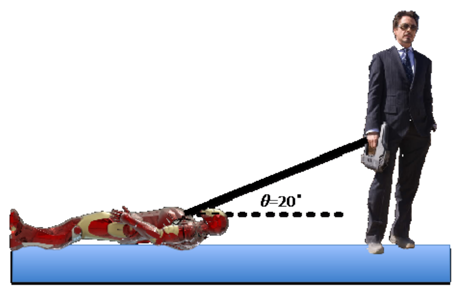
8. In Harry Potter a broom allows its rider to fly by applying a force at 34.4°, as shown below. A) What force must the broom be exerting to keep Harry Potter at a set height, with no acceleration in the *y* direction? Assume the total mass of Harry Potter and broom is 60.0 kg. B) When the force found in part A is applied, what is Harry Potter's acceleration?



Chapter 4b: Forces with friction

1. A car is traveling at 90.0 mph on a flat highway, when its driver sees a rogue snowman in the road and suddenly slams on the breaks, locking them up. If the coefficient of kinetic friction between road and tires on a rainy day is 0.400, what is the minimum distance in which the car will stop? (hint: 1 mile = 1609m)

2. In Iron Man 3, Tony Stark pulls his Iron Man suit through the snow by a strap (sorry for the spoilers). The producers of the movie claim the suit weighs 700 lbs. If he pulls on the suit with a rope at an angle of 20˚, and the coefficient of static friction between ice and iron is 0.15, what minimum force does Tony Stark need to exert to move the suit? (Hint: 1 lb = 0.454 kg) (2nd hint: start with a free body diagram.)

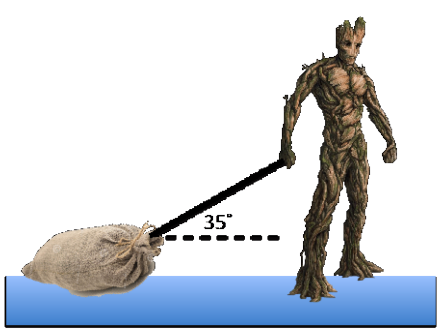


3. In the sport curling, one person (known as the skipper) slides a granite stone down ice and tries to place it on the center of a bull's-eye, while other people (named sweepers) use brooms to change the coefficient of friction and affect the stone's travel. Let's say a skipper decides to wave off his sweepers, and just slide the stone on his own. What initial velocity must the skipper use to have the stone come to rest at the center of the bull's-eye, which is 93.0 feet away, due to friction between the ice and stone? The coefficient of kinetic friction for granite on ice is approximately 0.0168. (1 foot = 0.3048 m) (Hint 1: Draw free body diagram for the stone, which will be worth points.) (Hint 2: solve for acceleration first.)

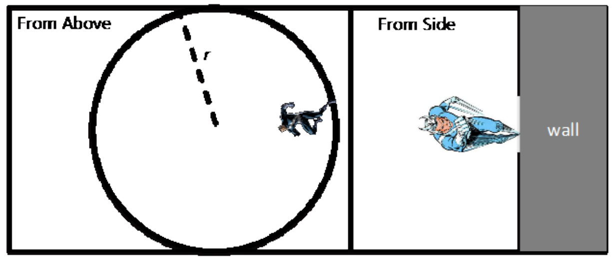
4. Darth Vader is attempting to force-push Jabba the Hutt into a sarlacc pit. Jabba has a mass of 935 kg and has a coefficient of static friction of 0.76 with the surface of the sand barge. a) How much force (in Newtons, not midichlorians ... never midichlorians) does Vader need to get the Hutt moving? (As in to overcome max static friction) b) If the coefficient of kinetic friction is 0.43, what acceleration does Jabba have after he starts moving? Assuming Vader is still pushing with the same force you found in part A. (hint: correct free body diagrams get you points!)

5. In the movie *Fast 5* (The 5th *The Fast and the Furious* movie) a rather large safe full of $100,000,000 in $20 bills is pulled behind two Dodge Chargers down the streets of Rio De Janeiro during a bank heist. The total mass of the safe with the money in it is 15.4 tons. a) Assuming a flat, horizontal ground, what minimum total force is required to start the safe moving? (Hint, pretend 1 car.) b) Once the safe starts moving, if Brian and Dom (who are driving the cars) keep pulling with the same force, what is the acceleration of the safe? The coefficient of static friction for steel on asphalt is 0.7 and the coefficient of kinetic friction is 0.45. Also, 1 ton = 907.2 kg.

6. In Guardians of the Galaxy, Groot captures Peter Quill (aka Starlord) in a bag and begins dragging him away. Starlord has a mass of 90.0 kg and Groot is pulling the bag with a force of 400. N at an angle of 35.0˚ as is shown in the figure below. What is the coefficient of kinetic friction if they are moving at a constant speed of 2.00 m/s?



7. In the movie *X-Men: Days of Future Past*, the mutant Quicksilver runs around a circular room so fast that he can run on the walls, as shown below. A) If the room's radius is 18.0m, at what minimum speed does Quicksilver need to run to stay on the walls without sliding down? Assume the coefficient of friction between Quicksilver and the wall is 0.250. (Hint 1: Start with a free body diagram on the side view. Hint 2: This uses information from multiple chapters.)



8. A classic scene in many movies consist of a bartender sliding a drink down the bar to someone at the end. Let's say a bartender slides a drink so that it leaves their hand at 3.2 m/s. If the coefficient of kinetic friction between the drink and the countertop is 0.53, how far down the bar does the drink slide? (Hint: Solve for acceleration first.)

9. A common mechanic in many video games is the need to push a large stone block onto a switch or to climb up on to reach a higher ledge. Let's say you decided to push a stone cube that is four feet per side. A) If this block has a mass of 4900 kg and you pushed on it applying a force horizontally, what minimum force would be required to get it to start moving? B) Once it starts moving, if you kept pushing with the same force found in part A, what would be its acceleration? The coefficient of static friction for stone on stone is 0.80 and the coefficient of kinetic friction for stone on stone is 0.60.

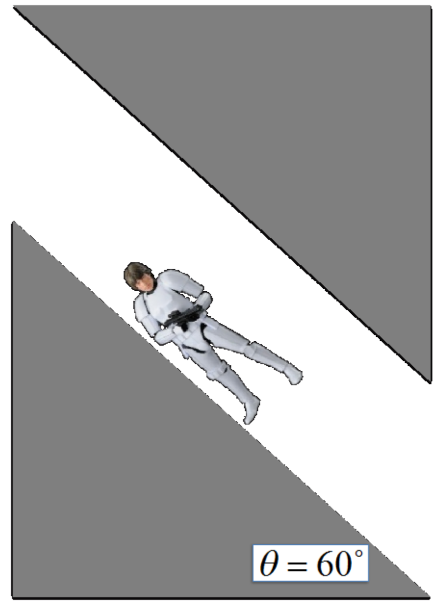
10. Rey from *The Force Awakens* decides to use The Force to pull a lightsaber to herself, which is sitting on a table to her side. A) If the lightsaber has a mass of 2.27kg, what minimum force would be required to pull the sword to her, assuming it does not leave the table's surface and the force is completely horizontal? The coefficient of static friction is 0.300 and the coefficient of kinetic friction is 0.129. B) What acceleration does the lightsaber have when it starts moving? Assume Rey is pulling with the same force you found in A.

11. In the classic 1966 western *Django*, the titular character travels across the desert on foot while dragging a coffin in the mud behind him. The coffin and whatever is inside it (spoilers) has a mass of 385 kg and the coefficient of kinetic friction between the coffin and the mud is 0.400. If Django starts pulling the coffin with a force of 1980 N at an angle of 20.0˚ what is the acceleration of the coffin?

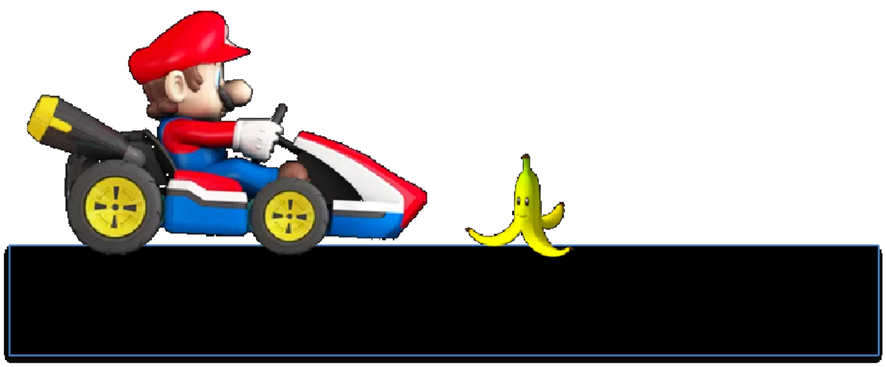
12. In Germanic folklore, Krampus is a horned figure described as "half-goat, half-demon", who during the Christmas season punishes children who have misbehaved by shoving them into a sack and dragging them off. Krampus's bag-o-children has a mass of 60.0 kg and Krampus is pulling the bag with a force of 400. N at an angle of 35.0˚ as is shown in the figure below. What is the coefficient of kinetic friction if Krampus is moving at a constant velocity?

13. Eleven, from *Stranger Things,* pulls a box of Eggo waffles across a table using telekinesis. A) If the box of Eggos has a mass of 0.349kg, what minimum force would be required to pull the box to her, assuming it does not leave the table's surface and the force is completely horizontal? The coefficient of static friction is 0.289 and the coefficient of kinetic friction is 0.113. B) What acceleration does the Eggos have when they start moving? Assume Eleven is pulling with the same force you found in A.

14. In *Star Wars: A New Hope,* Luke and his friends slide down a chute into a trash compactor to get away from some Stormtroopers. The chute makes an angle of 60.0˚ with the horizontal, and the coefficient of kinetic friction between Luke and the compacter walls is 0.273. What is Luke's acceleration down the chute?



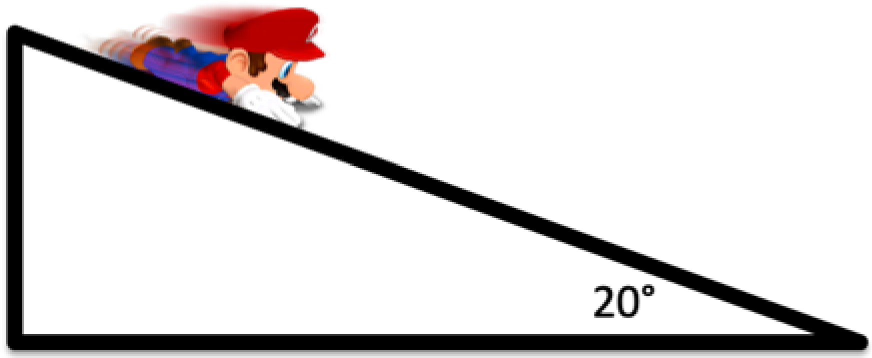
15. Mario is racing his friends on a go-kart track when he hits a banana someone threw on the track. Before hitting the banana Mario is traveling at 30.0 mph. He then slams on his break, and skids to a stop. How far does Mario's go-kart slide? The coefficient of kinetic friction between the go-kart and the road is 0.850. (Hint, solve for acceleration first.) (1 mile = 1609m)



16. I In the new *God of War* game, Kratos pushes a canoe with his son in it across the sand towards water. The combined weight of the boat and the boy is 125 lbs. The static coefficient of friction between the boat and the sand is 0.812, while the kinetic coefficient of friction is 0.627. A) If Kratos pushes the boat horizontally, how much force is requires to get the boat to start moving? B) If Kratos continues to push with the same force found in part A, what is the acceleration of the boat after it starts to move? (1 kg = 2.20 lb)

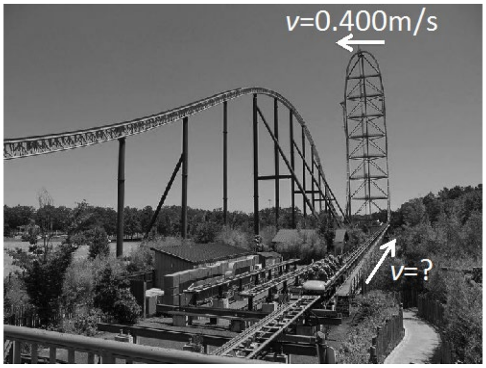
17. In the video game *Transistor,* the main character, Red, drags behind her a rather large sword, as shown below. To move the 22.7 kg sword Red pulls with a force *F* of 175 N at an angle of 30˚ from the horizontal. Assume the kinetic coefficient of friction for the sword against the ground is 0.570. At what rate does the sword accelerate?

