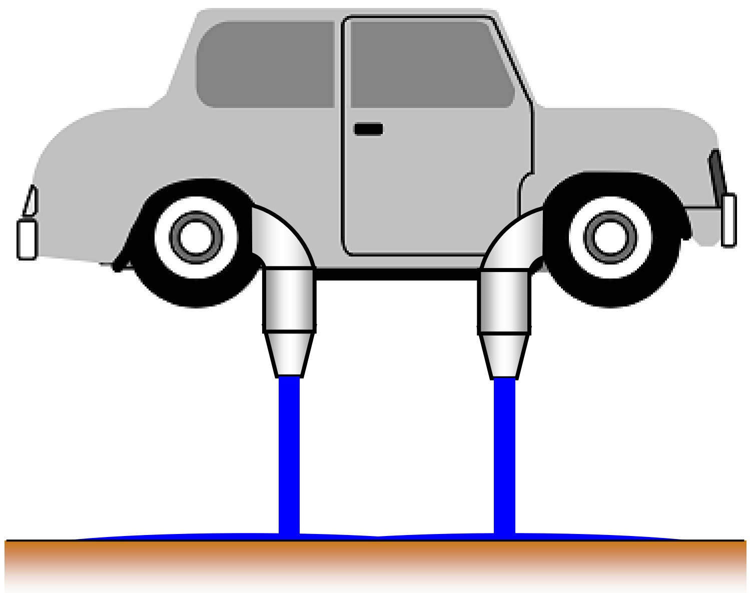
MythBusters For High School Physics



MythBusters For High School Physics

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Description of Content

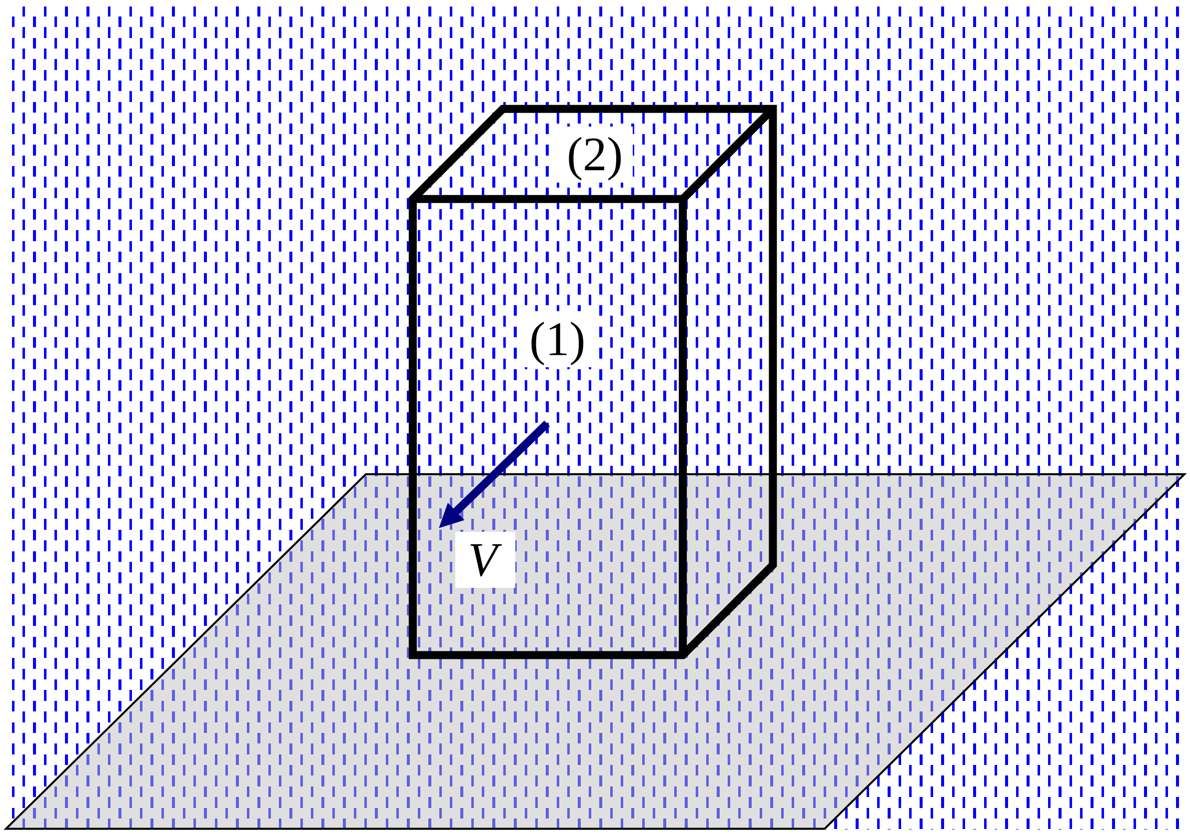
Content suitable for introductory high school physics courses is denoted by the text "Introductory Level" placed beside each topic. Content suitable for advanced high school physics courses (such as Advanced Placement Physics) is denoted by the text "Advanced Level" placed beside each topic. Note that the introductory level topics can also be used as course material for advanced courses, as deemed suitable by the instructor.

The topics in this ebook are taken from select episodes of the Mythbusters television show. The topics chosen lend themselves well to a physics analysis. The topics, in general, do not fit neatly into individual and separate concept groups. This is the norm when analyzing and solving real-world problems. This forces you to draw on your own knowledge and experience in a way that end of chapter textbook problems do not. And in so doing it challenges you to think in broader scientific and engineering terms, which fits well with the spirit of, say, the Next Generation Science Standards being adopted by K-12 schools in the United States.

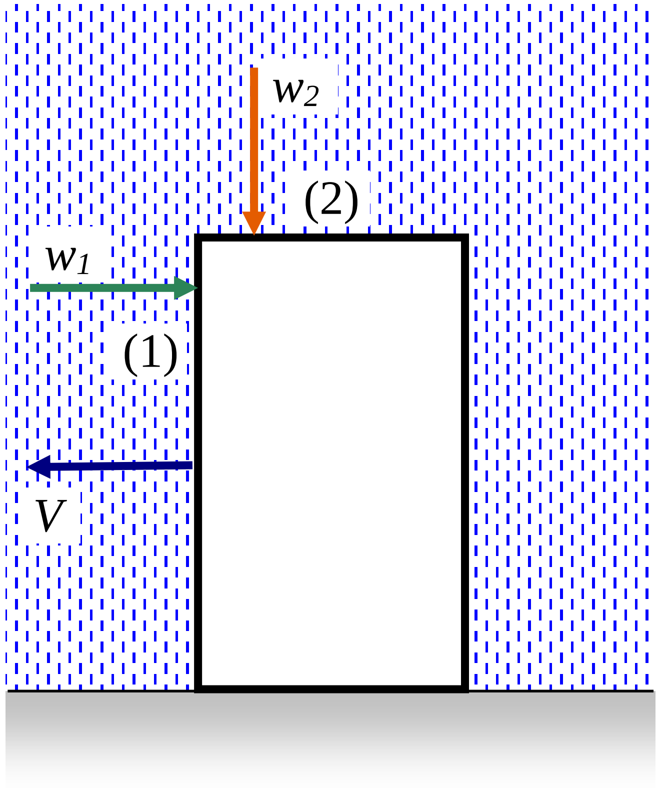
Contents (organized chronologically by episode)

Advanced Level - Is running better than walking to keep dry in the rain? (2003 season, episode 1)

Model the person as an upright rectangular box moving through the rain at speed *V* as shown. The surface (1) represents the front of the person and the surface (2) represents the top of the person.



The figure below shows a side view of the set up. Assume that the rain is falling straight down.



Let w_1 be the rate of rain impingement on the front of the person (given as volume of water per second). Let w_2 be the rate of rain impingement on the top of the person (given as volume of water per second).

If the person is standing still $w_1 = 0$. If the person is moving then $w_1 \neq 0$. The faster the person moves (at greater speed V) the greater is w_1.

The rate w_2 is always the same whether the person moves or not.

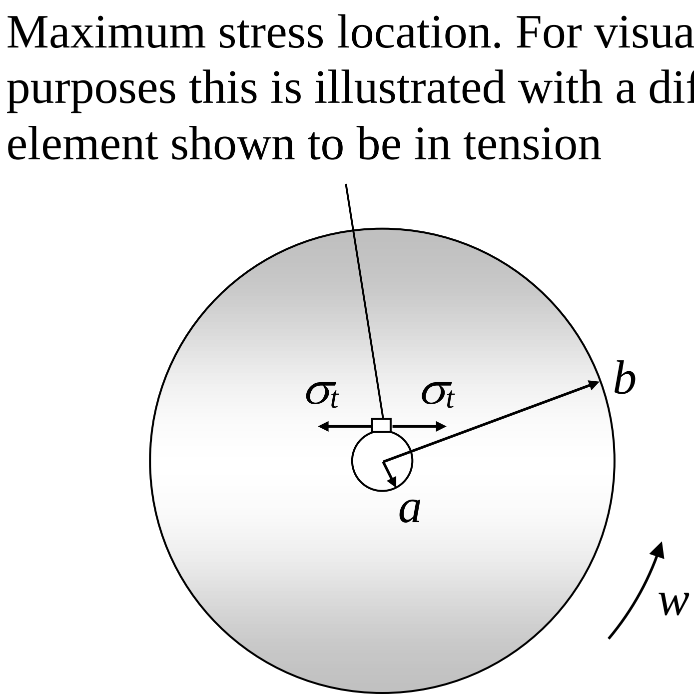
The rate w_1 is proportional to V. Mathematically this means that $w_1 = aV$, where a is a constant.

Let's say the person has to travel a distance d through the rain. We have to determine if this person should walk or run. The total amount (volume) of water that impinges on the front of the person as he/she travels the distance d is equal to $A_1 = w_1T$, where T is the total time (in seconds) it takes for the person to travel the distance d to their destination

Now, $T = d/V$, therefore $A_1 = w_1(d/V) = aV(d/V) = ad$, which is constant. Now, the total amount of water impinging on the person is $A_1 + A_2$, where A_2 is the amount (volume) of water impinging on the top of the person, and $A_2 = w_2T$. Since A_1 is constant, then to minimize getting wet we must minimize A_2. Since w_2 is always the same no matter what V is, then to minimize A_2 we must minimize the time T spent in the rain. Therefore to minimize getting wet the person must run as fast as he/she can to their destination.

Advanced Level - Can a standard CD-ROM drive shatter a CD? (2003 season, episode 2)

A CD can be treated as an annular disk with inner hole radius *a* and outer radius *b*. The maximum stress occurs at the inner hole location at radius *a*. This is the part of the CD that will break first if it is spun too quickly. As the disk spins centripetal forces are generated inside the structure of the CD and these forces are what put the CD material under stress. If the stress is too great (due to the CD spinning too fast) the CD will break.



Assume the CD has no cracks or flaws in it, which would complicate the analysis.

The maximum stress of the rotating CD is located at the inner hole location (at radius *a*). This stress is tensile. At this location the stress is given by the following solid mechanics equation:

$$\sigma_t = \left(\frac{3+\nu}{4}\right)\rho w^2 b^2 \left(1 + \left(\frac{1-\nu}{3+\nu}\right)\frac{a^2}{b^2}\right)$$

Where:

σ_t is the tangential stress, which acts as tension in the circumferential direction. The maximum tensile yield stress which can be withstood by CD material (polycarbonate plastic) is roughly 65×10^6 pascals (newtons per square meter).

