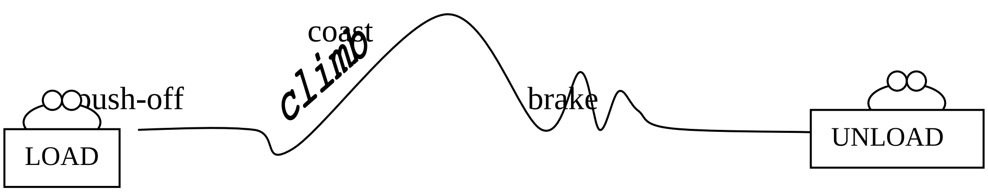
2. Starting & Stopping Roller Coasters

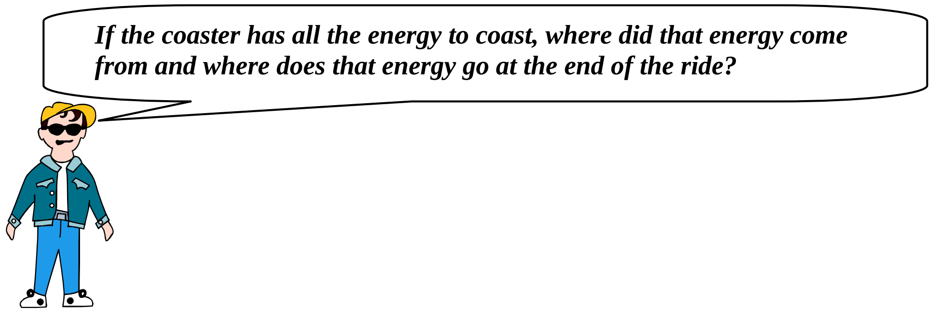
Work, Power, Machines

2.1 The six stages of a coaster ride



Conventional coasters require six general functions to complete a complete trip: loading, pushing-off, climbing, coasting, braking, and unloading. A coaster ride can be thought of as a six-stage process.

First, the passengers must be loaded safely on a car which is either stationary or moving very slowly. Then the coaster is pushed out of the loading area and down the track to the bottom of the climbing hill. A mechanical mechanism, called a chain dog, then catches and pulls the coaster up the first hill. From the top of the hill the coaster has all the energy needed to coast up and down without any outside assistance. At the end of the ride brakes of some sort are applied to slow down the coaster to no or very little speed. Finally, the passengers unload from the car and new passengers load to repeat the cycle.



By the end of this unit, you should be able to answer the above question as well as the following:

1) How do you define and calculate the work to start, pull, and stop a coaster?

2) What determines the power provided by machines to do work?

3) How do you determine a coaster's speed when work is also done?

2.2 Work, Power, & Machines

Work

To know how to start and stop a coaster, one needs to also understand the concepts of work, power, and machines. You already know the potential energy of the first hill is what keeps the coaster coasting. After passengers are loaded something has to be first done to start the coaster moving- work has to be done! Work changes the kinetic energy of the car. Once the car is moving, even further work is needed to climb the first hill. **Work** is a means to increase or decrease an object's energy. In fact, the units for work are the same as for energy – joules. As the coaster is pulled up the hill, the potential energy of the coaster is increased. During the ride, the potential energy of the coaster is converted back and forth to kinetic energy along with some unrecoverable transfer to heat energy. What happens to the kinetic energy remaining at the end of the ride? Work must be done to stop the coaster and hence convert the coaster's kinetic energy to other forms, mainly heat energy.

Power & Machines

The work needed to start, pull, and brake a coaster is done by machines since machines can do the same work as humans without getting tired and in less time. **Power** equals the rate at which work is done. A very powerful machine can do a lot of work in a very short time. A machine is a device which changes how the work is done, not the amount of work done. All machines consist of one or more of the six **simple machines**: lever, screw, pulley, ramp, wedge, and the wheel/axle set. Typically, a lever-based catapult propels the coaster from the loading platform. Then a pulley-ramp system helps the coaster climb the first hill. At the end of the ride, a combination of levers, wedges, and screws applies braking pads to the coaster wheels. All of these machines use electrical energy sold to the coaster park by an energy company in units of energy called kilowatt-hours. In fact, one of the major costs of operating a roller coaster park is the electricity to start and stop the coasters. The ride itself is free!

Project Clue:

The ultimate coaster is both money and time efficient in getting riders on and off the ride! More powerful machines will load and unload passengers faster, but will cost more money to run.