18. Mario, of *Super Mario Bros* fame, slides down an icy slope while trying to race a large penguin. The slope makes an angle of 20.0° with the horizontal. If the coefficient of kinetic friction between Mario and the slope is 0.0647, what is Mario's acceleration down the ramp?

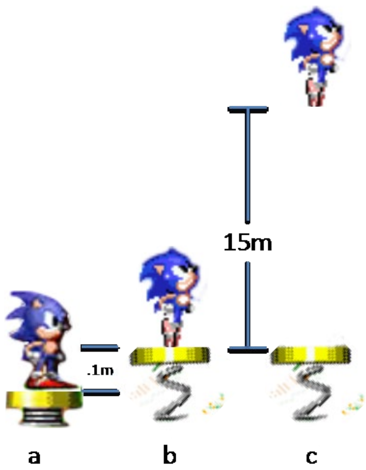


Chapter 5: Conservation of Energy

1. Presently the tallest roller coaster in the world is Kingda Ka at Six Flags Great Aventue in Jackson, NJ. This rollercoaster, using hydrolics, accelerates you quickly and shoots you up 127 meters (no slow ascent here). You then go over the top at a slow speed of 0.400 m/s before desending back down while spiraling (rather quickly and possibly while screaming). a) What velocity at the bottom is needed to get you up and over the top at that 0.400m/s? b) What velocity is the roller coaster going when it goes over the secound hump (shown to left in photo) which is 47.5 m tall?

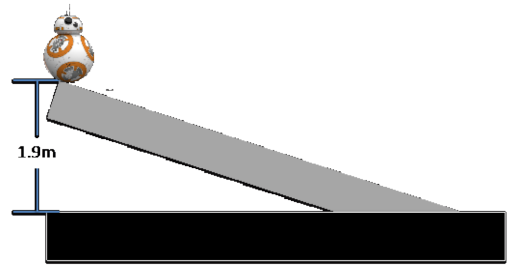


2. In the Sonic the Hedgehog games Sonic would use a jump pad (which is just a big spring) to jump very high. Sonic (who according to the web has a mass of 35.0 kg) can use a jump pad to get a maximum height of 15.0 m above the spring's equilibrium position (figure c) after compressing the spring 0.100m below the spring's equilibrium position (figure a). A) What is the spring constant of the jump pad? B) What is Sonic's velocity when the spring passes through its equilibrium position? (figure b)

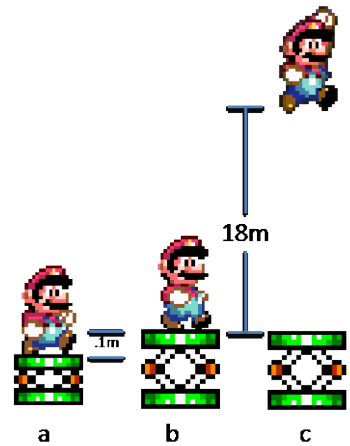


3. In the original Donkey Kong video game Donkey Kong rolled barrels down a ramp at Mario, who tried to get to the top to save Pauline. If Donkey Kong places a barrel at the top of a ramp and lets it go, what is the linear velocity of the barrel at the bottom of that ramp? The top of the ramp is 1.30m above the bottom of the ramp. Assume the barrel is a cylinder, which has a moment of inertia of $I=1/2mr^2$.

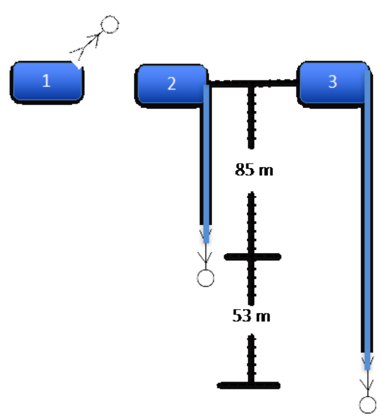
4. BB-8, the droid from *Star Wars: The Force Awakens*, is basically a solid sphere with a small head. Lets say BB-8 was at the top of a ramp coming from the Milenium Falcon to the ground. The top of the ramp is 1.9m above its bottom. If BB-8 starts from rest and rolls down the ramp, what is his velocity at the bottom of the ramp? Assume he is a solid sphere, which has a moment of inertia of 2/5 mr^2 (we are ignoring his "head").



5. In Super Mario World, Mario could use a jump pad (which is just a big spring) to jump very high. Mario (who has a mass of 97.0 kg) can use a jump pad to get a maximum height of 18.0 m above the spring's equilibrium position (figure c) after compressing the spring 0.100m below the spring's equilibrium position (figure a). A) What is the spring constant of the jump pad? B) What is Mario's velocity when the spring passes through its equilibrium position? (figure b)

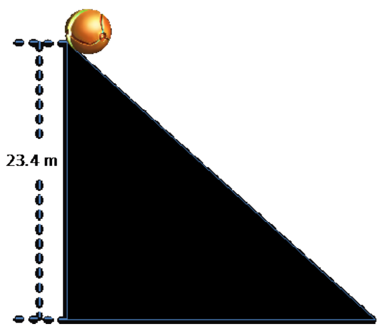


6. A brave student who has a mass of 68 kg decides to go bungee jumping. The student is attached to a bungee cord that has a length of 85 m unstreatched, and steps off of a cliff with zero initial velocity (figure 1). A) What is their speed when they fall 85 m, and are at the unstretched length of the bungee? (figure 2) B) The person then falls an additional 53 m as the bungee stretches. They momentarially come to rest at this point. (figure 3) What is the spring constant on the bungee cord, assuming it works as a simple spring? Hint: define the height in figure 2 as the y=0 point



7. The Cooper's Hill Cheese-Rolling and Wake is an annual event held in England where a wheel of cheese is rolled down a hill while people chase after it competing on who can catch it first. The wheel of cheese can be approximated as a solid disc of mass m and radius r. If the hill has a height of 75.0 m and the cheese starts at rest, what is the cheese's linear speed at the bottom of the hill? The moment of inertia of a disc is ½ mr^2. Note, you will not get full credit without showing all work.

8. Samus Aran from the Metroid series has the ability to roll into a ball to get into smaller areas. Samus rolls down a path which drops down 23.4 m. If she was at rest when she started at the top, what is her linear velocity at the bottom of the path? Treat her as a solid sphere with a moment of inertia of $2/5mr^2$



9. A 90.7 kg bear which was shot by a tranquilizer falls out of a tree onto a trampoline that wildlife officials set-up (figure A is a real photo). The trampoline can be approximated as if it is a spring. A) If the bear falls from 10.0 m above the trampoline, what is the bear's velocity when it first hits the trampoline, as shown in figure B? B) If the trampoline sags 0.800 m when the bear is at its lowest point, as shown in figure C, what is the trampoline's spring constant?

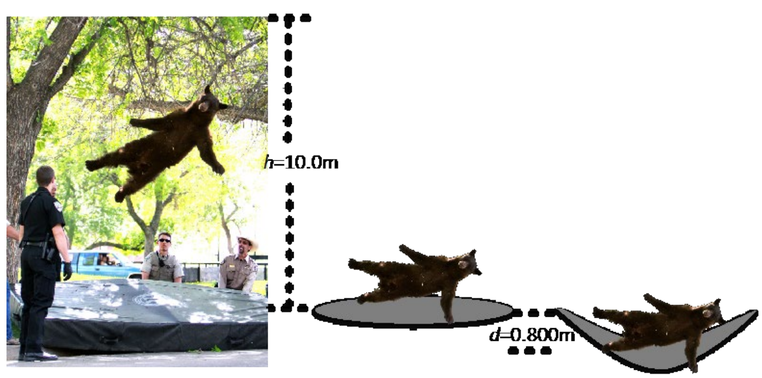
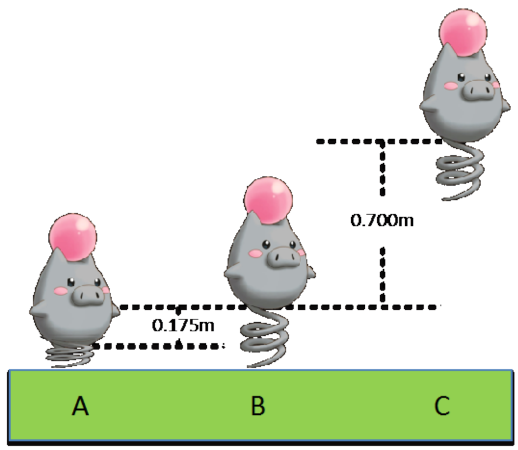


Figure A Figure B Figure C

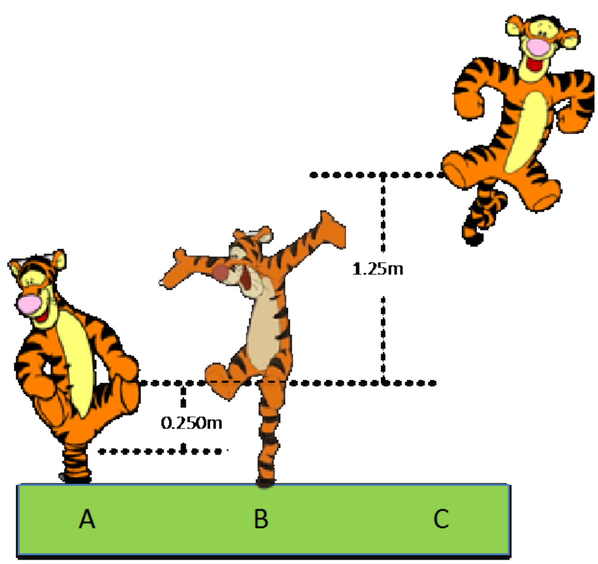
10. Indiana Jones in *Raiders of the Lost Ark* finds himself running from a large round, solid boulder that was released due to a trap. If the ball starts 2.43m above Indy, and rolls down a ramp towards him, how fast is it traveling at when it gets to the bottom of the ramp? The moment of inertia for a solid sphere is 2/5 mr^2

11. The ninja Chojin Akimichi, from *Naruto*, has the ability to turn into a large sphere to roll down his enemies. Choji starts at rest at the top of a hill that is 6.72 m higher then the bottom. What is Choji's linear velocoty at the bottom of the hill? Assume Choji's moment of inertia is the same as that of a sphere, 2/5 mr^2.