ν is the Poisson's ratio for the CD material, which is 0.37

ρ is the density of the CD material, which is 1200 kg/m^3

w is the angular velocity of the CD, in radians per second. This quantity must be determined

b is the outer radius of the CD, which is 0.06 m

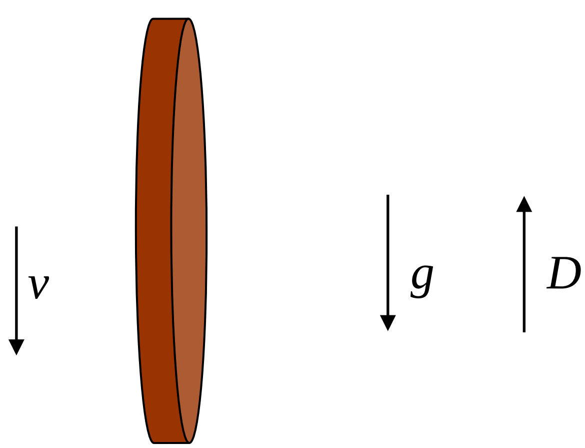
a is the inner hole radius of the CD, which is 0.0075 m

Now solve for *w*. We get *w* = 4220 radians/second. This is equal to 40,300 RPM. This is well above the maximum rotational speed of CD-ROM drives which may top out at about 24,000 RPM. Therefore a standard CD-ROM drive *cannot* shatter a CD.

Advanced Level - Will a penny dropped from the top of the Empire State Building kill a person or penetrate the ground? (2003 season, episode 4)

The fastest speed a penny can achieve is terminal speed. This is the speed at which the drag force from air resistance exactly balances the force of gravity pulling down on the penny. As the penny falls it accelerates until its speed is high enough so that the corresponding air drag force exactly balances the force of gravity pulling down on the penny.

Consider the schematic showing a penny falling with the thin side facing down. This orientation results in the greatest terminal speed, as will be explained.



The general equation for the drag force acting on a body is:

$$D = \frac{1}{2} C \rho A v^2$$

Where:

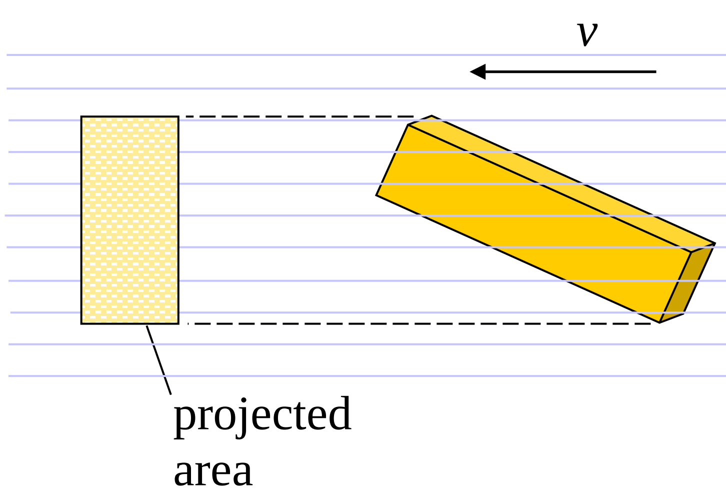
D is the drag force acting on the body

C is the drag coefficient, which can vary along with the speed of the body. But typical values range from 0.4 to 1.0 for different fluids (such as air and water)

ρ is the density of the fluid through which the body is moving (in this case, the fluid is air)

v is the speed of the body relative to the fluid

A is the projected cross-sectional area of the body perpendicular to the flow direction (that is, perpendicular to *v*). This is illustrated in the figure below.



The force of gravity pulling down on the penny is:

$$W = mg$$

Where:

W is the force of gravity pulling down on the penny

m is the mass of the penny

g is the acceleration due to gravity, which is 9.8 m/s^2

When terminal speed is reached $D = W$ so we have

$$mg = \frac{1}{2} C \rho A v^2$$

Set $v = v_t$ and solving for terminal speed we have

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

An important observation is that, the smaller the cross-sectional area A, the higher the terminal speed. The minimal value of A occurs when the penny is falling with the thin side facing down. In reality the penny will likely tumble through the air but in the interest of testing the validity of this myth we shall assume a "best case" scenario in which the penny is falling at the fastest possible speed.

We have the following values for a U.S. penny:

m = 0.0025 kg

diameter = 0.019 m

thickness = 0.0015 m

A = diameter x thickness = 0.019 x 0.0015 = 2.85x10^{-5} m^2

ρ = 1.2 kg/m^3 (density of air)

C = 0.5 (crude approximation based on drag coefficient for sphere as shown on http://en.wikipedia.org/wiki/Drag_coefficient)

Using the above values we get v_t = 54 m/s which is 190 km/h. Although high, this would not be enough speed to kill a person, or even badly injure them. But it would definitely hurt! It would also not be enough speed to penetrate a concrete surface. And keep in mind that this is the highest possible speed. The penny, as it tumbles through the air, spends some time in different orientations which produce a greater value of A, thus resulting in a lower terminal speed than the one calculated here.

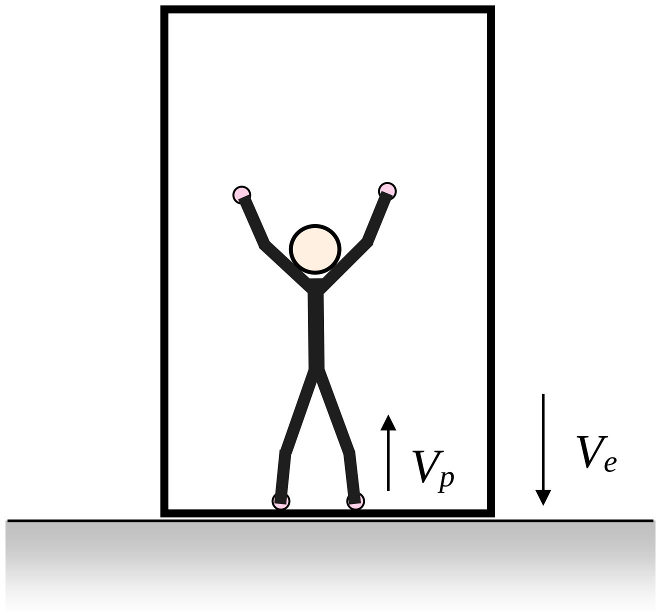
Introductory Level - Do frozen chickens cause more damage than thawed chickens when shot at a plane's windshield? (2004 season, episode 10)

Yes they do because they are harder. It's like throwing a tennis ball at a wall versus a rock (both having the same mass and thrown at the same velocity). The rock will do more damage since it's harder. You can think of this in terms of the impulse and momentum equation: $F\Delta t = mv_2 - mv_1$, where F is the average force during the impact, Δt is the time duration of the impact, m is the mass of the object, v_1 is the object velocity before impact, and v_2 is the object velocity after impact. The right hand side $mv_2 - mv_1$ is the change in momentum of the object, during impact, which can vary somewhat depending on the hardness of the object. But the biggest effect of hardness is on Δt which becomes much smaller as an object becomes much harder. This means the force F must increase by a large amount to produce a similar change in momentum during impact. Hence, a harder object results in a larger F, and causes more damage during impact.

Introductory Level - Can mirrors be used to make a death ray? (2004 season, episode 16)

Yes. By using a large number of mirrors, with adjustable orientation, a death ray can be created. For example, a solar power tower, which uses the sun's energy to produce electricity, uses many mirrors to focus concentrated sunlight onto a central receiver. This receiver then becomes very hot as a result. A control mechanism is used to track the position of the sun and orient the mirrors accordingly so that they each reflect sunlight onto the central receiver. Alternatively, this control mechanism can be used to focus concentrated sunlight anywhere you want, such as at an enemy. The only drawback is that it can't be used at night or when it's cloudy.

Introductory Level - Can someone survive a multi-story elevator fall by jumping right before the elevator hits the bottom of the shaft? (2004 season, episode 17)



Let's say a top-level athlete can jump straight up with a maximum speed of V_p = 4 m/s. This results in a maximum jump height of close to 1 meter, which can be determined from projectile motion equations. The speed of 4 m/s will be subtracted from the elevator speed at the point of impact. If an elevator hits the bottom of the shaft at a speed of V_e = 24 m/s (corresponding to 53 mph as tested in the episode) then the impact energy is equal to the kinetic energy at the point of impact, which is equal to $(1/2)x(\text{mass})x(24–4)^2$. If the mass of the person is 70 kg then the impact energy is equal to 14,000 Joules. If the person did not jump up the impact energy would be equal to $(1/2)x(\text{mass})x(24)^2$ = 20,160 Joules. So clearly there is a significant reduction in impact energy. However, the 14,000 Joules of impact energy resulting from the jump would still be fatal.

Introductory Level - Is it possible to make a hovercraft with a vacuum motor? (2004 season, episode 17)

Yes you can. In fact, as proof of concept you can also do it on a smaller scale using blowdryer fans. For example, you can get two blowdryer fans and connect them in series using tape, and wire them so that they are powered by an external power source. For safety reasons, the power requirement should be low, so the power source should be either batteries, or a small toy transformer; such as the kind used for toy trains.

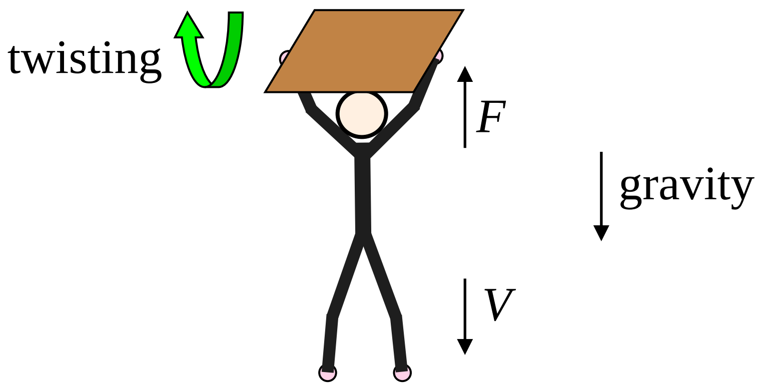
You then insert the fan assembly into a hole cut into a plastic container. When you turn the fans on, they blow air into the container which pressurizes the chamber, causing lift.

The result is a miniature hovercraft that floats on a thin cushion of air. The figures below illustrate the construction.

You can easily build one yourself, perhaps experimenting with only one fan instead of two. You can then describe the physics behind the lift. The lift is generated by pressurization of the chamber which causes separation between the surface and the cup. The separation gap is such that the internal pressure force inside the chamber is equal to the weight of the hovercraft. Mathematically, you can determine the size of the gap depending on the fan power and the weight of the hovercraft. This calculation goes beyond high school level, however.

Introductory Level - If someone falls off a building, can that person glide to safety using a sheet of plywood? (2004 season, episode 18)

The best case scenario is that the person will glide down at a slow (and constant) speed *V* while experiencing an upward air drag force *F*. In this case he, or she, will have to support their own weight. So in this regard it is possible to do. However, the plywood will have a tendency to twist (as shown below) as the air pushes up against the plywood in an uneven and somewhat chaotic manner. This will make the plywood impossible to hold on to since the person would have to resist the twisting motion of the plywood in addition to supporting their own weight. Probably no one has a strong enough grip to do this.



Introductory Level - How many balloons are needed to lift a 40-lb child off the ground? (2004 season, episode 21)

To solve this determine the amount of buoyant lift force for a typical helium balloon and then divide 40 pounds by this force to get the number of balloons needed. A typical amusement park helium balloon might have a lifting capacity of 10 grams (0.01 kg). So to lift a 40 pound child (18.2 kg) it would take 18.2/.01 = 1820 balloons. That's a lot of balloons!

A useful exercise is to perform a more involved calculation. First calculate the volume of helium inside a typical balloon, and then determine the lift force of this volume of helium based on Archimedes' principle. Next, subtract the mass of the balloon. This will give you the lift force of the balloon.