2.3 physics definition of work:

You may think of work as something to do and get paid. The physics definition is more nebulous. **Work** can be thought of as a general term for energy situations for which other categories of energy don't apply, and something either happens to the object or to the object's motion. In all cases, work is only done on an object when a force must be overcome. For example, the catapult machine does work on a coaster by overcoming friction and making the coaster move. Work is done on the coaster as it is pulled up the first hill since the force of gravity (i.e. the coaster's weight) must be overcome. Power brakes must overcome the force of friction to stop the coaster. Excessive braking force may cause work of deformation if the wheels or brake pads are worn down. If there is no force needed to do the job, there is no work done. Thus there is no work needed to lift an object in deep outer space where there is practically no gravity. Likewise, a car will continue to move forward on a frictionless surface without any needed force. (But, work is done if a force is used to change direction). A **force** is any pull or push measured in Newtons (N). Examples of forces on roller coasters are the push-off force to start a coaster, the lifting force needed to get up the first hill, and the braking force to stop a coaster,. Here are more clues to "physics" work.

You know you did work if:

1. You exert a force (push or pull) on an object

   \- AND -

2. the object moves some distance in the same or opposite direction of your force

No work is done if:

1. no force is needed to keep the object moving

   \- AND -

2. the object is not being deformed

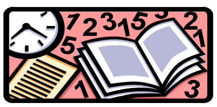
2.4 How do you calculate work from energy?

If a force causes a change in the motion of an object, the work done is simply the change in kinetic energy. No force information is needed! The answer for work will be a positive number if the object's speed is increased. Likewise, negative work is done by braking since the coaster's kinetic energy is reduced.

$$W = \Delta K.E. = KE_{final} - KE_{initial}$$

W = work in joules (J)
KE = $1/2mv^2$ (J)

Sample Problem Work - KE



1. How much work is done to catapult a 4500kg coaster from rest to 4.0 m/sec?

answer

$KE_{initial}$ = 0, since at rest so v=0

KE_{final} = $\frac{1}{2}$*4500*4^2 = 36,000 J

W = ΔK.E = 36,000 - 0 = 36, 000 J

(positive work is done to accelerate the car)

2.5 How do you calculate work from force?

All work involves applying a force over a certain distance to move, redirect, or deform an object. In the simplest case, the force stays constant and the object moves either in the same or opposite direction of the force. The equation for work then involves multiplying the force times the distance. For example, a quarter pound hamburger weighs about 1 Newton. If you exert just enough force (1 N) to lift the burger about 1 meter, you have done about 1 Joule of work on the burger. Positive work will be done if an object moves or gains speed in the direction of the applied force. Negative work is done when a force is used to slow down or reverse an object.

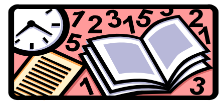
$$W = F * d$$

W = work in joules (J)

F = force in Newtons (N)

d = distance moved (m)

Sample Problem Force-Work



2. What work is done by a pulley that uses 31,000 Newtons to pull a 1600kg coaster along a 47 m long incline to a height of 30m?

answer:

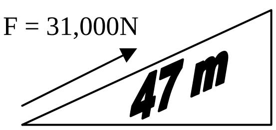
F = 31,000 N pulley force along the incline

d = 47 m (use the distance parallel to the force)

W = 31,000 N * 47 m = 1.5×10^6 J

(positive work done to pull up and move up)

F = 31,000N

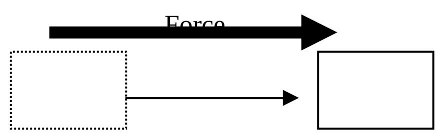


3. For the same problem, how does the work change if the job is done in half the time?

answer:

No difference, work doesn't't' depend on the time to do the job (but power would double!)

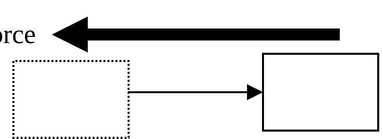
POSITIVE WORK:



Object moves faster

NEGATIVE WORK:

Force



Object moves slower

2.6 What is physics power?

Which pulley is more powerful? An express pulley that takes only 30 seconds to lift you to the top of a hill, or an economy pulley that takes 4 minutes to get to the top? Of course …. the express pulley. Why? Because it does the same job in less time! The more work done in the shortest amount of time, the higher the power. The units of power are watts; yes just like the light bulb! A 100 watt motor puts out 100 J of energy every second. Power is calculated by dividing the work done (or energy change) by the time required to do the work:

P = W/t

W = work (J)
t = time (s)

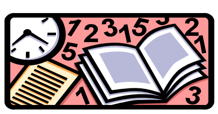
metric units for power:

1 J/s = "watt"
1000 watts = 1 kilowatt (kw)

to convert from metric to US units:

1 horsepower (hp) = 746 watts

Sample Problem Power



1. **A quarter pound hamburger has a mass of about 0.10 kg. If you lift it 0.20 meters to your mouth in 3.0 seconds, how powerful of an eater are you?**

assumption:
you apply a force just equal to the burger's weight so work done is just weight * height