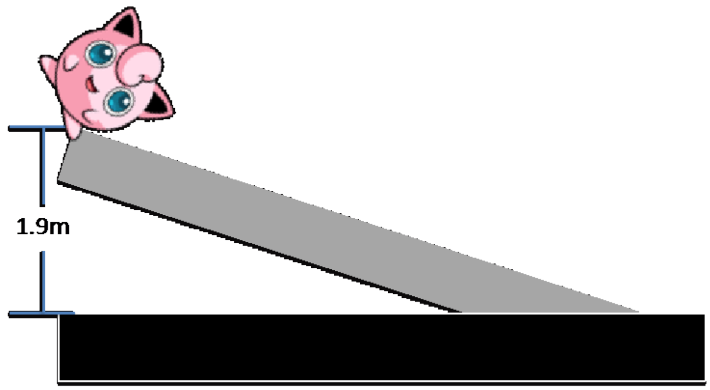
12. A Spoink is a Pokémon who has a large spring for its legs. By bouncing on its spring a Spoink can achieve a maximum height of 0.700m (figure c) by compressing his spring 0.175 m (figure a). A Spoink has a mass of 30.6 kg. A) What is the spring constant of the Spoink's spring? B) When traveling upwards, what is a Spoink's maximum velocity as it passes through the equilibrium (figure b)



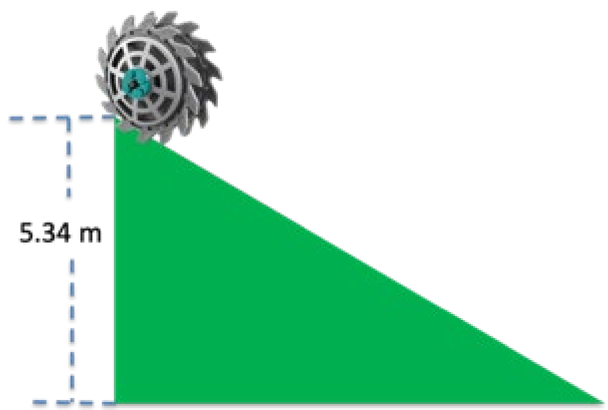
13. Tigger, from Winnie-the-Pooh, has a tail made out of a spring. By bouncing on his tail Tigger can achieve a maximum height of 1.250m (figure c) by compressing his spring/tail 0.250 m (figure a). A) If Tigger's body has a mass of 11.0 kg (low since "his top is made of rubber, his bottom is made of springs"), what is the spring constant of Tigger's tail? B) When traveling upwards, what is a Tigger's velocity as he passes through the equilibrium? (figure b)



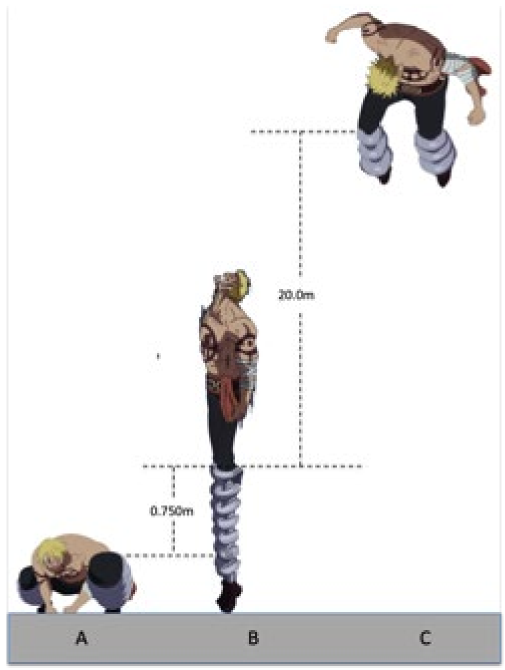
14. In *Super Smash Bros* (and also *Pokémon* games), Jigglypuff is a spherical Pokémon which attacks by rolling at people. If Jigglypuff starts at rest on the top of a ramp that is 1.90 m high, what is its linear velocity at the bottom of the ramp? Assume Jigglypuff is a solid sphere, which has a moment of inertia of 2/5 mr^2.



15. During *Avengers: Infinity War* Thanos's troops deploy large round machines called "threshers" which roll across the battlefield crushing everything under them. (Shown below in Lego form). These threshers are large bladed cylinders, and therefore have a moment of inertia of ½mr^2. If one started at rest at the top of a 5.34 m high hill, what would be its velocity at the bottom?



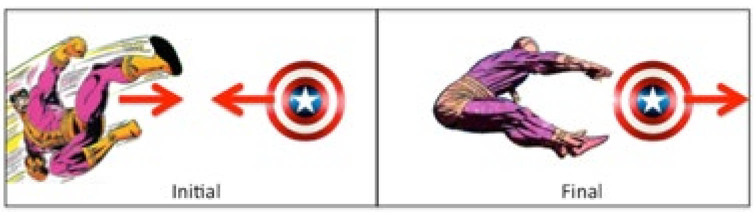
16. Bellamy the Hyena from *One Piece* can turn any part of his body into springs. Let us say he turns his legs into springs to jump really high. Bellamy can achieve a maximum height of 20.0 m (figure c) by compressing his spring 0.750 m (figure a). Bellamy has a mass of 152 kg. A) What is the spring constant of Bellamy's legs? B) When traveling upwards, what is a Bellamy's maximum velocity as it passes through the equilibrium (figure b)?



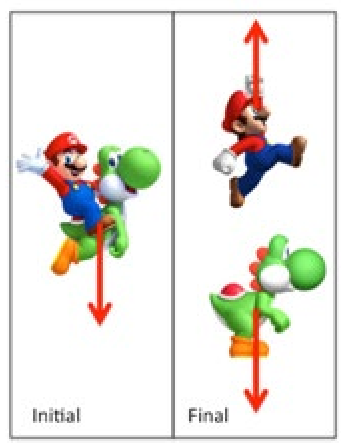
Chapter 6: Conservation of Momentum

1. A 60-kg soccer player jumps vertically upwards and heads the 0.45-kg ball as it is descending vertically with a speed of 25 m/s. If the player was moving upward with a speed of 4.0 m/s just before impact, what will be the speed of the ball immediately after the collision if the ball rebounds vertically upwards? Assume the velocity of the player directly after the collision is upwards with a magnitude of 3.6m/s.

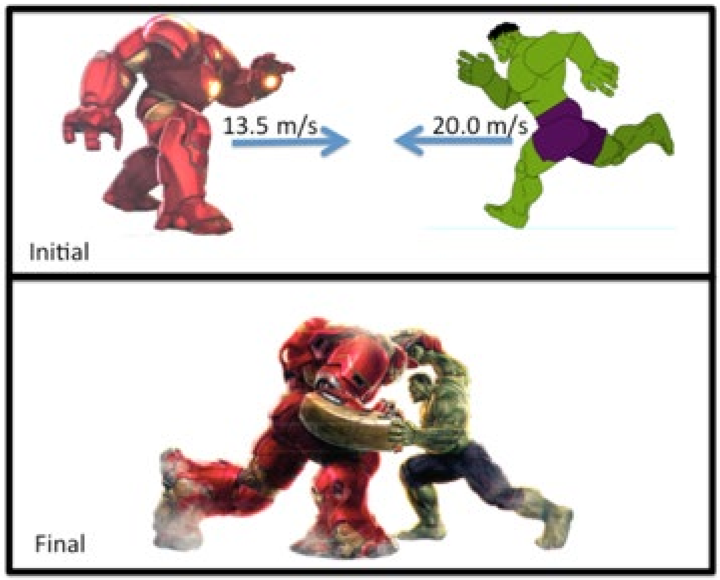
2. A criminal with mass 100kg leaps directly at Captain America with a speed of 8 m/s. Captain America throws his shield (which has a mass 15kg) at the criminal with a speed of 15 m/s. After the collision the shield returns to Cap at 12 m/s. What is the velocity (magnitude and direction) of the criminal after the collision?



3. Mario, while riding his faithful stead Yoshi, tries to jump over a bottomless pit. However, Mario realizes he isn't going to make it. Mario and Yoshi are initially falling straight downwards at a rate of 5m/s when Mario jumps off Yoshi, to get some extra height and distance. If Mario leaves Yoshi with a speed of 8 m/s, how fast is Yoshi plummeting to his doom immediately after Mario leaves his back? Mario has a mass of 90 kg and Yoshi has a mass of 180kg.



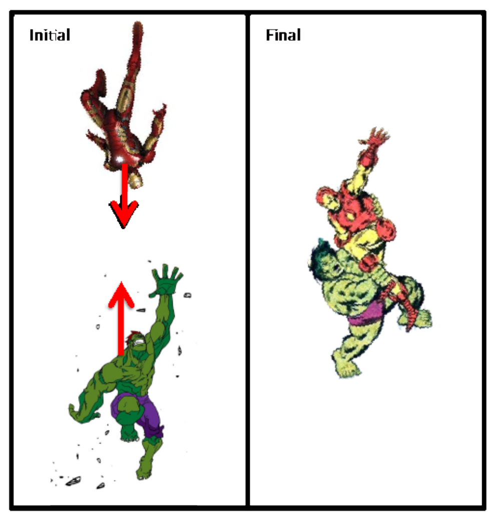
4. In *Avengers 2: Age of Ultron* The Incredible Hulk fights Iron Man in a special suit of armor made just for fighting Hulk (called the Hulkbuster armor). One scene shows them charging at each other. Let us say that Iron Man is running with velocity of magnitude 13.5 m/s while the Hulk runs in the opposite direction with velocity of magnitude 20.0 m/s before they collide. On collision they grab each other and grapple. What velocity (magnitude and direction) will the pair of Avengers move directly after they collide in this completely inelastic collision? Assume Iron Man's mass in the Hulkbuster armor is 813 kg while the Hulk's mass is 635 kg.



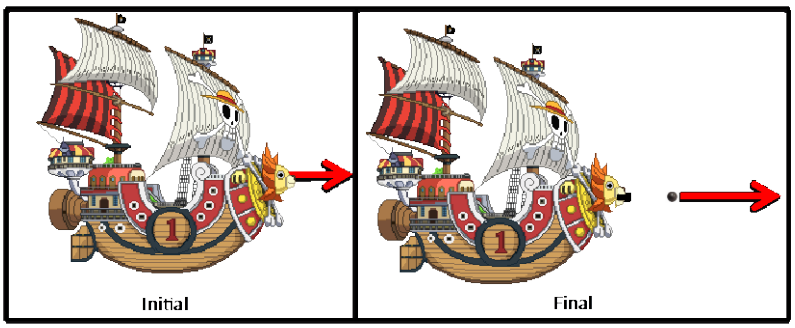
5. Magneto floats towards the X-men at 2.00 m/s. Someone throws Wolverine, claws first, at Magneto (a move known in the comics as the "fastball special") at 15.0 m/s directly at Magneto. Magneto, seeing a metal-skeletoned mutant flying at him, uses his powers over metal to repel Wolverine directly backwards at 8.00 m/s. Upon repelling Wolverine, what is Magneto's new velocity (both magnitude and direction)? According to Marvel's database Wolverine has a mass of 136 kg (heavy due to adamantium skeleton) and Magneto has a mass of 86.0 kg.