<u>Example:</u>

Assume the volume of a balloon is a sphere. And let's say the radius of a typical balloon is 15 cm (0.15 m). The volume of a sphere is $(4/3)\pi(0.15)^3 = 0.0141$ m^3. The density of helium is 0.166 kg/m^3 at 20 degrees Celsius and at atmospheric pressure. The density of air is 1.2 kg/m^3 at these same conditions. By Archimedes' principle the buoyant force acting on this volume of helium is (1.2–0.166)x0.0141 = 0.0146 kg. To find the lift force for the balloon subtract the mass of the balloon from 0.0146 kg. This will give you the approximate lift force of the balloon. This lift force is approximate because the shape of a balloon is not exactly spherical.

Introductory Level - Do free energy devices seen on the Internet actually work? (2004 season, episode 24)

Free energy devices cannot work using the following proof: Let's say you have a device that outputs more energy than it uses. From this you can create a feedback loop which feeds the output energy back into the device, which then results in even more energy being outputted by the device. This process can be continued indefinitely until, say, something as small as a battery can power an entire city. This is clearly impossible!

Introductory Level - Does a clothed snowman melt slower than a "naked" one? (2004 season, Special 1)

Yes. The clothes act as insulation. So when it warms up outside the coolness of the snowman will be insulated from the warmer outdoor air. The clothes, acting as a thermal barrier, slow down the rate of heat flow into the snowman, so it melts slower.

Introductory Level - Can a urine stream freeze in the winter? (2004 season, Special 1)

No. The urine stream droplets are far too large to freeze during the short time they are airborne. However, if a urine stream were comprised of a very fine mist they would freeze much more quickly, due to the much higher ratio of droplet surface area to droplet volume. Under this condition a urine stream could freeze.

Introductory Level - Can a person be blown away by a bullet? (2005 season, episode 25)

Let's say a bullet of mass 0.06 kg is moving at a velocity of 300 m/s. And let's also say that it embeds itself inside a person. Could this person be thrust back at high speed (i.e. blown away)?

To solve this assume the mass of the person is, say, 70 kg.

Apply conservation of linear momentum to the bullet and person, between the point just before the bullet strikes the person, and after it embeds inside the person (so that bullet + person both have the same final velocity).

We have,

$0.06(300) + 70(0) = (70+0.06)V$

where V is the velocity of the bullet + person after the bullet embeds in the person. Solve for $V = 0.26$ m/s. This speed is far too low to cause the person to be "blown away".

Introductory Level - Does buttered toast always land buttered side down? (2005 season, episode 28)

If this is a common occurrence (occurring more than half the time) then it is likely due to the fact that the toast tends to rotate about 180 degrees between the time at which it falls off the edge of the table and when it hits the floor. This 180 degree rotation is a function of table height, which is fairly standard. If the table were much taller the toast may rotate 360 degrees and land with buttered side up. If the table were much shorter it would rotate much less than 180 degrees and likely land buttered side up as well. The rotation of the toast upon falling off the table is due to one edge of the toast falling before the other and rotation being induced as a result. And the speed of rotation is due to the dynamics of the problem, and the physical properties of the toast, such as mass and inertia. The buttering of one side of the toast likely affects these properties in a negligible way and does not affect how much the toast rotates before hitting the ground. This is easy to experiment with!

Introductory Level - What is the fastest way to cool a six pack of beer? (2005 season, episode 29)

You need to immerse the beer in a fluid that is as cold as possible and which is vigorously stirred in order to maximize the convection coefficient between the fluid and the surface of the beer cans. This maximizes the heat loss from the beer cans.

Using liquid nitrogen may be a good way to do this. However, according to: http://en.wikipedia.org/wiki/Liquid_nitrogen:

"Despite its reputation, liquid nitrogen's efficiency as a coolant is limited by the fact that it boils immediately on contact with a warmer object, enveloping the object in insulating nitrogen gas. This effect, known as the Leidenfrost effect, applies to any liquid in contact with an object significantly hotter than its boiling point."

Introductory Level - Will diving underwater protect a person from bullets? (2005 season, episode 34)

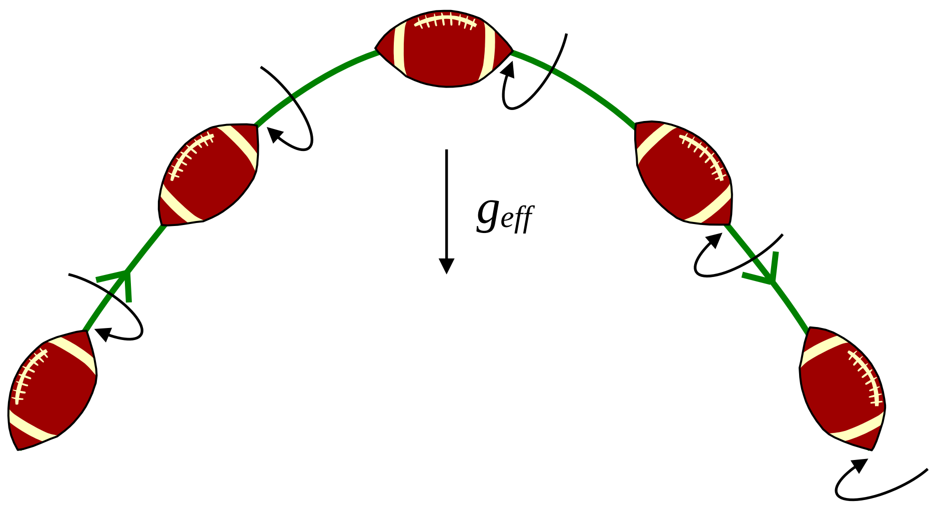
Yes, if you dive deep enough. The drag force exerted by the water on the bullets will be very high which will quickly slow down the bullets. There is also the inelastic collision between bullets and water which slows down the bullets even more. But you may need to dive several feet to be protected from the bullets.

Introductory Level - Will a black car heat faster than a white one? (2005 season, episode 38)

The color black absorbs all colors of the visible electromagnetic spectrum, therefore it heats up the most of all the colors. The color white reflects all colors of the visible electromagnetic spectrum. As a result, a black painted car heats up faster and to a higher temperature than a white painted car.

Advanced Level - Can a football fly farther if it is filled with helium? (2006 season, episode 47)

When a football is thrown it is given spin about its axis. This creates gyroscopic stability which enables the football to keep its symmetric (long) axis aligned with its flight trajectory, without tumbling end over end when in flight. The spin imparts a gyroscopic response to the aerodynamic forces acting on the football, which results in the football long axis aligning itself with the flight trajectory (as shown below). The physics necessary to describe this is a combination of gyroscopic analysis and aerodynamic force analysis due to drag and (potentially) the Magnus effect. This is quite complicated and will not be discussed here. However, there is a lot of literature available online on gyroscope physics, as related to projectile spin and gyroscopic stability, if one wishes to study this topic further.



The fact that the football keeps its long axis aligned with its flight trajectory helps make this problem more solvable. This is because the drag force equation, used in the solution, has a constant projected frontal area as well as having a reasonably constant drag coefficient, as a result. This is directly a result of the alignment of the long axis of the football with its flight trajectory.

To start off, consider the general equation for the drag force acting on a body:

$$D = \frac{1}{2} C \rho A v^2$$

Where:

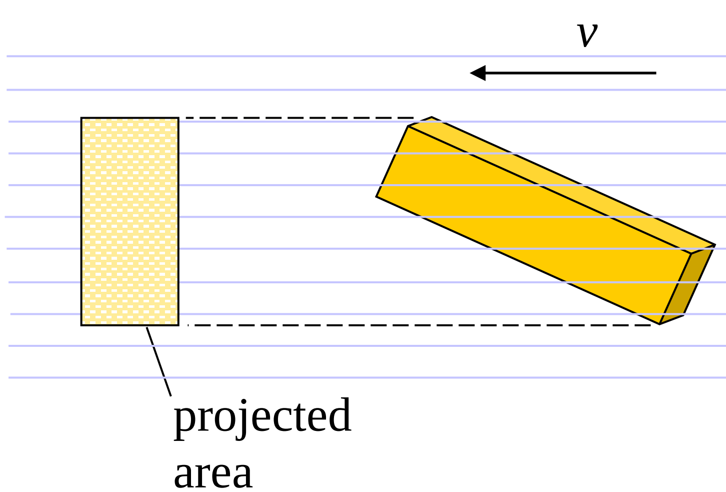
D is the drag force acting on the body

C is the drag coefficient, which can vary along with the speed of the body. For a football this value is about 0.05 (reference: http://users.df.uba.ar/sgil/physics_paper_doc/papers_phys/fluids/drag_football.pdf)

ρ is the density of the fluid through which the body is moving. In this case, the fluid is air so ρ = 1.2 kg/m^3

v is the speed of the body relative to the fluid

A is the projected cross-sectional area of the body perpendicular to the flow direction (that is, perpendicular to *v*). This is illustrated in the example figure below. For a football in flight $A = \pi r^2$, where r = 0.085 m is the radius of the football at the mid point. So A = 0.023 m^2.



The above variables stay the same whether the football is filled with air or helium.

The two variables which depend on whether the football is filled with air or helium are mass and effective gravity. In both cases the football is filled to the same pressure.

The mass of the football will vary depending on if it's filled with air or helium, since they have different densities (helium has a lower density). If a football is filled with air it will typically have a mass of about 410 grams. If it is filled with helium it will weigh about 7 grams less (reference: http://www.discovery.com/tv-shows/mythbusters/mythbusters-database/football-helium-fly-farther). So it would have a mass of 403 grams.

The effective gravity takes into account the buoyant force acting on an object. Air exerts a buoyant force on objects but its effect is usually negligible in projectile motion calculations. To calculate effective gravity we need to know the volume of a football, which is 0.0042 m^3 (reference: http://www.csus.edu/indiv/o/oldenburgj/ENGR1A/NFLFootballWtCalc.pdf).

The equation for calculating effective gravity is

$$g_{eff} = g - \frac{\rho V g}{m}$$

Where:

g_{eff} is the effective gravity

g is the acceleration due to gravity, which is 9.8 m/s^2

V is the volume of the football, which is 0.0042 m^3

ρ is the density of air which is 1.2 kg/m^3

m is the mass of the football (0.41 kg for an air filled football and 0.403 kg for a helium filled football)

For an air filled football the effective gravity is g_{eff} = 9.68 m/s^2. For a helium filled football the effective gravity is g_{eff} = 9.68 m/s^2. There is negligible difference.

Since this is a projectile motion problem we need to know the initial velocity of the football in the horizontal and vertical direction. A football in professional competition is typically thrown at about 27 m/s. It can also be thrown at various launch angles. So for the sake of argument let's test out two launch angles, say 20° and 45° above the horizontal. For the 20° launch angle the horizontal velocity is 27cos20 = 25.4 m/s, and the vertical velocity is 27sin20 = 9.2 m/s. For the 45° launch angle the horizontal velocity is 27cos45 = 19.1 m/s, and the vertical velocity is 27sin45 = 19.1 m/s.

Lastly, we shall ignore the Magnus effect due to the spinning of the ball. This is likely an unimportant effect anyway since the equation for Magnus force is independent of whether the football is filled with air or helium.

To solve this problem we need to use a suitable projectile motion simulator program, such as the one described on http://www.real-world-physics-problems.com/projectile-motion-simulator.html.

Inputting the above values into the simulator we find that an air filled football flies a (horizontal) distance of 45.8 m when launched at 20°, and a distance of 68.7 m when launched at 45°. A helium filled football flies a distance of 45.7 m when launched at 20°, and a distance of 68.6 m when launched at 45°. The difference is clearly negligible, so it makes no difference whether the football is filled with air or helium. This is what the Mythbusters concluded.

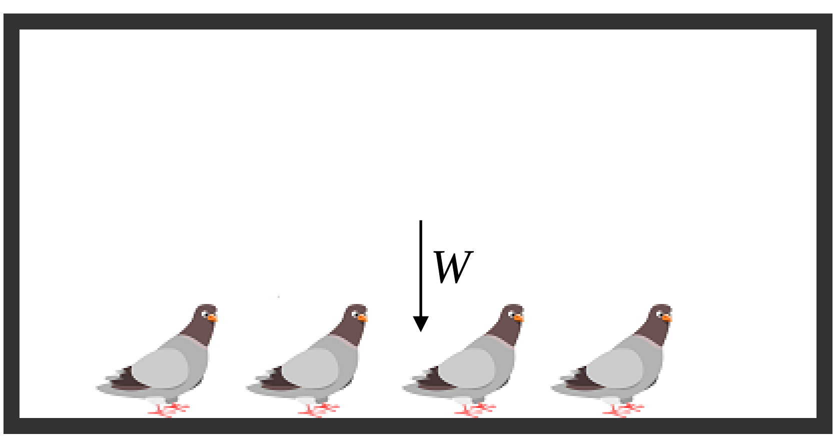
Introductory Level - Can a bullet fired straight up in the air kill someone on the way back down? (2006 season, episode 50)

No. On the way back down the maximum speed of the bullet will be terminal speed (due to air resistance) which is much less than the speed at which the bullet was fired. However, if the bullet was fired in a vacuum then it would fall back to earth at the same speed as it was fired, and it could indeed kill someone.

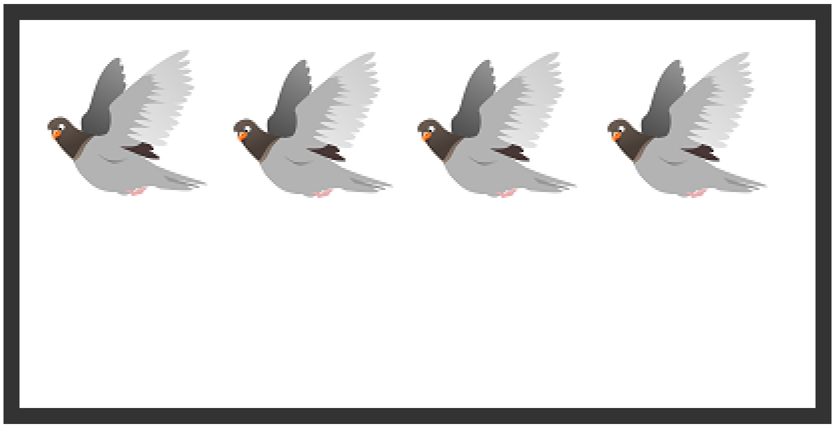
The bullet can be fired at a speed much faster than the terminal falling speed because of the explosive force of the gunpowder propelling the bullet. But once the bullet leaves the gun the only forces acting on it are gravity and air resistance. On the way down these are the only forces acting on the bullet and they combine to produce terminal speed, similar to how a [skydiver](#) reaches terminal speed on the way down.

Advanced Level - Do birds flying in a trailer cause the trailer to become lighter? (2007 season, episode 77)

When the birds are standing still they exert a combined weight *W* on the trailer, as shown.



But when the birds are flying the situation becomes more complex.



Pigeon pictures taken freely from https://openclipart.org

An answer to this difficult problem is given in this article:
http://www.telegraph.co.uk/news/uknews/11345183/Birds-in-a-lorry-riddle-finally-solved-by-Stanford-University.html

According to this article the weight of the trailer would change. The weight of a trailer containing flying birds fluctuates up and down with each wing beat.

In reality, a group of birds would flap their wings out of sync with each other, which would tend to reduce the total weight fluctuation. But if they were to all flap their wings at the same time the trailer weight would noticeably fluctuate.

The researchers (mentioned in the article) discovered that during the downstroke of the birds' wings, a force equal to twice the bird weight is produced. This allows the bird to stay suspended in air during the upstroke of the wings which generates no lift force at all.

For more information on this subject see:

http://phys.org/pdf340475172.pdf

http://rsif.royalsocietypublishing.org/content/12/104/20141283

Introductory Level - Can fuel be saved by tailgating a semi-trailer truck? (2007 season, episode 80)

Yes. This is called drafting. It reduces aerodynamic drag and improves fuel efficiency as a result.

Introductory Level - Can dry balls be hit farther than humid ones? (2007 season, episode 83)

Yes. Dry balls, when dropped, will bounce higher than humid balls. In physics lingo, the dry balls have a higher coefficient of restitution so they rebound off the bat faster than humid balls and as a result fly further.

Introductory Level - Can balls be hit further with a corked bat? (2007 season, episode 83)

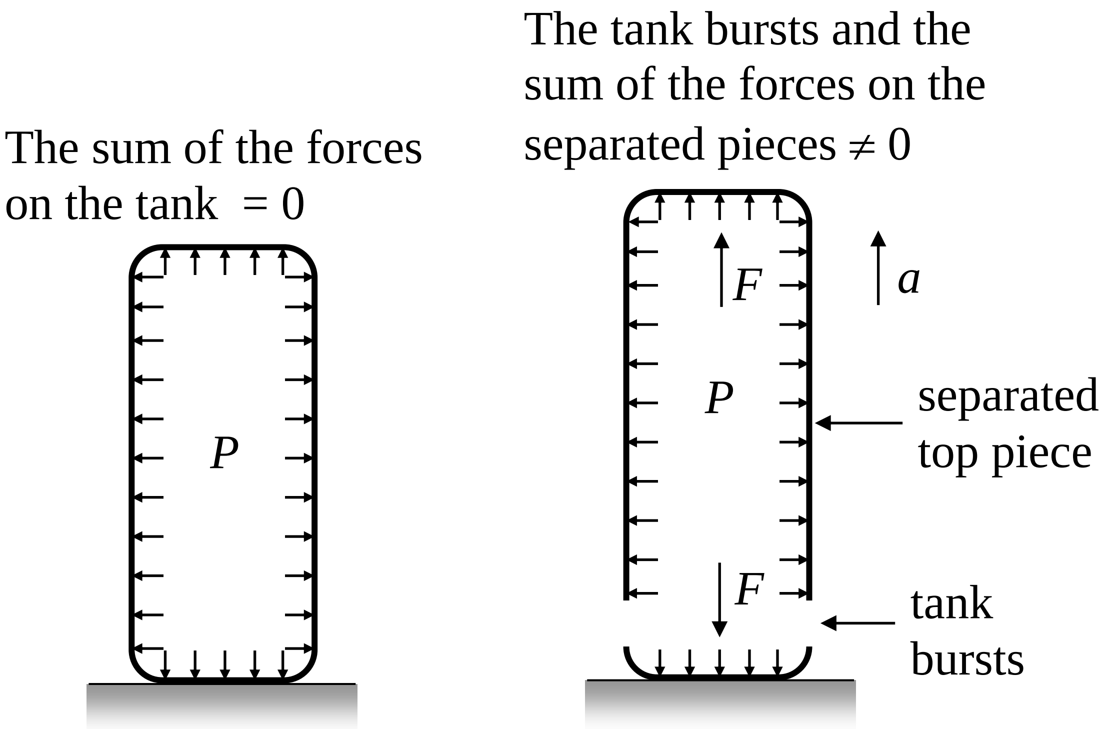
According to http://mythbustersresults.com/episode83:

"This myth operates under the assumption that cork-filled bats can be swung faster because of their lighter weight, and that the springiness of the cork could propel the ball farther. To eliminate the human factor of the myth, Adam and Jamie constructed a special batting rig and used a pressurized air cannon to launch the baseball at it. Tests showed that the cannon could launch the ball 80 miles per hour, which is the average speed of most MLB pitches. Regulation bats could propel the ball away at 80 mph while corked bats could only propel the ball 40 mph, half the speed of regulation bats. The reason was because cork bats have less mass to transfer force into the ball, and the cork actually absorbs some of the ball's impact. The Mythbusters concluded that using a cork filled bat will not improve your performance (it will in fact hurt it), and the major league batters who were caught using cork-filled bats risked their careers for nothing."

Physics explanation: If you swing a lighter corked bat as fast as you can versus a heavier regular bat, chances are that the corked bat will be swung a bit faster. But since the corked bat has less mass, the net result may be that the corked bat has less kinetic energy, upon swinging. Furthermore, it appears that cork has a lower coefficient of restitution than regular bat material. This makes the corked bat less able to flex elastically upon impact, than a regular bat, and will absorb more energy during impact as a result. The net result of all these factors combined is that the ball rebounds with less speed off a corked bat and doesn't fly as far as a result.

Advanced Level - Can a water heater explode like a rocket and shoot through the roof of a house? (2007 season, episode 89)

Initially, before the tank bursts, the sum of the forces acting on the tank equals zero. But when the tank bursts and the bottom of the tank blows off, an immediate imbalance of forces is experienced by the separate tank pieces (shown below). The net sum of the forces acting on the separate tank pieces does not equal zero. The net force acting on the separated top piece is pointing upward and is equal to (pressure)x(area), where the area is the top inside area of the tank, which is equal to πR^2, where R is the inside radius of the tank. If the burst pressure is P = 350 psi (pounds per square inch, gauge pressure) and the inside radius is, say, 10 inches, then the net force F propelling the top piece upward (ignoring gravity) is equal to $350 \times \pi(10)^2$ = 110,000 pounds! Clearly this is sufficient force to propel the tank upward like a rocket, at a very high acceleration *a*.



Introductory Level - If a person jumps out of an airplane with the last parachute, can another person jump out later and catch the person? (2007 season, episode 94)

If the person with the parachute is spread eagled the other person can orient themselves so that their body is vertical, making themselves as streamlined as possible. This will make their aerodynamic drag force less than that of the parachute person and they will be able to catch up. Now if the parachute person attempts to minimize their aerodynamic drag by also orienting their body in the vertical position, the other person can still catch up because the parachute pack on the back of the person creates additional drag which the non-parachute person does not experience. So he can still catch up.

Advanced Level - Does a 4,000 foot fall take 90 seconds? (2007 season, episode 94)

According to http://mythbustersresults.com/episode94:

"The Build Team dropped a dummy from a plane at a height of 4,000 feet (1,200 m) and measured the amount of time it took for it to hit the ground. They timed the total free fall time at just 31 seconds, which would make the ninety second free fall scene in the movie impossible."

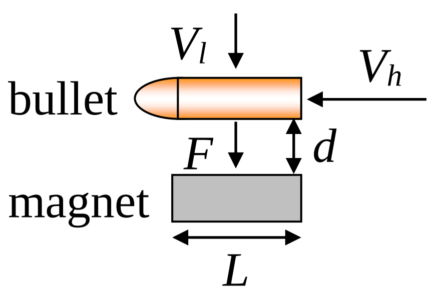
From the skydiving physics page the terminal speed is:

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

It is known that terminal speed for a skydiver in the spread-eagle position is about 120 mph, or 54 m/s. Setting v_t = 54 m/s, m = 80 kg, g = 9.8 m/s^2 we can solve for $C\rho A$ = 0.54, from the above equation. This will be a constant term in the equations of motion used in the projectile motion simulator described in http://www.real-world-physics-problems.com/projectile-motion-simulator.html. We can use arbitrary values for C, ρ, A as long as $C\rho A$ = 0.54. For convenience use C = 0.5, ρ = 1.2 kg/m^3, and A = 0.9 m^2. Now, the plane is moving as the dummy is dropped but let's assume that the initial horizontal velocity of the dummy is zero. And of course the initial vertical velocity is also zero. Using the simulator we can now solve for how long it takes the dummy to fall 4000 feet (1200 m). We find that the falling time is 26 seconds. This is within range of the 31 seconds determined by the Mythbusters.