6. In the movie *Avengers: Age of Ultron,* there is a scene where Thor throws his hammer, Mjölnir, at Quicksilver. Quicksilver is running towards the oncoming hammer when he grabs Mjölnir and is then yanked backwards (I guess spoilers but it is a tiny scene). Let's say Thor throws Mjölnir at 45.0 m/s (a value that is reasonable according to comics) and Quicksilver, who has a mass of 79.0 kg, is initially running in the opposite direction at his top speed of 1650 m/s. After Quicksilver grabs Mjölnir the two together travel at 40 m/s (the hammer losing very little speed) in the hammer's original direction. Assuming no magic (an incorrect assumption here) what large mass must Mjölnir have for this completely inelastic collision to occur?

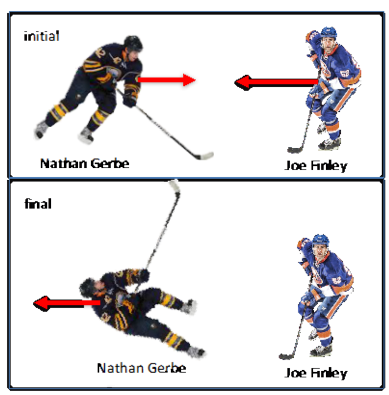
7. In the movie *The Avengers,* the Hulk catches a falling Iron Man (sorry, spoilers, but the movie has been out long enough to not care). Let's say Iron Man is falling straight down at a rate of 53.0 m/s (terminal velocity) and he has a mass of 279 kg. Hulk, who has a mass of 521 kg, jumps straight up and is traveling at 23.5 m/s right before catching Iron Man. What is the final velocity (magnitude and direction) of Hulk and Iron Man immediately after Hulk catches him?



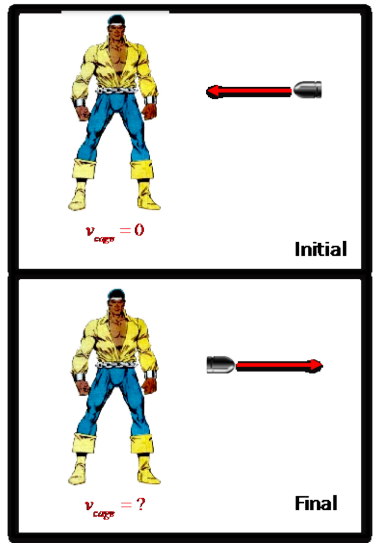
8. A certain pirate ship from a cartoon, which has a total mass of 42300 kg, is traveling at a speed of 5.00 knots when it shoots an oversized cannonball out of the front of the ship, in the same direction that the ship was traveling. The cannonball, which has a mass of 46.2 kg, leaves the cannon at 438 m/s. How fast, and in what direction, is the ship traveling after the canon is fired? (1 knot = 0.514 m/s)



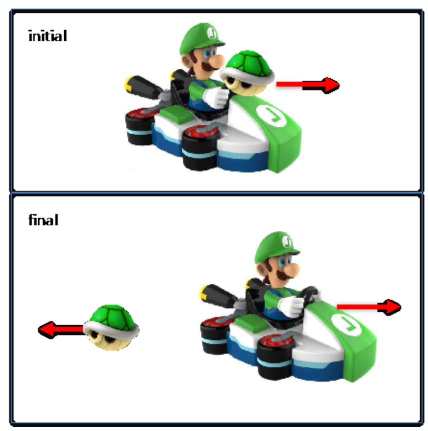
9. Nathan Gerbe, a hockey player who has a mass of 81.2kg, is skating to the right with the puck at 8.94 m/s when he gets hit by Joe Finley, who has a mass of 118 kg. Finley is initially traveling in the opposite direction as Gerbe at 7.71 m/s before the collision. After the collision Gerbe flies backwards at 1.23 m/s. How fast, and in what direction, is Finley traveling after the hit? Assume frictionless ice. (note: these are real former NHL players with their real playing masses)



10. The superhero Luke Cage, in both the comics and the Netflix series, has unbreakable skin. When shot with a bullet, the bullet bounces off him. Let's say for some undisclosed reason Luke Cage is standing still on a frictionless surface, when a villain shoots him with a bullet. If the bullet has an initial velocity of 475 m/s and bounces straight backwards with a velocity of the same magnitude, what is Luke Cage's velocity, magnitude and direction, after the collision? The mass of a bullet is 18 g and the mass of Luke Cage is 193 kg

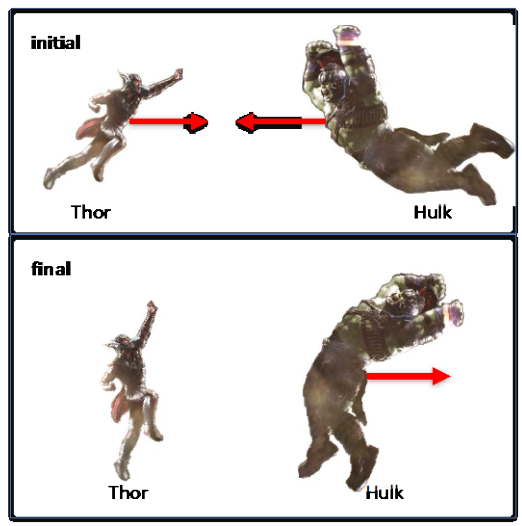


11. Lugi is driving a go-kart at 17.9 m/s while holding a koopa shell. The mass of Luigi and the go-kart is 164 kg and the mass of the koopa shell is 11.3kg. If Luigi throws the shell behind him at a speed of 31.3 m/s, what is Luigi's velocity immediately after throwing the shell?

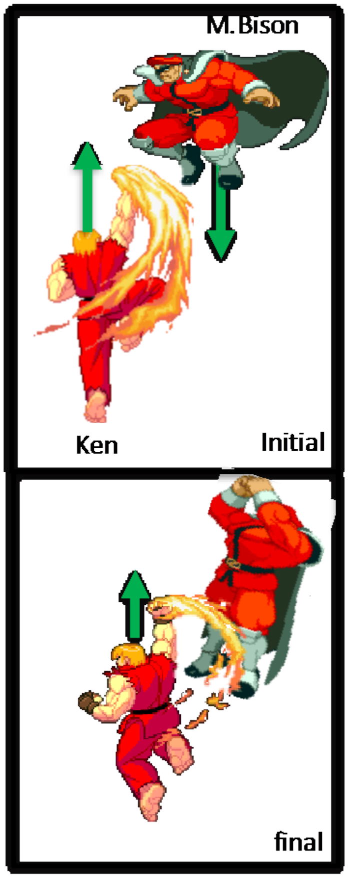


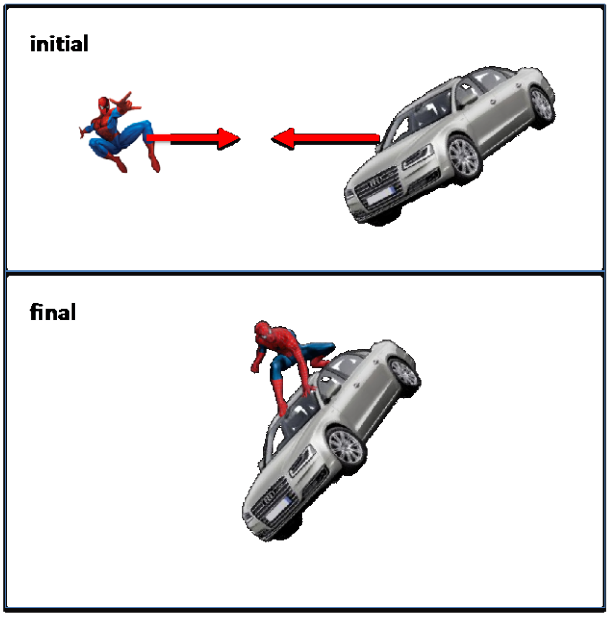
12. There is a scene in *Captain America: Civil War* where the Black Panther chases down Bucky Barnes who is riding on a motorcycle and jumps on the bike with him (spoilers, but was in trailer so I say fair game). Assume that before the collision Bucky with the motorcycle, who has a mass of 298 kg, is traveling at 21.6 m/s. The Black Panther, who has a mass of 90.7 kg, can run as fast as 60 mph (yay superpowers). If he is running at his maximum speed right before jumping on, what is the velocity of the two superheroes and bike immediately after the collision? 1 mile = 1609 m

13. In *Thor: Ragnarok* we see Thor and Hulk leaping at each other in a gladiatorial arena. Before the collision Thor is traveling at 11.2m/s while Hulk is traveling at 10.8m/s. After they collide, Hulk flies backwards at a rate of 9.72 m/s. What is Thor's velocity (magnitude and direction) after they slam into each other? Thor has a mass of 290 kg and Hulk has a mass of 635 kg.



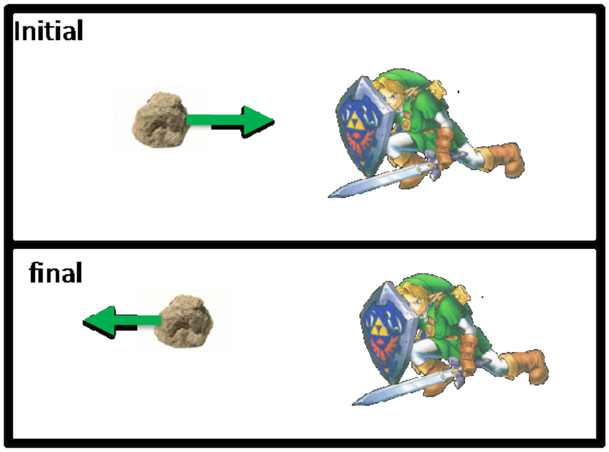
14. Ken, from the *Street Fighter* series, is known for his Shoryuken, which is a jumping uppercut. Ken's opponent, M. Bison, jumps towards him and is falling at a rate of 1.17 m/s when Ken begins to rise upwards at 3.21 m/s. Ken then connects with his Shoryuken, after which he is then traveling at 1.45 m/s, still upwards. Right after the impact what velocity, magnitude and direction, is M. Bison traveling at? Ken has a mass of 75.0 kg and M. Bison has a mass of 80 kg.



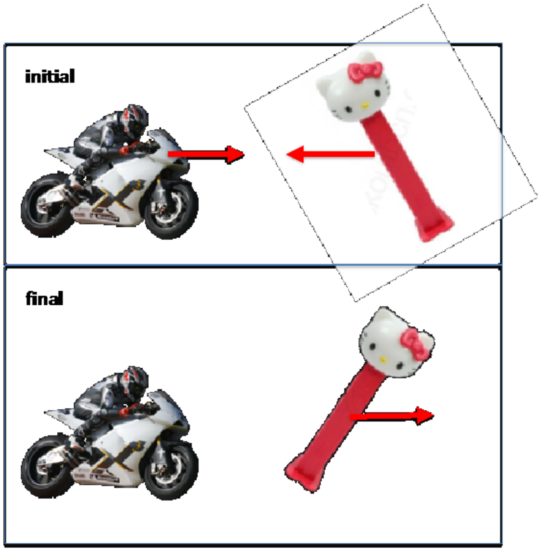


15. Spider-man jumps towards Dr. Octopus at 18.3 m/s in an attempt to capture him. Seeing Spider-man approaching, Dr. Octopus throws a car at Spider-man at 9.00 m/s. Spider-man sticks to the car in the air in a completely inelastic collision. What is the velocity (magnitude and direction) of Spider-man and the car after the collision? Spider-man has a mass of 76.0 kg and the car has a mass of 1240 kg.