Advanced Level - Can a watch-sized electromagnet deflect a bullet? (2008 season, episode 95)

To analyze this let's say a bullet flies past a watch as shown in the figure below, with dimensions as shown.



For example, let's say the bullet moves at V_h = 300 m/s and we wish to deflect it a significant amount so that it misses its mark completely. If the intended target of the bullet is the one wearing the magnetic watch then the bullet would have to deflect a great deal to avoid hitting the target. So let's reasonably say the bullet would have to be deflected by an angle of 45°. This means that the lateral speed of the bullet (V_l) would be equal to the horizontal bullet speed (V_h). So V_l = 300 m/s. Before the bullet passes by the watch, its lateral speed is zero. As it passes by the watch the lateral bullet speed would have to be increased to 300 m/s. This means that the magnetic force of attraction F between bullet and watch would have to be very large in order to cause such a rapid lateral speed increase in the short time period it takes the bullet to pass by the watch. To maximize the magnetic force the bullet would have to pass as close as possible to the watch, so *d* would have to be as small as possible.

If we suppose the watch is L = 2.5 cm in diameter, then it takes the bullet 0.025/300 = 8.33×10^{-5} seconds to pass by the watch. Let's also suppose the mass of the bullet is 0.06 kg.

To solve for the force F we can use the impulse and momentum equation: $F\Delta t = mv_2 - mv_1$, where F is the average lateral force pulling on the bullet during the bullet pass, Δt is the time duration of the pass, m is the mass of the bullet, v_1 is the lateral bullet speed before the pass, and v_2 is the lateral bullet speed after the pass. Using the variables given previously, we have $F(8.33\text{x}10^{-5}) = 0.06(300) - 0.06(0)$. Solving for F we get F = 216,000 N. This is equal to 22 tons! Clearly a watch sized magnet cannot even come close to sufficiently deflecting a bullet.

Note that a magnetic force varies with the inverse cube of the distance from the magnet. This means that the magnetic force F can only be high when the bullet is in very close proximity to the watch. This proximity requirement is approximately modeled by assuming that the magnetic force F is only acting on the bullet while it passes over the watch. In reality the magnetic force would also be acting on the bullet while it is some distance away from the watch, but in the calculations we assume that the force is only acting on the bullet as it passes over the watch, which is a reasonably good approximation.

Introductory Level - Can a lead balloon fly? (2008 season, episode 96)

Thin lead foil is available at a thickness of 0.006" = $1.52\text{x}10^{-4}$ m. Let's see if you can make a floating balloon out of this, using helium as the gas inside the balloon.

The density of lead is 11,340 kg/m^3.

To solve this first calculate the volume of helium inside a typical balloon, and then determine the lift force of this volume of helium based on Archimedes' principle. Next, subtract the mass of the balloon. This will give you the lift force of the balloon.

<u>Example:</u>

Assume the volume of a balloon is a sphere. And let's say the radius of a typical balloon is 15 cm (0.15 m). The volume of a sphere is $(4/3)\pi(0.15)^3 = 0.0141$ m^3. The density of helium is 0.166 kg/m^3 at 20 degrees Celsius and at atmospheric pressure. The density of air is 1.2 kg/m^3 at these same conditions. By Archimedes' principle the buoyant force acting on this volume of helium is (1.2–0.166)x0.0141 = 0.0146 kg. To find the lift force for the balloon subtract the mass of the lead balloon from 0.0146 kg. The mass of the lead balloon can be closely approximated by the following formula: (surface area of balloon)x(balloon wall thickness)x(density of lead) = $4\pi(0.15)^2\text{x}(1.52\text{x}10^{-4})\text{x}(11340)$ =

0.49 kg. This is much greater than the buoyant lifting force provided by the helium, which is 0.0146 kg. So a normal sized lead balloon cannot float.

A helium filled lead balloon would have to be much bigger in order to float. Let's calculate how big.

Use the same equations as before but this time solve for the required radius *R* of the balloon.

The lift force acting on the volume of helium in the balloon is $(1.2–0.166)\text{x}(4/3)\pi R^3$. The mass of the balloon is $4\pi R^2\text{x}(1.52\text{x}10^{-4})\text{x}(11340)$.

The lift force of the balloon is equal to $(1.2–0.166)\text{x}(4/3)\pi R^3–4\pi R^2\text{x}(1.52\text{x}10^{-4})\text{x}(11340)$. Set this equation equal to zero to find the minimum balloon radius *R*. Solving for *R* we find that minimum $R = 5$ m. This is a big balloon!

Introductory Level - Can an airplane take off while on a conveyor belt? (2008 season, episode 97)

Yes. The wheels of the airplane are free to turn and as a result exert little resistance on the plane due to the motion of the conveyor belt. So from the point of view of the airplane engine there is no difference in the thrust required for takeoff.

Introductory Level - Will a feather and a hammer drop at the same rate in a vacuum? (2008 season, episode 104)

Yes. In a vacuum air resistance is removed and there is only the force of gravity acting on a dropped object, so both the feather and hammer fall at the same rate.

With air resistance present the weight of a falling object is an important influence on how fast it falls. A feather will fall much more slowly than a solid object such as a hammer, because the air drag force relative to body weight is much higher for a feather.

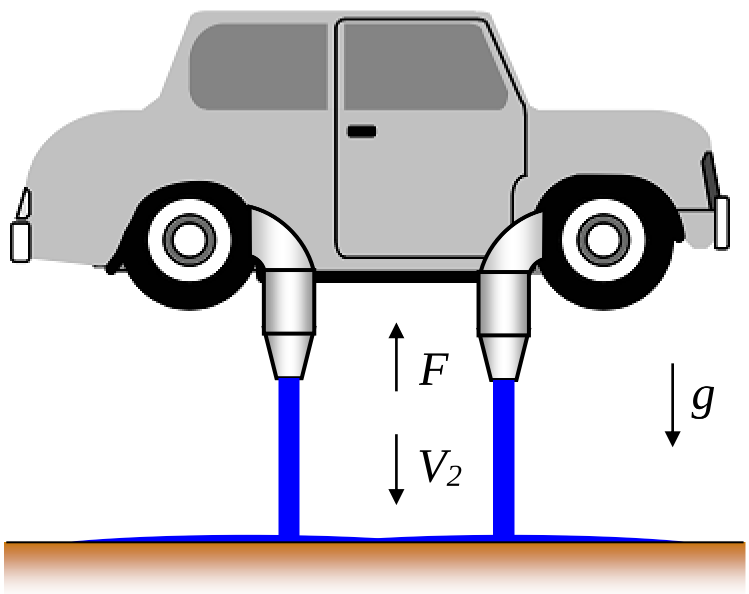
Introductory Level - Could the flag have flapped like it did on the moon? (2008 season, episode 104)

According to http://mythbustersresults.com/nasa-moon-landing:

"The Build Team placed a replica of the American flag planted on the moon into a vacuum chamber at the Marshall Space Flight Center. They first tested at normal pressure and manipulated the flag. The momentum moved the flag around but the motion quickly dissipated. In vacuum conditions, manipulating the flag caused it to flap vigorously as if it were being blown by a breeze. This demonstrated that a flag could appear to wave in a vacuum, as the Apollo flag did."

Advanced Level - Is it possible to lift a car using fire hoses? (2008 season, episode 105)

Yes, it is possible, provided there are enough hoses, and a suitable hose geometry is used, one which will generate a force that pushes up on the car. A suitable hose geometry is one in which there is a 90 degree bend between the inlet and the outlet (nozzle). The inlet flow direction must be horizontal and the outlet flow direction must be vertical and pointing down (as shown below). The resulting upward push force F produced by this hose is approximately given by $F = M_F V_2$, where M_F is the mass flow rate of the water, and V_2 is the velocity of the water right after it exits the nozzle. Note that we do not have to know the initial velocity of the water entering the hose (call this V_1). The physics behind this equation is covered in introductory fluid mechanics textbooks.



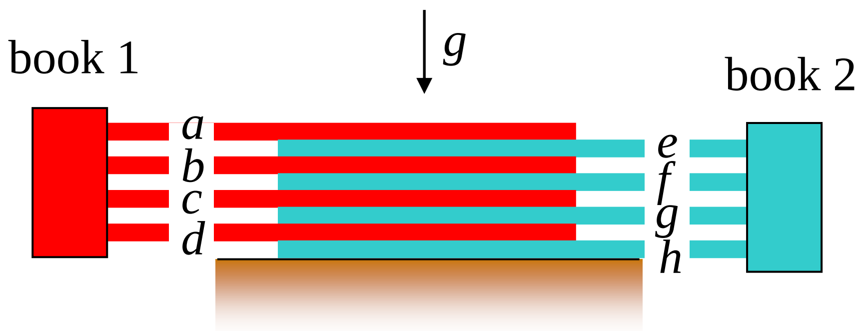
Car image taken freely from https://openclipart.org

For a given fire hose, let's say we have the following values: M_F = 9 kg/s, and V_2 = 30 m/s. This results in a push force of F = 270 N (27.5 kg). If a car weighs 1 ton then it will take 37 hoses to lift it.

Note: We can calculate mass flow rate with the following formula: M_F = (cross-sectional area of hose inlet)x(density of water)xV_1. Since mass is conserved M_F is also given by M_F = (cross-sectional area of nozzle)x(density of water)xV_2. Since water is incompressible its density is constant and it cancels out when we equate the two M_F formulas given previously. So we have the following useful equation for solving flow problems where the fluid density is constant: (cross-sectional area of hose inlet)xV_1 = (cross-sectional area of nozzle)xV_2.

Advanced Level - Are two interlaced phone books impossible to pull apart by any means? (2008 season, episode 106)

The phone books have to be sitting on a surface so that the weight of the pages is felt throughout the thickness. This will maximize the friction force. To analyze this problem consider the figure below showing four interlaced pages from two books. From this result we will generalize.



Let's say the weight of each page is W and the coefficient of static friction between the pages is μ_s.

To calculate the total friction force holding the books together we have to add up the individual friction forces acting on all the page surfaces that are in contact with other page surfaces.

Let's start from the topmost page and work down.

The weight of page *a* is W so the friction force between *a* and *e* is $W\mu_s$.

The combined weight of pages *a* and *e* is $2W$ so the friction force between *b* and *e* is $2W\mu_s$.

The combined weight of pages *a*, *e*, *b* is $3W$ so the friction force between *b* and *f* is $3W\mu_s$.

The combined weight of pages *a*, *e*, *b, f* is $4W$ so the friction force between *c* and *f* is $4W\mu_s$.

The combined weight of pages *a*, *e*, *b*, *f*, *c* is $5W$ so the friction force between *c* and *g* is $5W\mu_s$.

The combined weight of pages *a*, *e*, *b*, *f*, *c*, *g* is $6W$ so the friction force between *d* and *g* is $6W\mu_s$.

The combined weight of pages *a*, *e*, *b*, *f*, *c*, *g*, *d* is $7W$ so the friction force between *d* and *h* is $7W\mu_s$.

The total friction force holding the books together is $F_{TOT} = W\mu_s + 2W\mu_s + 3W\mu_s + 4W\mu_s + 5W\mu_s + 6W\mu_s + 7W\mu_s = W\mu_s(1+2+3+4+5+6+7) = 28W\mu_s$. From this result we can generalize for two identical interlaced books, each having *N* number of pages, and where each page has weight *W*:

$F_{TOT} = W\mu_s(1+2+3+...+2N-1) = W\mu s(N)(2N-1)$, where $(1+2+3+...+2N-1) = (2N)(2N-1)/2 = (N)(2N-1)$ from math class.

Let's say we have a phone book that weighs 2.5 pounds and has $N = 1000$ pages. What is the friction force holding two of these interlaced phone books together?

Each page has weight $W = 0.0025$ pounds (equal to 2.5/1000). Let's say $\mu_s = 0.2$ Using the above formula we have:

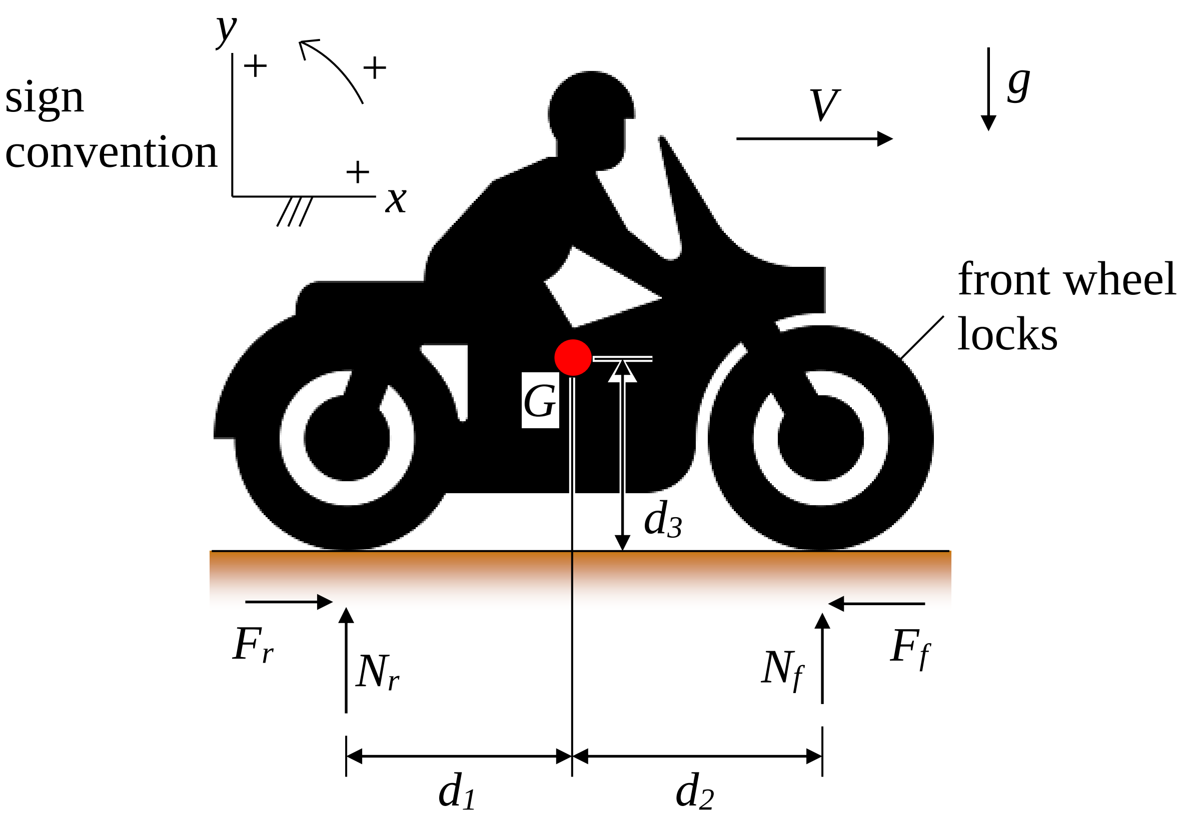
$F_{TOT} = 0.0025(0.2)(1000)(2x1000-1) = 1000$ pounds

This is an incredible amount of force required to pull these two books apart!

Advanced Level - Will a motorcycle flip if a pole is thrust into the front wheel? (2008 season, episode 111)

To analyze this problem set up a free body diagram as shown below, with sign convention shown. It is assumed that the motorcycle is traveling on a flat horizontal surface at velocity *V* at the instant the pole is thrust into the front wheel. It is also assumed that the front wheel locks up when the pole is thrust into it.

Ignore the effects of air resistance.



Motorcycle image taken freely from https://openclipart.org

Where:

g is the acceleration due to gravity, which is 9.8 m/s^2

V is the forward velocity of the motorcycle

G is the center of mass of the motorcycle + rider system

F_r is the push force acting on the rear wheel, at the contact point with the ground

N_r is the normal force acting on the rear wheel, at the contact point with the ground

d_1 is the horizontal distance between the rear wheel contact point (with the ground) and the center of mass *G*

d_2 is the horizontal distance between the front wheel contact point (with the ground) and the center of mass *G*

d_3 is the vertical distance between the ground and the center of mass *G*

F_f is the push force acting on the front wheel, at the contact point with the ground. This is a kinetic friction force since the front wheel will slide (to the right) after it locks up.

N_f is the normal force acting on the front wheel, at the contact point with the ground

Treat this as a problem in two-dimensional rigid body dynamics. For simplicity assume the mass of the wheels is negligible. This allows the problem to be solved as a single rigid body, otherwise the wheels would have to be analyzed with separate equations which will not appreciably improve the accuracy of the solution.

Apply Newton's second law in the horizontal direction:

$$F_r - F_f = ma_x$$

where *m* is the mass of the motorcycle + rider and a_x is the horizontal acceleration of the center of mass *G*.

Since the front wheel is sliding $F_f = \mu_k N_f$, where μ_k is the coefficient of kinetic friction between the front wheel and ground.

The above equation becomes

$$F_r - u_k N_f = ma_x \quad (1)$$

Apply Newton's second law in the vertical direction:

$$N_r + N_f - mg = 0 \quad (2)$$

Assume the system is in a state of rotational equilibrium. This means there is zero torque acting on the system about the center of mass *G*, about an axis pointing out of the page. Mathematically we can write this as

$$-N_r d_1 + F_r d_3 + N_f d_2 - F_f d_3 = 0$$

Since $F_f = \mu_k N_f$ this equation becomes

$$-N_r d_1 + F_r d_3 + N_f d_2 - u_k N_f d_3 = 0 \quad (3)$$

Let's assume a worst case where $F_r = 0$. This makes it easier for the motorcycle to flip. F_r exerts a counterclockwise torque on the motorcycle (about *G*), whereas flipping would be in the clockwise direction. With $F_r = 0$ flipping the motorcycle therefore becomes easier. There are now three equations (1)-(3) and three unknowns which we can solve for (N_r, N_f, and a_x).

Solve for N_r. We get

$$N_r = \frac{mg(d_2 - u_k d_3)}{d_1 + d_2 - u_k d_3}$$

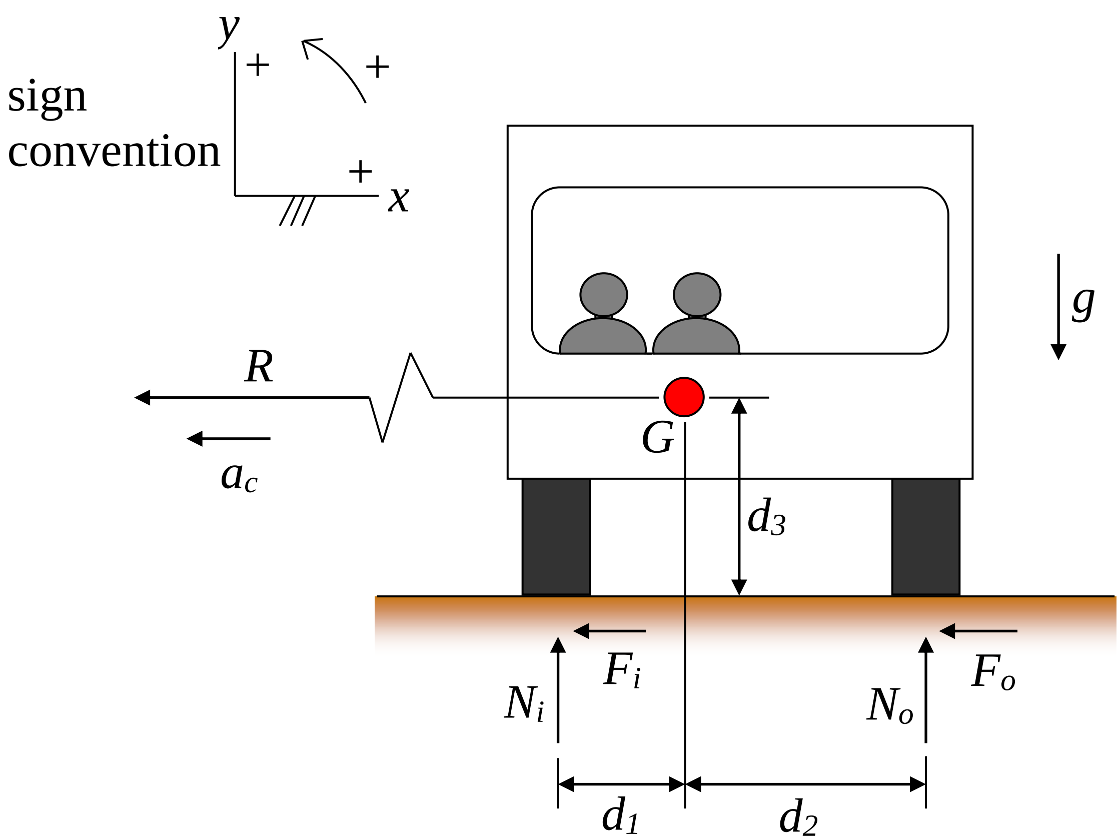
Observing this equation we see that N_r is greater than zero for typical values of d_1, d_2, d_3, and μ_k. Therefore the motorcycle will not flip.

If N_r is less than zero this means that the ground must pull down on the rear wheel (an impossibility) to prevent the motorcycle from flipping, and this would indicate that the motorcycle would have a tendency to flip. This is not the case here.

Note: The initial velocity *V* of the motorcycle is not used in this analysis. Sometimes you may have problems where you are given more information than what is necessary.

Advanced Level - When a bus is moving at over 50 miles per hour, will moving passengers to the inside of the turn keep the bus from flipping? (2009 season, episode 114)

This myth is taken from the 1994 movie *Speed*. To analyze this problem set up a free body diagram as shown below, with sign convention shown. As in the movie, the bus is traveling on a flat horizontal surface and going around a turn at speed *V*.



Where:

g is the acceleration due to gravity, which is 9.8 m/s^2

G is the center of mass of the bus + rider system, which is shifted to the left due to the passengers moving to the left of the bus

V is the speed of the bus at the center of mass location *G*

R is the radius of the turn, measured from the center of the turn to the center of mass G of the system

a_c is the centripetal acceleration of the center of mass of the bus + rider system

F_i is the horizontal force acting on the inside wheels, at the contact point with the ground

N_i is the normal force acting on the inside wheels, at the contact point with the ground

d_1 is the horizontal distance between the left wheel contact point (with the ground) and the center of mass *G*

d_2 is the horizontal distance between the right wheel contact point (with the ground) and the center of mass *G*

d_3 is the vertical distance between the ground and the center of mass *G*

F_o is the horizontal force acting on the outside wheels, at the contact point with the ground

N_o is the normal force acting on the outside wheels, at the contact point with the ground

Assume the bus is on the verge of tipping so that $N_i = 0$ and $F_i = 0$. Then find the turn radius *R* of the bus for a speed *V* of 50 mph. If the turn radius is greater than this value the bus will not flip over.

Treat this as a problem in two-dimensional rigid body dynamics. For simplicity assume the mass of the wheels is negligible. This allows the problem to be solved as a single rigid body, otherwise the wheels would have to be analyzed with separate equations which will not appreciably improve the accuracy of the solution.

Apply Newton's second law in the horizontal direction:

$$-F_o = ma_x$$

where *m* is the mass of the bus + rider system and a_x is the horizontal acceleration of the center of mass *G*.