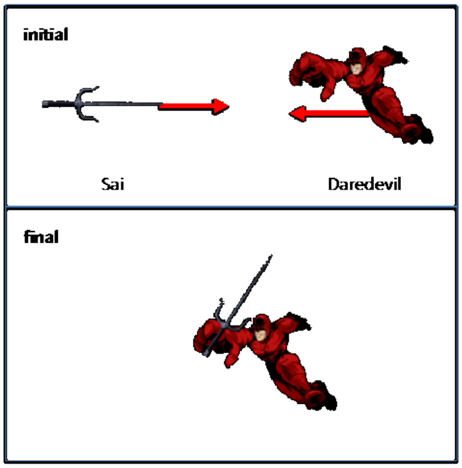
16. An Octorock from *The Legend of Zelda* spits a rock at Link. The rock, which has a mass of 9.08 kg flies towards Link at 3.23 m/s. Link is initially standing still. The rock hits Link's shield and deflects back in the opposite direction at 2.78 m/s. If Link weighs 125 lbs what is Link's velocity after the collision? (1kg = 2.20 lb)

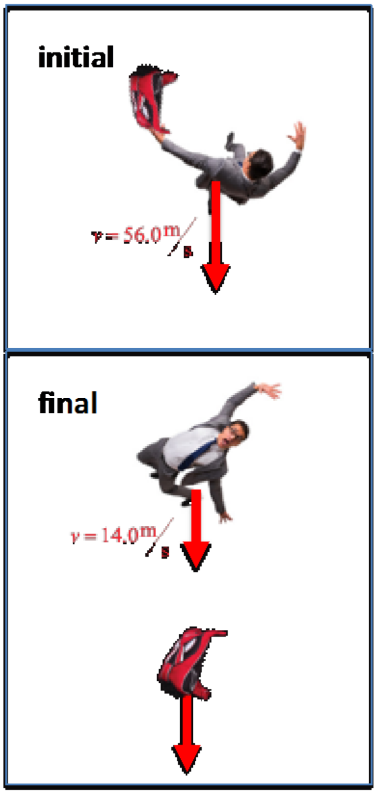


17. In a scene from *Ant-Man and the Wasp*, The Wasp throws an enlarged Hello Kitty Pez dispenser at a motorcyclist. The motorcyclist's total mass (him and bike) is 215 kg and the enlarged Pez dispenser has a mass of 50.0 kg. Initially the motorcyclist is moving at 26.8 m/s and the Pez dispenser (which is moving in the opposite direction) is moving at 31.3 m/s. After the collision the Pez dispenser has a velocity of 45.0 m/s to the right, as shown below. What is the velocity (magnitude and direction) of the motorcyclist after the collision?



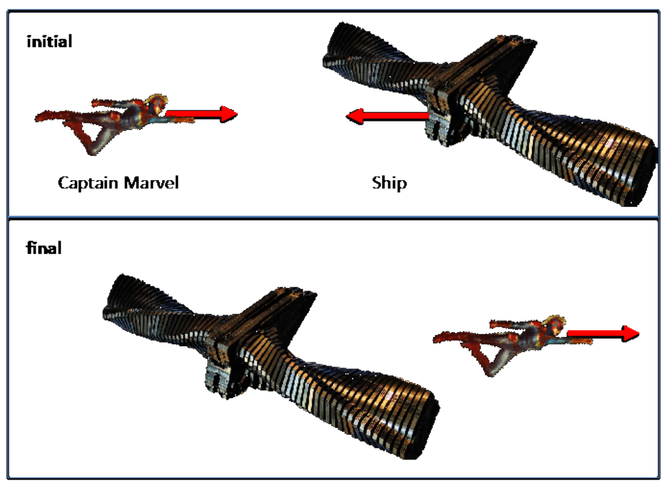
18. The super-hero Daredevil jumps towards the villain Bullseye at a rate of 7.60 m/s. Seeing him coming, Bullseye throws a 1.27 kg sai directly at Daredevil at a rate of 90.0 miles/hour. If Daredevil catches the sai and holds onto it, what is the velocity (magnitude and direction) of Daredevil and the sai after the collision? Assume Daredevil's mass is 84.0 kg. (1 mile = 1609 m)



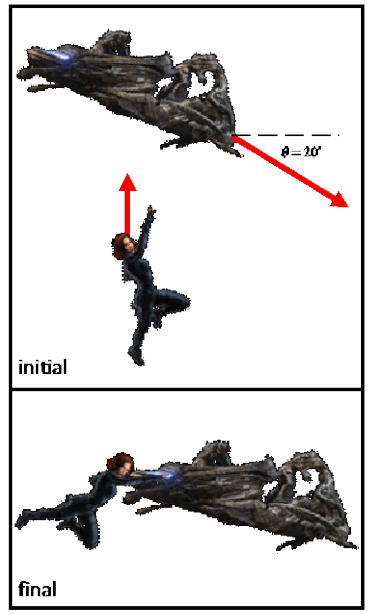


19. A 75.0 kg person decides to go skydiving and jumps out a plane wearing a 12.0 kg parachute. However, after reaching terminal velocity, 56.0 m/s, they realize that the chute isn't opening. Remembering their general physics class, this person decides to throw the (now useless) 12.0 kg pack straight down, hoping to slow their decent. To safely land on the ground, you need to be traveling less then 14.0 m/s downward. How fast must this doomed person throw their chute to get down to this speed?

20. Captain Marvel flies through a Kree ship, disabling it. The ship, which has a mass of 500. tons, flies directly at Captain Marvel at 22.4 m/s. Captain Marvel, who has a mass of 56.0 kg, flies at the ship at 103000 m/s. Captain Marvel passes through the ship, which slows both her and it down. After leaving the other side Captain Marvel's speed is now only 13500 m/s. What is the new velocity (magnitude and direction) of the ship? (1 ton = 907 kg)

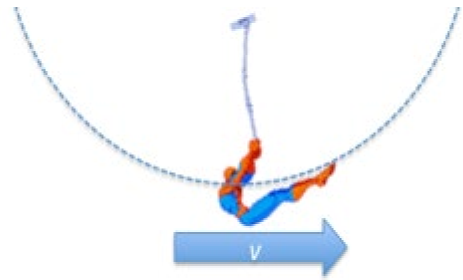


21. In a scene from *The Avengers* (the first one) Black Widow is boosted directly upwards, where she grabs on to a speeding Chirauri speeder and hangs on. Let's say that Black Widow, who has a mass of 59.4kg, is traveling directly upward at 3.25 m/s when she hits the speeder. The speeder, before she grabs on, has a mass of 204 kg and is moving at 25.8 m/s at an angle of 20˚ below the horizontal. If she holds on and we have a completely inelastic collision, what is their velocity (magnitude and direction) after the Black Widow grabs on?

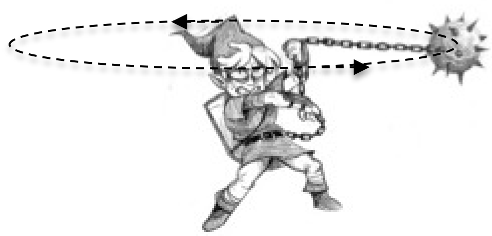


Chapter 7: Rotational Physics

1. Spider-man (who's mass m=85.0 kg) is about to use his webs to swing through the city of New York to chase down a bank robber. If he is swinging from a web that is 20.0 m long, and his speed at the bottom of the swing is 18.00 m/s, (a) what is the tension in the web and (b) what is his angular momentum at the bottom of the swing? Assume his swing makes a circular path and that the moment of inertia for Spider-man is that of a particle (mr^2).



2. A courageous warrior starts spinning a ball on a chain in the horizontal plane using a torque of 5 Nm. a) If the ball on the end weighs 8 kg and the radius of the motion is 0.9 m, what is the angular acceleration? b) If it started from rest, what is the angular velocity after 5 s? c) At t = 5s, what is the tension in the chain? (consider the spiked ball as a point mass. The moment of inertia of a point mass is mr^2. Ignore the mass of the chain.)



3. A Blu-ray disc spins at 10,000 revolutions per minute and has a radius of 58mm and a mass of .02kg. a) What is the translational velocity of a point on the edge of the disc? b) What is the centripetal acceleration of a point on the edge when spinning at full speed? c) If it takes the disc 0.5 seconds to get up to full speed from rest, what value of torque must be applied to reach these speeds (hint, find angular acceleration). The moment of inertia for a disc is $1/2mr^2$

4. In the comics, movies, and Norse mythology the god Thor flies by spinning his hammer, Mjölnir, really fast from a leather strap at the end of the handle, letting go, then grabbing it and having it pull him. This is completely nonsensical but let's pretend he can do this. If Thor wants to reach escape velocity (velocity needed to leave Earth's atmosphere), he will need the translational velocity of the center of mass of the hammer to be 11,200 m/s. a) If the hammer starts from rest, and the distance from the end of the strap to the center of mass of the hammer is .4 m, what angular acceleration does Thor need to reach that velocity in 5 s? (hint, find angular velocity first) b) If

the moment of inertia of the hammer is 2.79 kg*m^2, what torque does Thor need to exert to achieve this angular acceleration? c) Once he hits max speed, but while the hammer is still spinning, what impossibly large tension does the leather strap, which the hammer is spinning by, exert when Mjölnir is at its lowest point? Mjölnir has a total mass of 20kg.

5. A student decides to go bowling. The student launches the bowling ball with an initial linear speed of 4.60 m/s, where it hits the lane and begins rolling without slipping. A) If the radius of the bowling ball is 0.159 m and its mass is 8.16 kg, what is its initial angular velocity when it begins to roll? B) Due to the slight angle of the lane, the ball has an angular acceleration of 0.210 rad/s^2. If the ball goes through 18.0 revolutions as it travels down the lane, what is the angular velocity of the ball right before it hits the pins? C) What torque must be acting on the ball to cause that angular acceleration? Assume the ball is a solid sphere where the moment of inertia of a solid sphere is given as $I=2/5\ mr^2$

6. Sonic the Hedgehog, coming straight from exam 2, runs through a loop-de-loop, which has a radius of 20.0m. A) At what minimum speed does Sonic need to run to make it around the loop without falling off at the top? (figure a) B) Sonic often rolls in a ball instead of running, however. If he were rolling without slipping, what rotational velocity would Sonic be spinning at? (figure b) When in ball form, assume his radius is 0.800 m. C) To roll in ball form Sonic "charges up" in place and then shoots off (a move called the spin dash). If he goes from rest to the rotational speed you found in part B in 2.00 seconds, what is his angular acceleration while charging?

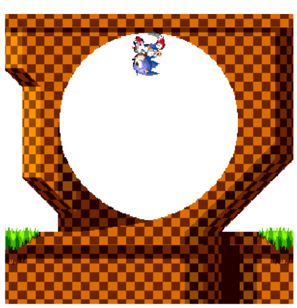


Figure A

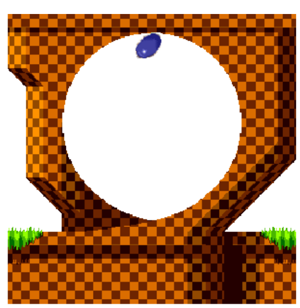
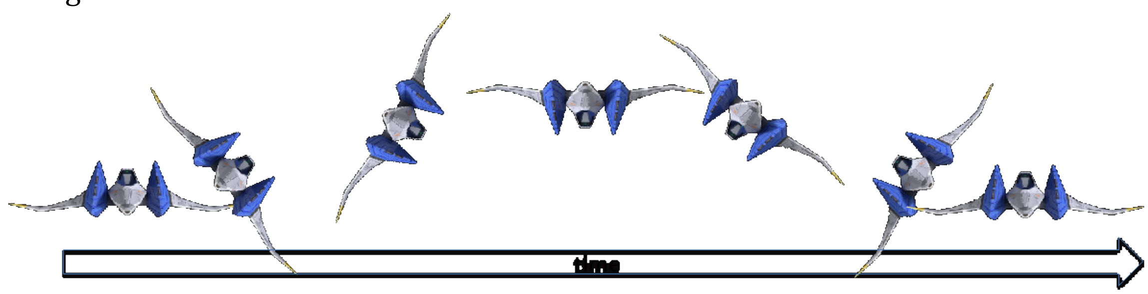
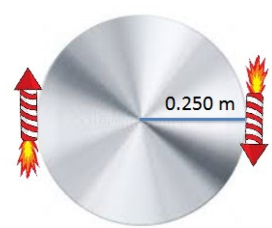


Figure B

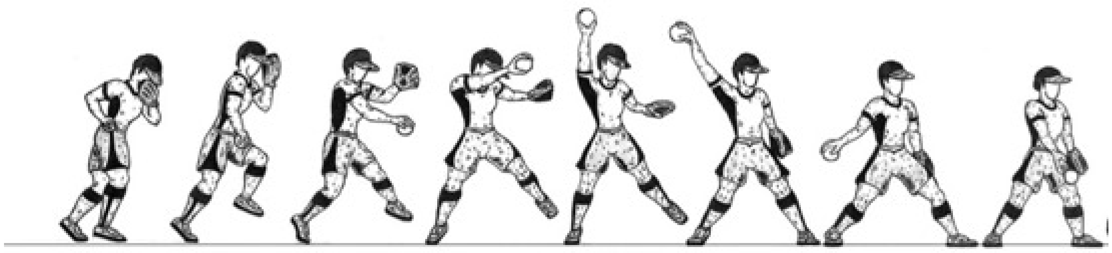
7. Fox McCloud from the Starfox video game is flying over the planet Corneria in his ship when he is told to "do a barrel roll." Fox then makes his plane spin so the wings go end over end, as shown below. A) If the distance between the center of mass of the ship (which the plane spins around) and Fox's seat is 1.25m, at what minimum angular velocity does the plane need to spin for Fox to stay in his seat when he is upside down? Assume the gravity of Corneria is the same as earth. B) While the ship is spinning at the rate you found in part a it slows down its roll by adjusting the flaps on the wings, which changes the moment of inertia of the ship. If the moment of inertia is 142000 kg*m^2 when it is spinning at the angular velocity you found in part a, what is its angular velocity after the flaps open and change the moment of inertia to 147000 kg*m^2?



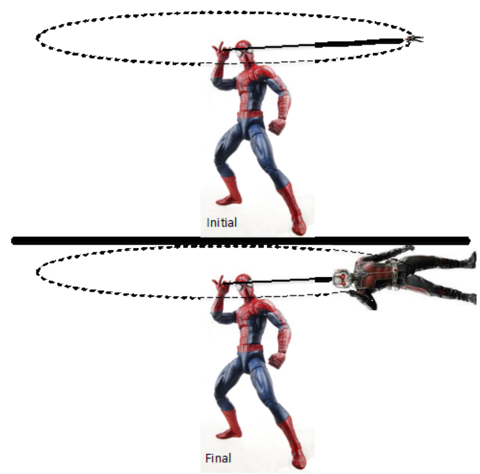
8. For a fireworks display two bottle rockets are attached to the edge of a disc of radius 0.250 m that can spin around its center as shown below. The disc/rocket combination is laid down horizontally and both rockets are lit at once, each applying a continuous force of 68.6 N pointing in the direction of the rocket. A) If the moment of inertia of the system is 0.0313 kg*m^2 what is the angular acceleration of the system? B) After 12.0s, what is the angular velocity of the disc? C) What is the magnitude of the linear velocity of one rocket at that moment?



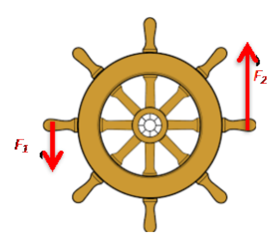
9. In fast pitch softball a pitcher throws the ball by spinning their arm a full 1.25 revolutions and letting go at the end. Monica Abbott holds the record for fastest softball pitch at 34.4 m/s. She has an arm that is about 0.637m long. A) What is the angular velocity of the softball right before she releases it? Use the length of her arm as the radius and assume perfectly circular motion. B) If Monica starts the ball at rest, what angular acceleration is needed to reach that speed in the 1.25 revolutions? C) If the moment of inertia of her arm is 4.03 kg*m^2, what torque does Monica exert to reach that speed?



10. Spider-man, in a fight with other heroes, snags Ant-man with a web while Ant-man is at a reduced size and has a mass of 0.500 kg. Spider-man then swings him around, horizontally, at a radius of 2.81 m at a rate of 52.3 rev/min. A) What is Ant-man's linear velocity? B) What is the tension in the webbing holding Ant-man? C) While Ant-man is swinging he goes back to regular size, increasing his mass to 86.0 kg. If Spider-man does not apply any additional torques, what unrealistically small angular velocity does Ant-man have after his size change? Assume the moment of inertia of Ant-man is that of a particle, mr^2.



11. A ship captain, in an attempt to turn his boat, grabs the wheel (which starts at rest) and tries to turn it with both hands. Each hand applies a force on the wheel a distance 0.609 m from the center, one of force F_1 = 8.00N and the other of force F_2 = 12.0N (the forces are shown below). A) If the moment of inertia of the wheel is 0.334 kg*m^2, what is its angular acceleration? B) If this angular acceleration found in part A is constantly applied without changing, what is the angular velocity after the wheel turns 1.57 radians? C) What is the kinetic energy of the wheel when spinning at the angular velocity found in part B?



12. To prove he isn't in a dream Cobb from *Inception* spins a top. He starts the top spinning, bringing it from rest to an angular velocity of 1500 rev/min. To do this he accelerated it for 1.05 radians. A) What is the top's angular acceleration? B) If the moment of inertia of the top is 4.3 x 10^{-7} kg*m^2, what is its torque? C) While at its final speed, what is its angular momentum (which is what causes it to stay upright)?

13. In 1931 a man named M. Goventosa built the monowheel shown below. This one wheeled motorcycle's wheel maximum angular velocity was 433 rev/min. A) Given that it's radius was 0.920 m, what was the largest linear velocity of the monowheel? B) The monowheel could not accelerate fast or the rider would start spinning inside. The maximum angular acceleration was 10.9 rad/s^2. How long, in seconds, would it take it to hit maximum speed from rest? C) Given that the wheel itself had a mass of 22.7 kg, what torque did the engine need to apply to create the above acceleration? Treat the wheel as a hoop with a moment of inertia of mr^2.

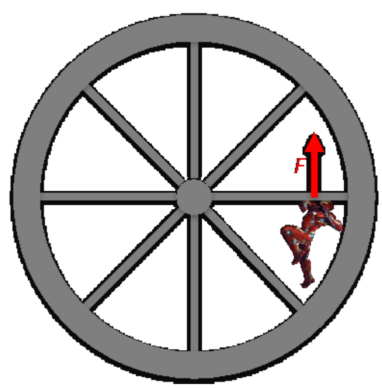
14. In the movie *Ant-man* there is a scene where Ant-man is riding on a turntable. A record has an angular velocity of 33.3 rev/min and a radius of 15.2 cm. A) If Ant-man weighs 0.0500 kg while small and stands on the edge of the record player, what minimum coefficient of friction is needed to keep Ant-man from flying off? B) Ant-man then jumps off, making the moment of inertia of the record and Ant-man to go from an initial value of 2.55x 10^{-3} kg*m^2 to a value of 1.39 x 10^{-3} kg*m^2. What is the angular velocity of the record once Ant-man leaves the record?

15. When Captain America throws his shield it spins like a Frisbee. When he throws it he applies a torque of 44.8 Nm. A) If the shield has a radius of 0.381 m and a mass of 5.44 kg, what is the angular acceleration of the shield as it is thrown? Assume the shield is a disc with a moment of inertia of 1/2mr^2. B) To throw the shield Captain America applies that acceleration over a distance of a half of a revolution. What is the angular velocity of the shield as it leaves his hands? C) While the shield is traveling at the rate found in B, what is its angular kinetic energy?

16. In the movie *Prometheus* there is a scene where a hoop shaped spaceship is rolling on its side at the main characters of the movie, who are running away (mild spoilers). This hooped shaped ship has a radius of 230 m and a mass of 9.6 x 10^7 kg. The hoop is slowing down due to a torque of -4.1 x 10^9 Nm. A) What is its angular acceleration? B) The ship travels 0.75 revolutions after which it comes to rest. What is the ship's initial angular velocity? C) What is the ship's initial angular momentum? (Hint: the moment of inertia for a hoop is mr^2.)

17. In the video-game *Uncharted 4* the main character, Nathan Drake, often swings from place to place on a grappling hook on a circular path, as shown below. A) If the rope from the grappling hook is 9.57 m long, what is Drake's angular velocity when he has a linear velocity of 7.12 m/s? B) If Drake has a mass of 86.2 kg, what is the tension in the rope at his lowest point?

18. A scene from *The Avengers* (very mild spoilers) involves Iron Man getting into a stalled rotor of a Helicarrier and pushing it to get it moving, as shown below. He pushes with a force of 7,860 N at a distance of 17.0 m from the center pivot point. He is pushing perpendicular to the radius of the rotor. A) If the moment of inertia for the rotor is 5.10 x 10^9 kg*m^2, what is the angular acceleration due to Iron Man pushing? B) After 3.00 s seconds what is the angular velocity? Assume it starts at rest. C) At that moment what is the angular momentum?

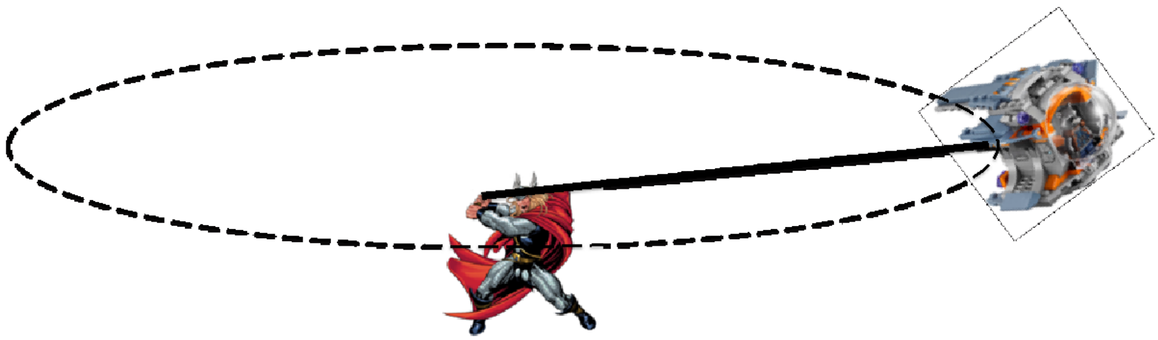


19. Kratos, from the *God of War* video game series, fights with blades attached to chains. Kratos is spinning one of his weapons vertically with a radius of motion of 1.22 m. He spins the blade, which has a mass of 4.57 kg, with an angular speed 125 rev/min. A) What is the tension in the chain at the highest point? B) Kratos then lets out more chain, increasing the radius to 1.89 m. If he applies no other torques, what is the new angular velocity of his blade? Assume that his blade is a point mass with a moment of inertia of mr^2 and ignore the mass of the chain.