Now, due to centripetal acceleration

$$a_x = -\frac{V^2}{R}$$

Where $a_x = a_c$. So the above equation for Newton's second law becomes

$$F_o = m\frac{V^2}{R} \quad (1)$$

Apply Newton's second law in the vertical direction:

$$N_o - mg = 0 \quad (2)$$

Assume the system is in a state of rotational equilibrium. This means there is zero torque acting on the system about the center of mass *G*, about an axis pointing out of the page. Mathematically we can write this as

$$N_o d_2 - F_o d_3 = 0 \quad (3)$$

(Note that we are ignoring three-dimensional dynamic effects in this equation. They are assumed to be negligible).

Solve for *V* from the above equations (1)-(3). We get

$$V = \sqrt{\frac{g d_2 R}{d_3}}$$

Assume a bus width of 2.6 meters and a center of mass height d_3 of 1.0 m. If we assume that *G* is in the center of the bus (corresponding to the passengers evenly distributed on both sides) then d_2 = 1.3 m. Since the 19 passengers altogether weigh much less than the bus, they would shift the center of mass only by a bit if they all moved to one side, so we can use d_2 = 1.3 m. For a bus speed of 22.35 m/s (50 mph) calculate the radius *R*. This is the minimum radius of the turn to avoid flipping over. We get *R* = 39 m.

As an exercise estimate the radius of the turn the bus made in the movie to see if it is at least 39 m.

Advanced Level - Will a car dropped from 4,000 feet fall faster than a speeding car? (2009 season, episode 114)

Let's assume the car is falling nose first, which would correspond to its fastest falling speed. In this orientation we can use the standard drag coefficient for cars. Use *C* = 0.25 which is for a Toyota Prius. Use a Toyota Prius for this sample calculation, which will serve as a representative case.

The general equation for the drag force acting on a body is:

$$D = \frac{1}{2} C \rho A v^2$$

Where:

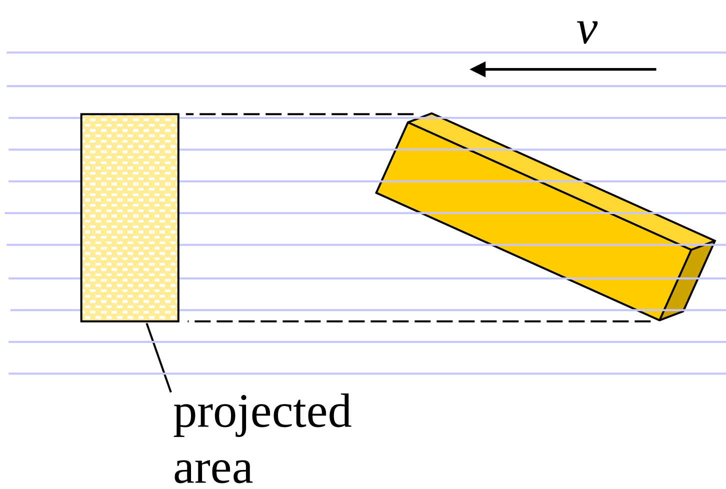
D is the drag force acting on the body

C is the drag coefficient

ρ is the density of the fluid through which the body is moving (in this case, the fluid is air where ρ = 1.2 kg/m^3)

v is the speed of the body relative to the fluid

A is the projected cross-sectional area of the body perpendicular to the flow direction (that is, perpendicular to v). This is illustrated in the figure below.



For a Toyota Prius, $A = 2.3\ \text{m}^2$.

The force of gravity pulling down on the car is:

$$W = mg$$

Where:

W is the force of gravity pulling down on the car

m is the mass of the car, which for a Toyota Prius is 1300 kg

g is the acceleration due to gravity, which is $9.8\ \text{m/s}^2$

When terminal speed is reached $D = W$ so we have

$$mg = \frac{1}{2} C\rho A v^2$$

Set $v = v_t$ and solving for terminal speed we have

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

For a Toyota Prius we have v_t = 192 m/s, which is 430 mph. This is much faster than a speeding car. But this assumes that the car reaches terminal speed by the time it reaches the ground. This is actually not the case. According to the results of the projectile motion simulator as described in http://www.real-world-physics-problems.com/projectile-motion-simulator.html, the car reaches a speed of 130 m/s just before it hits the ground, which is equal to 290 mph, which is still faster than a speeding car.

However this still assumes an ideal situation where the car is pointed nose down for the entirety of the fall. In reality it will experience somewhat chaotic motion as it falls through the air, which affects the aerodynamic drag and as a result will likely affect the maximum speed reached by a significant amount. However, from this result we can conclude that the car will reach a speed close to that of the fastest cars out there.

Advanced Level - Did Hungarian archers get twice the penetration shooting a bow from a galloping horse? (2009 season, episode 119)

Getting twice the penetration would imply that the kinetic energy of the arrows approximately doubled when shooting them from a horse. Doubling the kinetic energy would approximately produce twice the penetration since (Kinetic energy) = (Work done during penetration of the target) = (penetration force)x(penetration distance). This assumes the penetration force is roughly constant, as a first estimate. And with penetration force constant the penetration distance would double for a doubling of the kinetic energy.

A galloping horse runs at about 14 m/s. This speed would be added to the arrow speed (measured when shot from the ground). The arrow speed would have to be such that the kinetic energy of the arrow, when shooting from a horse, is twice the kinetic energy when shooting from the ground. For the arrow shot from the ground, the kinetic energy is equal to $(1/2)mV^2$, where m is the mass of the arrow and V is the arrow speed. For the arrow shot from the horse, the kinetic energy is equal to $(1/2)m(V+14)^2$. We can solve for V by setting the ratio of these kinetic energies equal to 2. We have $(V+14)^2/V^2 = 2$. Solve for V = 34 m/s (76 mph). If the arrow speed of the Hungarian archers was close to this speed then the myth is at least plausible.

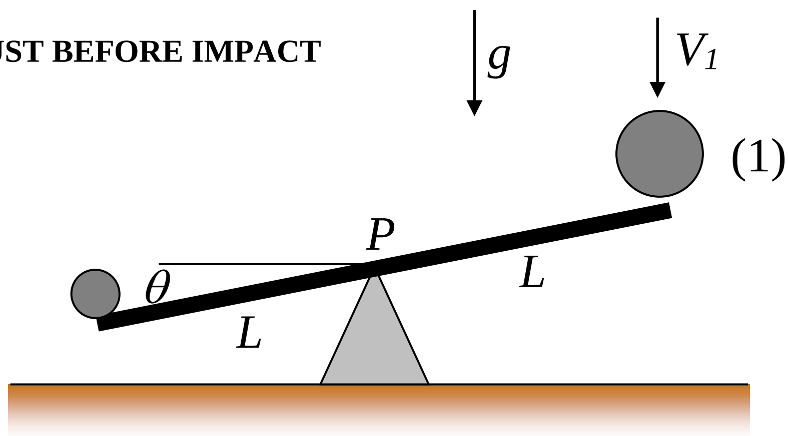
Advanced Level - Could a skydiver whose parachute failed to open hit a playground seesaw and send a small girl flying seven stories high, and she could still survive? (2009 season, episode 120)

We shall assume a conservative case where the skydiver does not rebound off the seesaw and instead "sticks" to it right after impact.

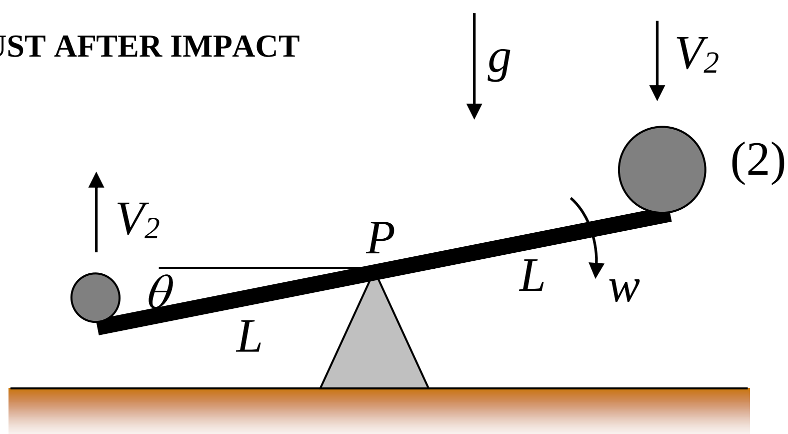
We can apply conservation of angular momentum to analyze this problem between stages (1) and (2) as shown in the figures below, with variables shown. The larger ball on the right represents the skydiver. The smaller ball on the left represents the girl.

The angle θ is small, which is a good approximation for the typical seesaw.

JUST BEFORE IMPACT



JUST AFTER IMPACT



Apply the conservation of angular momentum equation about point *P*, between stages (1) and (2)

$$m_s V_1 L = m_s V_2 L + m_g V_2 L + I_P w$$

Where:

m_s is the mass of the skydiver

m_g is the mass of the girl

V_1 is the velocity of the skydiver just before he impacts the seesaw

V_2 is the velocity of the skydiver (and girl) just after the skydiver impacts the seesaw

L is the distance from the pivot point *P* to the ends of the seesaw where the skydiver and girl are located

I_P is the rotational inertia of the seesaw about point *P*, which coincides with the center of mass of the seesaw (by assumption)

w is the angular velocity of the seesaw just after impact

Now, $w = V_2/L$ from the geometry. The above equation then becomes

$$m_s V_1 L = m_s V_2 L + m_g V_2 L + I_P (V_2 / L)$$

Solve for V_2.

$$V_2 = \frac{m_s V_1 L}{m_s L + m_g L + I_P / L}$$

As a reasonable approximation treat the seesaw as a slender rod, where

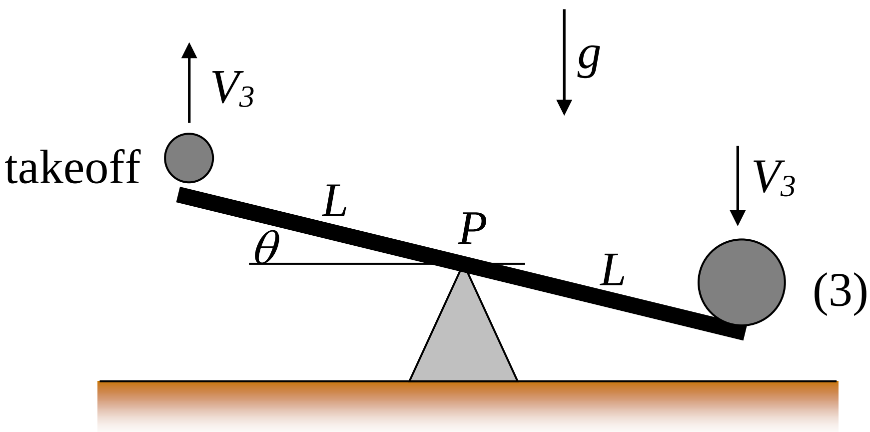
$$I_P = \frac{1}{12} m_r (2L)^2 = \frac{1}{3} m_r L^2$$

where m_r is the mass of the seesaw. It follows that

$$V_2 = \frac{m_s V_1}{m_s + m_g + \frac{1}{3} m_r}$$

Suppose we have V_1 = 120 mph (approximate terminal speed of skydiver), m_s = 80 kg, m_g = 30 kg, and m_r = 100 kg. Then from the above equation we have V_2 = 67 mph.

The figure below shows the takeoff point of the girl. This is stage (3).



At takeoff, the girl leaves the seesaw at $V_3 = V_2$ (approximately). There is very little time for the velocity of the girl on the seesaw to change beyond V_2 given the high V_2 velocity after impact (which quickly rotates the seesaw). This results in a negligible velocity change for the girl, between the time the impact occurs and when the girl takes off. Since we are considering a conservative case (sticking upon impact) then V_3 is the minimal takeoff velocity of the girl.