20. Okoye, the head of the Dora Milaje from *Black Panther*, wields a spear with a mass of 8.07 kg. The 1.73 m long spear is initially at rest when she starts to spin around its center (labeled O in attached figure) using both hands. One hand applies a force F_1 of 6.52 N at a distance of .0450 m from the center and the other a force of F_2 of 5.23 N at a distance of 0.200 m from the center. Both forces are perpendicular to the spear, as shown below. A) What is the angular acceleration of the spear? Assume the moment of inertia of the spear is $1/12\ mL^2$ where L is the total length. B) If Okoye keeps up that constant angular acceleration, what is the spear's angular velocity after one complete rotation? C) What is the linear velocity of the end of the spear (which is 0.865 m from point O) at the moment found in part B?

21. A hamster in a hamster ball of radius 5.00cm begins to run, applying a force of 3.50×10^{-3} N at the edge of the ball. A) If the ball has a mass of 39.0g, what is the angular acceleration of the ball? Use the moment of inertia of a hollow sphere, $2/3mr^2$. B) If the hamster starts at rest, what is its angular velocity after 3 full revolutions?. C) What is the hamster's linear velocity at the moment found in part B?

22. During *Infinity War* Thor spins a small escape pod (with Rocket Raccoon in it) which is attached to the end of a 15.0m long tether, as shown in the figure below. Assume the motion of the escape pod is completely horizontal. A) Thor can get the pod from rest to its max speed of 3.25 rad/s over the course of 6.00 rev. What is the angular acceleration of the pod? B) Treating the pod as a point mass with a moment of inertia of mr^2, how much torque is required to accelerate the pod at that rate? The pod has a mass of 4530 kg C) At the maximum speed what is the tension in the cable?



23. The Earth, which has a mass of 5.97 x 10^{24} kg and a radius of 6.37 x 10^6 m, spins at a rate of 6.94 x 10^{-4} rev/min (1 rev/day). You can assume the earth is a solid sphere, which has a moment of inertia of $2/5mr^2$. A) How fast is a point on the surface of the earth moving from the spinning? (ignoring moving in space) B) How much rotational kinetic energy does the earth have? C) What is the angular momentum of the Earth?

24. Michelangelo of the Teenage Mutant Ninja Turtles fights by spinning a nunchucks. A) If the nunchuck start from rest what angular acceleration does Michelangelo need to reach an angular velocity of 300 rev/min in 2.00 s? B) If the moment of inertia of the nunchuck is 0.112 kg*m^2, what torque does Michelangelo need to exert to achieve this angular acceleration? C) Once he hits max speed, but while the nunchuck is still spinning, what is the tension in the chain of the nunchuck at its lowest point? The distance from the point where Michelangelo holds the nunchuck to the center of mass is 0.280 m and the mass of the end is 0.23 kg.

25. Son Goku, from the classic Chinese novel and later anime *Dragon Ball Z,* has a magical staff that can change length. Goku starts with the 0.879 kg staff being 1.86 m long. A) If Goku spins the staff around its center by applying a force of 5.48 N that is 0.465 m from the center and perpendicular to the staff, as shown, what is its angular acceleration? Assume the moment of inertia of the spear is 1/12 mL^2 where L is the total length. B) If Goku keeps up that constant angular acceleration, what is the spear's angular velocity after five complete revolutions? Assume he is starting from rest. C) Goku then shrinks the pole to a length of 1.20 m while no longer applying any torque. What is the staff's new angular velocity?

26. The character Ness from *Earthbound* (and later *Super Smash Bros)* fights with a yo-yo by spinning it around its string, as shown below. Let's assume the length of the string when he spins it is 0.850 m and it has a mass of 0.0585 kg. A) If he spins it at a rate of 107 rev/min what is the tension in the string at the highest point? B) What is the linear speed of the yo-yo?

27. During *Avengers: Infinity War* there is a scene where Bucky Barnes picks up Rocket Racoon with his cybernetic arm, holds Rocket out at arm length, and spins as they both fire guns (This is my favorite sentence ever written). Bucky spins Rocket at a rate of 30.0 rev/min. Assume the moment of inertia of Rocket is 14.1 kg*m^2 and Bucky is holding Rocket a distance 0.750 m from the axis of rotation. A) What is Rocket's centripetal acceleration at this speed? B) It only took Bucky one quarter of a rotation to get Rocket from rest to the 30.0 rev/min. What is the angular acceleration? C) What torque did Bucky exert to cause such an angular acceleration?

Chapter 8: Deformation of Solids and Buoyancy

1. A certain brightly colored submarine caries a group of musicians deep underwater to an octopus's garden. The yellow submarine has windows with a diameter of 20 cm. The manufacturer says the window can withstand forces up to 1×10^6 N. What is the submarine's maximum safe depth in seawater? The density of saltwater is 1030 kg/m^3, and above the water is air of pressure 1.01×10^5 Pa, which is maintained inside the submarine.

2. A man named Larry Walters once attached 45 helium filled weather balloons to a lawn chair and lifted off, flying away on nothing but a lawn chair. He then flew over controlled airspace near LAX airport, where he was forced to land and arrested for violating the Federal Aviation Act. (This is a true story). If he used one large balloon, what volume of helium would be needed to lift Larry if Larry and his chair weighed 80 kg? (Hint, find the net force on the balloon at equilibrium) The density of air is 1.225 kg/m^3 and the density of helium is 0.164 kg/m^3

3. Naval mines are large round explosive devices that are left underwater and explode on contact with a ship or submarine. On their own they float, but they are held in place by large chains. A naval blockade mine from the year 1909 has a mass 574 kg and a volume of 0.678 m^3. What tension is needed to hold one of these mines in place? The density of sea water is 1029 kg/m^3

4. In the Pixar movie *Up* a man named Carl Fredricksen decides to sail away in his house by attaching thousands of helium balloons. On average a house weighs approximately 45400 kg. What minimum volume of helium would be needed to support a house of average weight? The density of helium is 0.164 kg/m^3 and the density of air is 1.23 kg/m^3. Hint: Start with free body diagram for the forces acting on the helium balloons.

5. The current freediving world champion, Herbert Nitsch, managed to dive 831 feet downward. A) If the pressure above the water was 101,300 Pa, what was the pressure on Herbert at this depth? B) The average surface area of an adult male is 1.9 m^2. How much force was acting on Herbert at this depth? The density of seawater is 1029 kg/m^3 (1 m = 3.28 ft)

6. In the movie *Pirates of the Caribbean: The Course of the Black Pearl*, Capt. Jack Sparrow and his crew snuck up on their enemies by submerging an upturned wooden rowboat and breathing in an air pocket in the upside-down boat's cavity. What stupidly large force would be needed to hold such a boat underwater? The total volume of the wood is .064 m^3 and the density of the boat is 380 kg/m^3. It will hold 4.1 m^3 of air which has a density of 1.2 kg/m^3. The density of water is 1000 kg/m^3. (Hint: find the force needed to hold the boat underwater and then the force needed to hold the air underwater and add the two values)

7. The film director James Cameron has the record for the deepest solo dive in a submersible named *Deepsea Challenger* (The only dive deeper involved 2 people and was only 3 meters deeper). James Cameron was able to dive to a depth of 10,908 m. A) If the pressure above the water is 101,325 Pa and the density of saltwater is 1025 kg/m^3, what total pressure was pushing on the *Deepsea Challenger* at this depth? B) Convert the pressure found in part A to atms (where 1 atm = atmospheric air pressure = 101,325 Pa) C) If that same pressure was acting along the length of a steel bar that is 7.3 m long (the length of the *Deepsea Challenger*) how much shorter would the bar be? (Hint, use the pressure from A as the stress on the bar.) Young's modulus for steel is 20. x 10^{10} Pa.

8. In a scene from the movie *Big Hero 6* (sorry but VERY minor spoiler) the main characters find themselves underwater. The inflatable robot Baymax (who is mostly empty air) grabs the other five characters and rise to the surface using his natural buoyancy. What maximum mass of children would Baymax be able to grab and still be able to rise to the surface? Baymax has a volume of 3.32 m^3 and is filled with air of density 1.23 kg/m^3. The density of saltwater is 1020 kg/m^3.

9. The Great Molasses Flood of 1919 (this really happened) occurred when a tank containing over 2,300,000 gallons of molasses collapsed, flooding the streets with molasses. The wave of molasses was said to be 50.0 ft high at the peak. A) Given that the air pressure above the molasses is 1.01 x 10^5 Pa, what is the pressure at the bottom of the molasses wave? The density of molasses is 1420 kg/m^3 and 1 m = 3.28 ft. B) The average surface area of an adult male is 1.90 m^2. How much force would be acting on someone under the wave?

10. At the beginning of each *Fortnite* match you jump from a bus that is suspended from a hot air balloon. A full bus has a weight of 43500 lbs. The density of the air around the bus is 1.23 kg/m^3 and the density of the hotter air inside the balloon is 0.946 kg/m^3. If the bus is in equilibrium, what is the volume of the balloon? (1 kg = 2.20 lbs)

Chapter 9: Simple Harmonic Motion

1. A magician tries to hypnotize you by swinging a watch on the end of a chain in front of you. You realize, as you drift off, that this is a pendulum just like we talked about in class and that the period of motion is about 0.9s long. a) How long must the pendulum be? b) As you drift off you find yourself remembering other equations from physics and think about springs also. If we instead attached the watch to a spring, and it has a mass of 50 g, what would the spring constant need to be to have the same period as the pendulum in part a?

2. A naked popstar rides a wrecking ball back and forth in simple harmonic motion for a music video. a) If the wrecking ball's chain is 10 m long, what is the period of motion? b) What is her angular frequency? c) If her max displacement is 0.175 radians, what is the pop star's max velocity?

3. Tigger, from Winnie-the-Pooh, has a tail made out of a spring that he likes to bounce on, (because Tiggers, according to song, are "bouncy, trouncy, flouncy, pouncy, fun, fun, fun, fun, fun!"). He starts bouncing and moves back and forth in simple harmonic motion with a period of 0.800 s with a maximum displacement from equilibrium of 0.200 m. a) If Tigger's body has a mass of 11.0 kg (low since "his top is made of rubber, his bottom is made of springs"), what is the spring constant of Tigger's tail? B) What is Tigger's maximum velocity? C) What is Tigger's maximum acceleration?

4. The 15 g head of a bobble-head doll oscillates in simple harmonic motion with a period of 0.25 s. A) What is the spring constant of the spring in which the head is mounted? B) Suppose the head is pushed 2.0 cm against the spring, then released. What is the head's maximum velocity? C) What length string would be needed to make a pendulum with the same frequency?

5. To measure their mass while staying in zero-g environments, astronauts use a body-mass measuring device (BMMD). This consist of them grabbing a big spring, and oscillating on it in simple harmonic motion, and measuring the period. The spring constant of the BMMD is 3100 N/m. A) If the astronaut has a period of 0.95s, what is their mass? B) The amplitude of motion while on the BMMD is about 0.090m. What is the astronaut's maximum velocity? C) What is their maximum acceleration?

6. In Edgar Allen Poe's short story "The Pit and the Pendulum" includes a scene where a bladed pendulum swings over a person, slowly getting closer. A) If the pendulum has a period of 6.00s ("Its sweep was brief, and of course slow."), how long is the pendulum? B) The story also claims that the sweep of the pendulum was a yard. If it goes a full distance of one yard from side to side, what is the pendulum's maximum velocity? (1 yard = 0.914 m)

7. A child bounces up and down on a trampoline without leaving the surface in simple harmonic motion. A trampoline can be approximated as a giant spring. The period of motion for the child is 0.500s and this max displacement from equilibrium is 0.530 m. A) If the child has a mass of 27.2 kg, what is the spring constant of the trampoline? B) What is the child's maximum velocity? C) What is the child's maximum acceleration?

8. Tweety Bird, from Loony Tunes fame, swings back and force on his swing in his cage. A) He can be approximated as a simple pendulum with a period of 0.715s. How long is the pendulum (aka his swing)? B) When Tweety swings he goes a full distance, from side to side, of 10.0 cm. What is his maximum velocity? C) What is his maximum acceleration?

9. A person gets into a car and it lowers by 2.00cm due to the shock absorbers. The shock absorbers can be treated as a large spring. A) If the person has a mass of 90.0 kg, what is the spring constant of the shock absorbers? B) When hitting a bump the car will bounce in simple harmonic motion. If the total mass of the car (including person) is 1360 kg, what is the period of motion? C) If the car's max displacement is 2.00 cm, what is the maximum velocity at which the car bounces?

10. A child swings back and forth on a tire swing in periodic motion. A) He can be approximated as a simple pendulum with a period of 4.00 s. How long is the pendulum (aka the rope holding the tire up)? B) When the child swings he goes a full distance, from side to side, of 4.00 m. What is his maximum velocity? C) What is his maximum acceleration?

Chapter 10: Volume as function of Temperature

1. According to the comics, Johnny Storm of the Fantastic Four can reach a 1,000,000˚F (or 555538˚C) when he "goes nova." If he started at room temperature (20˚C) and "goes nova" what is the change in length of his femurs? The linear coefficient of expansion for bone is 8.5×10^{-5} 1/˚C and his femur is initially 0.442m long. (note, this number is not realistic, but neither is 1,000,000˚F) b) Bones will break if the stress exceeds 130×10^{6} Pa. If Young's modulus for bone is 1.8×10^{10} Pa, what much lower final temperature can Johnny Storm reach before his bones break? (Hint, use equations to find the change in length from this stress first)

2. A regulation football in the NFL should be inflated to an absolute pressure between 27 and 28 psi and has a volume of 0.004237 m^3. A) If a football is filled to the minimum 27.00 psi at room temperature (20˚C), how many molecules of air are in the football? B) During the NFL AFC championships in 2015 the Patriots, led by quarterback Tom Brady, were accused of deflating balls to make them easier to catch (this scandal was known as Deflategate). The balls used in this game were at 25.00 psi. Tom Brady and company argued that the balls were filled at room temperature, and the pressure simply went down due to it being cold out. Using the number of molecules you got in part A and assuming the volume does not change, what temperature, in Celsius, would it need to be for the balls to reach the low pressure of 25.00psi? Note that 1psi = 6,895 Pascals and that Boltzmann's constant is 1.38×10^{-23} m^2kg/s^2K

3. In the short-lived TV show *Firefly* the spaceship Serenity has an engine on the back that heats up to approximately 1310˚C. Let us assume the entire outside of the ship reaches those temperatures. A) If the ship is made of steel (which is unlikely) and has a length of 81.9 m at room temperature (20.0˚C), how much longer is Serenity when the engines are at max temperature? The coefficient of thermal linear expansion for steel is 11.0×10^{-6} 1/˚C. B) If the ship was made in such a way the steel could not stretch, what impossibly large strain would result from this temperature change? Put your final answer in units of atm where 1atm = 101325 Pa. Young's modulus for steel is 20.4×10^{10} Pa. (This is why real spaceships do not use steel, never mind science fiction ones.)

4. I put air in the tires of my car during the summer, while it was 25.0˚C outside (about 77˚F). My tires say to fill them to a pressure of 207,000 Pa. A) If my tires have a volume of 0.0100 m^3, how many air molecules are in the tire? B) These tires go all summer without losing any air, however come fall the temperature drops down to 5.00˚C (about 40˚F). Assuming the volume doesn't change (because it doesn't) what is the new pressure in my tires? Hint: $k_B = 1.38 \times 10^{-23}$ m^2 kg/s^2K

5. In *A Storm of Swords*, the third book in the *A Song of Ice and Fire* series by eorge R. R. Martin, it is said that the red priest Thoros of Myr would douse his sword with wildfire and light it on fire during tourneys to scare “the horses and some of the greener knights.” A) If his sword is steel and initially 1.20m long when it is at 20.0˚C, how much longer does the sword get when it is on fire at 1250˚C? The coefficient of thermal linear expansion for steel is 11.0 x 10^{-6} 1/˚C. B) If the sword was held in such a way the steel could not stretch, what large strain would result from this temperature change? Young’s modulus for steel is 20.4 x 10^{10} Pa.

6. A student decides to relax by a fire on a cool 15.6˚C night and roast a marshmellow on the end of a stick which they hold in the fire. The fire heats not only the marshmellow, but the stick also to about 86.0˚C. A) If the entire stick, which is 0.260 m long, is heated to this temperture (probibly not true, but deal) how much longer does it get? The coefficent of linear expansion for wood is 5.23 x 10^{-6} 1/˚C. B) If the stick was held in such a way the wood could not stretch, what large strain would result from this temperature change? Young’s modulus for wood is 1.03 x 10^{10} Pa.

7. A pressure cooker works by greatly increasding the pressure inside, affecting cooking times. A sealed pressure cooker has a volume of about 5.68 x 10^{-3} m^3. A) If one is closed at room temperature (20.0˚C) at atmospheric pressure (1.01 x 10^5 Pa), how many air molecules are in the cooker? B) The pressure cooker is then sealed and turned on. The temperature inside the pressure cooker reaches 121˚C. What is the pressure inside the cooker?

8. In *Dungeons and Dragons* there is a spell called “heat metal” which simply heats metal to the point where it injures anyone touching it. Lets say that “heat metal” is cast on a warrior wearing steel armor, heating the armor from 20.0 °C to 1.00 x 10^3 °C. If the armor is originally 1.88 m long, what is the change in length after it has been heated? The coefficient of thermal linear expansion for steel is 11.0 x 10^{-6} 1/°C. B) If the armor was held in such a way the steel could not stretch, what large strain would result from this temperature change? Young’s modulus for steel is 20.4 x 10^{10} Pa.

Chapter 11: Heat

1. To forge a weapon a blacksmith heats the metal up very high to shape it, and then douses it in either water or oil to cool and harden it. A blacksmith decides to make a replica of Thor's hammer, Mjölnir, out of iron (as opposed to Uru which is what Odin made it out of). The iron replica, which weighs 20kg, is 1150˚C while the blacksmith works on it. To cool it the blacksmith drops Mjölnir into a large bucket containing 500 kg of water at 20.0°C. What is the final temperature of the water and Mjölnir? Ignore the heat capacity of the container and the handle and assume a negligible amount of water boils away. (c_{water}=4186 J/kg C. c_{iron}=452 J/kg C)

2. Often people use cold soapstone rocks, known as whiskey stones, to cool drinks. This has the benefit of ice but does not dilute the liquor for they do not melt. If I take 2 whiskey stones (total mass of 10g) out of my freezer which is at -18˚C, and place them in 3 shots worth (96 g) of room temperature (20˚C) whiskey, what temperature does my whiskey end up at after the system reaches equilibrium? The specific heat of the stones is 980 J/kg˚C and whiskey is 3400 J/kg˚C

3. In Game of Thrones a blacksmith is hired by Tywin Lannister to take a great sword (named Ice) made of Valyrian steel and turn it into two long swords, named Oathkeeper and Widow's Wail. To make such a sword you shape the metal at 816˚C and then put it in oil heated to 49.0˚C. If Oathkeeper weighs 4.31 kg, and the oil it is placed in to cool has a mass of 9.20 kg what is the final temperature of the sword and oil? The specific heat of the oil is 1670 J/kg ˚C. For Valyrian steel use the specific heat of Damascus steel (which it is based off of) which is 490. J/kg˚C.

4. A student, who is trying to drink away memories of a physics final that just happened, decides to pour themselves a bourbon on the rocks. They put an ice cube of mass 12.0 g which is at 0.00 ˚C into 131.0 g of bourbon (about 4 fingers) that was originally at 20.0 ˚C (room temperature). What is the final temperature of the cooled bourbon after the ice has melted? The specific heat of bourbon is 3400 J/kg˚C. The specific heat of water is 4186 J/kg˚C. The latent heat of fusion for ice is 3.33×10^5 J/kg.

5. Snoop Dogg, in an effort to get laid back (with his mind on his money and his money on his mind) pours himself a gin and juice. He mixes 0.138 kg (3 shots) of gin with 0.591 kg (a pint) of orange juice. The gin starts at 20˚C, room temperature. The juice is refrigerated and starts at 2.78˚C. What is the final temperature after mixing of the gin and juice? The specific heat of gin is 3460 J/kg˚C and the specific heat of orange juice is 3730 J/kg˚C.

6. To cool down a student pours themselves an ice coffee. They put 240 g of ice at 0˚C into 280 g of coffee at 90˚C. What is the final temperature of the iced coffee? The specific heat of water and coffee is 4186 J/kg˚C for both. The latent heat of fusion for ice is 3.33×10^5 J/kg.

7. 0.236kg of 95.0˚C water is mixed with 0.0128 kg of ground coffee beans which is at 20.0˚C. At what temperature is the coffee after the two are mixed? The specific heat of water is 4,186 J/kg˚C and the specific heat of ground coffee beans is 1,670 J/kg˚C.

8. The student from problem 3 pours themselves a drink to go with their fire and marshmallows. The student pours 131.0 g of bourbon (about 4 fingers) that was originally at 15.6 ˚C onto an ice cube of mass 12.0 g which is at 0.00 ˚C. What is the final temperature of the cooled bourbon after the ice has melted? The specific heat of bourbon is 3400 J/kg˚C. The specific heat of water is 4186 J/kg˚C. The latent heat of fusion for ice is 3.33×10^5 J/kg.

9. For the creation of Thor's new axe, Stormbreaker, (mild *Avengers: Infinity War* spoilers) a 20.0 kg piece of Uru metal is heated using a dying star. This means the metal is heated to about 1.33×10^5 ˚C. After heating it, a handle is made of 1.39 kg of (living) wood that is at room temperature, 20.0˚C. Ignoring cooling due to air or any burning, what is the final temperature of the axe after the metal and wood are joined? The specific heat of Uru is 452 J/kg˚C and the specific heat of the wood is 2410 J/kg˚C

10. The warrior from problem 3, in an attempt to cool his 1.00×10^3 °C armor back down, throws it into a trough of water, which contains 485 kg of water that is at 17.0 °C. If the armor has a mass of 29.5 kg, what is the final temperature of the water and armor? Assume the warrior takes the armor off and no magic is at work here. The specific heat of water is 4186 J/kg ˚C and the specific heat for steel is 502 J/kg ˚C