Now, 67 mph = 30 m/s, which results in a peak height reached of 46 meters, assuming negligible air resistance and the girl flying straight up (a good approximation given a small angle θ). This height is much greater than seven stories so the myth is indeed possible. However, unless she lands somewhere soft she is unlikely to survive the fall. This is in addition to the sudden upward acceleration, at takeoff, which can fatally injure her as well.

Advanced Level - Why are dimples crucial to the flight of golf balls? (2009 season, episode 127)

The dimples on a golf ball create a thin turbulent boundary layer of air over the ball's surface. This reduces air resistance which results in the ball traveling a farther distance than a smooth ball would. Such a distance improvement is desirable for making a shot as long as possible. The figure below shows the flow of air over a dimpled golf ball.

The air flow over the ball follows smooth streamlines until some point beyond the halfway distance, at which the turbulent boundary layer "separates" and turbulent eddies form inside a resulting wake region. This wake region has lower pressure, which causes the (greater) pressure in front of the ball to exert a net pressure force opposite the direction of motion of the ball (known as drag). Turbulent flow, induced by the dimples, reduces the size of this lower pressure wake region (from that of a smooth ball). This results in a lower net pressure force, which results in less drag than with a smooth ball. A smooth ball with no dimples would cause the boundary layer to separate sooner resulting in a larger wake region, and hence more drag would result.

The number of dimples on a typical golf ball ranges from 250-450. Different manufacturers have different theories on the ideal number of dimples, the ideal depth of the dimples, and the ideal placement pattern of the dimples. In fact, all these attributes affect the balls overall aerodynamic qualities during flight.

Introductory Level - Can a bottle of beer, when given a sudden shock, turn from a liquid and freeze into a solid? (2010 season, episode 153)

Yes. This phenomenon is known as supercooling.

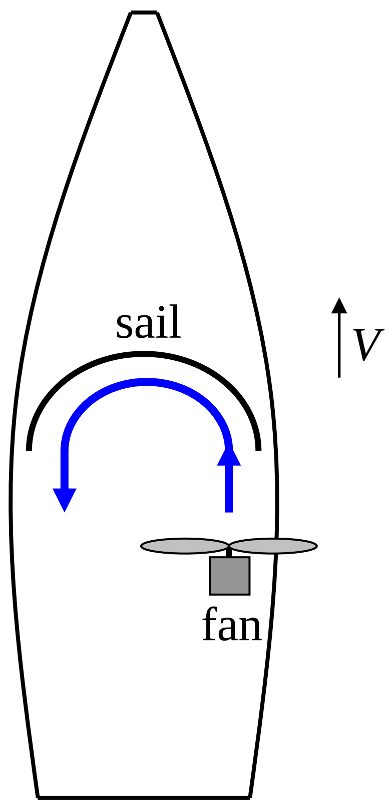
Introductory Level - Can a car's tire pressure affect its fuel efficiency? (2010 season, episode 153)

Yes. Lower tire pressure results in greater rolling resistance which increases fuel consumption. Tires must be properly inflated to reduce this effect.

Advanced Level - Can a sailboat stranded in calm water start moving by blowing air into its sail with an onboard fan? (2011 season, episode 165)

Yes it can provided the fan is strong enough and the shape of the sails allows the air flow to be redirected, as shown in the figure below. The backward moving air (accelerating in the backward direction) will push forward on the sailboat, moving the sailboat forward (Newton's third law). The same effect will be produced if the fan is pointing backward and blows air in the backward direction.

The shape of the sail must be such that it redirects the air flow so that it goes in the direction opposite to the desired direction of travel of the sailboat



Introductory Level - Will a super-sized Newton's cradle work? (2011 season, episode 172)

No. For explanation see http://www.real-world-physics-problems.com/newtons-cradle.html.

Advanced Level - Can you use a whip to swing safely across a chasm? (Indiana Jones) (2015 season, episode 224)

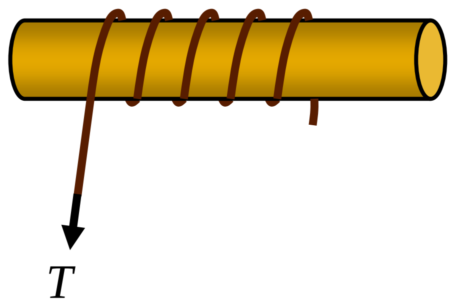
Yes, provided the whip is wound around a pole or branch enough times. The friction force between pole (or branch) and whip will increase with the number of windings.

This phenomenon can be described mathematically.

As an example, consider the following problem.

A rope is wrapped around a pole of radius R = 3 cm. If the tension on one end of the rope is T = 1000 N, and the coefficient of static friction between the rope and pole is μ = 0.2, what is the minimum number of times the rope must be wrapped around the pole so that it doesn't slip off?

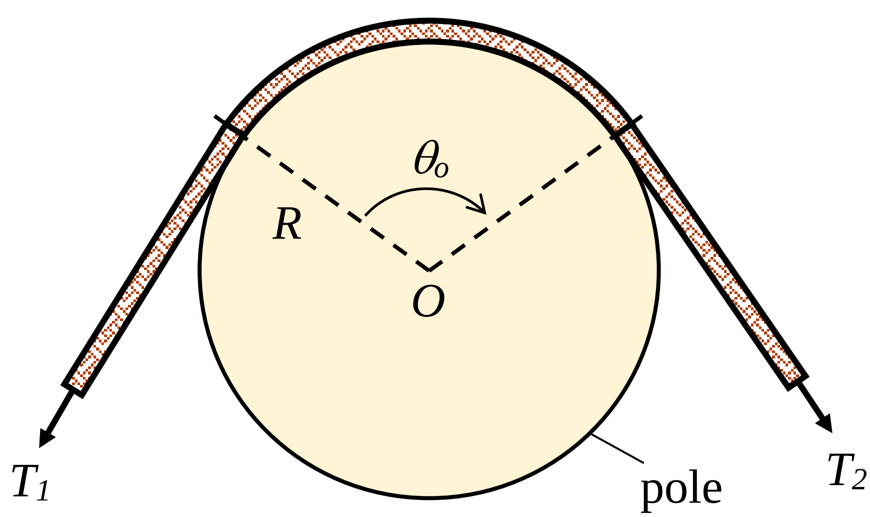
Assume that the minimum number of times the rope must be wrapped around the pole corresponds to a tension of 1 N on the other end of the rope.



Solution**:**

To solve this problem we have to derive an expression for the rope tension around the pole, using Calculus.

To start, consider a general case as illustrated below.



Where:

T_1 and T_2 is the rope tension on both ends of the rope

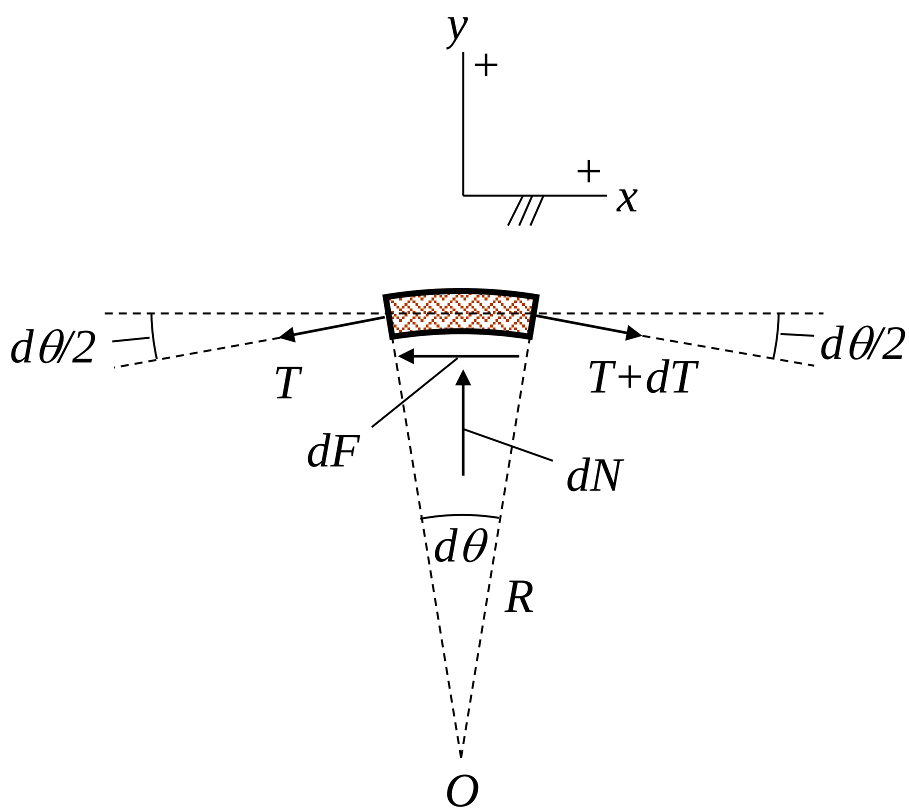
θ_o is the angle the rope is wrapped around the pole, as shown (in radians)

R is the radius of the pole

O is the center of the pole

Next, derive a general expression for the rope tension as a function of T_1, T_2, θ_o, and *R*.

Consider a differential segment of rope, illustrated below. Treat this as a two-dimensional problem in the *xy* plane.



Where:

dN is the differential normal force between the pole and differential rope segment

dF is the differential friction force between the pole and differential rope segment

T is the rope tension

$d\theta$ is the differential angle spanned by the differential section of rope (in radians)

Since the differential rope segment is in static equilibrium, the sum of the forces acting on it in the *xy* plane is equal to zero.

In the *x*-direction, take the sum of the horizontal forces and equate them to zero:

$$(T + dT)\cos\left(\frac{d\theta}{2}\right) - T\cos\left(\frac{d\theta}{2}\right) - dF = 0 \quad (1)$$

where

$$dF = \mu dN \quad (2)$$

Similarly, in the *y*-direction, take the sum of the vertical forces and equate them to zero:

$$dN - T\sin\left(\frac{d\theta}{2}\right) - (T + dT)\sin\left(\frac{d\theta}{2}\right) = 0 \quad (3)$$

Combine equations (1), (2), (3) and take the limit as $d\theta \to 0$. This gives us

$$\frac{dT}{d\theta} = \mu T$$

We can rewrite this as

$$\frac{dT}{T} = \mu d\theta$$

Integrate both sides of this equation and solve for T as a function of θ. We get

$$T = Ce^{\mu\theta}$$

where C is a constant.

At $\theta = 0$, $T = T_1$, which means that $C = T_1$.

Thus,

$$T_2 = T_1 e^{\mu\theta}$$

It is interesting that this equation does not depend on the radius R of the pole. But this is perhaps not too surprising since R does not show up in equations (1), (2), (3).

Set $\theta = \theta_o$ in order to remain consistent with the variables shown in the figure on page 45.

Therefore, the final equation is

$$T_2 = T_1 e^{\mu\theta_o}$$

If we assume that $T_2 < T_1$ then we must set $\mu < 0$, since the direction of static friction depends on which direction the rope will tend to slide. This in turn depends on the relative magnitude of T_1 and T_2.

Similarly, if we assume that $T_2 > T_1$ then we must set $\mu > 0$.

In our case, assume that T_1 = 1000 N, and T_2 = 1 N. This means that we must set $\mu = -0.2$. Using the above equation solve for θ_o.

Solving, we get θ_o = 34.54 radians. This is equal to 5.5 turns, which is the minimum number of times the rope must be wrapped around the pole to prevent it from slipping off. Since 1000 N = 102 kg, and Indiana Jones is probably quite a bit lighter than this, then wrapping the whip around a branch 5-6 times should be enough to support his weight, even with the extra bit of weight created by his centripetal acceleration as he swings along an arc.