Answer:
Work = F*d = wt.*h = mgh = .1*9.8*.2= .20 J
Power = work/time = .20J / 3 s = .06 watts

2. **The American Eagle uses a pulley to lift a train (mass of 4000 kg) containing 30 people (60 kg each) up an incline 100 meters long and 42 meters high in a total time of 37 seconds. What is the power ?**

Assume: work of the pulley is just the energy change it creates, i.e. no additional heat energy

Answer:

Total mass = 4000 + 30*60 = 5800 kg
Total weight = mass *9.8 = 58,000 Newtons
Work = total weight & height
= 58,000N*42m = 243,600 Joules
Power= work/time = 243,600/37s = 6584 watts

2.7 Cost of power

Companies which provide electricity charge (no pun intended!) in units of energy called kilowatt-hours (kWh). One kWh is equivalent to running a 100 watt light bulb (which is 0.1kW) for 10 hours and typically cost about 8 cents. There are 720 hours in an average month. One 100 Watt light bulb left on all month would cost about $6 (100 watts/1000 watt = .1 kW * 720 hrs * $.08 = $5.76). So how expensive is it to run a coaster? The answer can be found using the following simple calculation:

Cost = cost per kilowatt-hr* total kilowatt-hrs

A designer engineer ultimately must analyze how much each part of coaster costs to run. If a certain thrill feature adds $1 to the ticket price, then the thrill must be worth it to the paying public.

Project clue: you may also have to determine the power and cost of your ride and show that your ticket price covers your power expenses.

2.8 Roller Coaster problems – Finding speed when work is also done

A roller coaster designer would like to calculate the velocity of a coaster at any point along the track. Previously we learned how to use the conservation of energy to determine the speed of a coaster coasting up and down a frictionless track. Now we can use the same method to find the coaster's speed at the beginning or end of a track. The only difference is that in addition to kinetic and potential energies, another type of energy- work will be considered. Positive work will include the additional energies gained by a coaster when a catapult pushes-off the coaster and when a pulley pulls a coaster up the first hill. Negative work will include loss in energy when brakes stop a coaster. To solve for velocity, all of the energies at two different locations are added and set equal to each other since the total coaster energy is always constant. Heat energy is produced throughout the ride, but if we assume it is the same amount anywhere on a coaster then we can neglect it.. We will find velocities at the push-off, climb, and braking stages using three sample problems.

IN GENERAL:

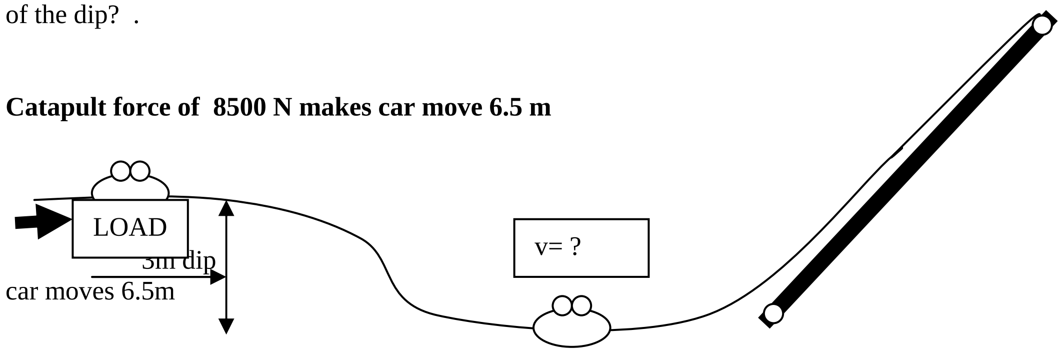
Work + PE + KE = Work + PE + KE

Work = Force used on the coaster * distance coaster moved

I. Starting the coaster- catapult work

During the first stage, a catapult type machine exerts a force of 8500 N and the coaster is moved a distance of 6.5 m from the loading platform to the top of a small dip. The coaster then falls down the dip (a 2m drop), and is engaged by a pulley motor at the bottom of the dip. What is the coaster's speed at the bottom of the dip? .

Catapult force of 8500 N makes car move 6.5 m



At the loading dock:	At the bottom of the dip:
Total Energy = Work + KE + PE	Total Energy = Work + KE + PE
Work = Fd = 8500N * 6.5m = 55,000	Work = 0
KE = 0	KE = ½ * 3200 * v^2 = ???
PE = mgh = 3200 kg * 9.8 * 2m= 63,000	PE = 0
Total Energy = 118, 000 or about 1.2×10^5	Total Energy 1.2×10^5 (same)

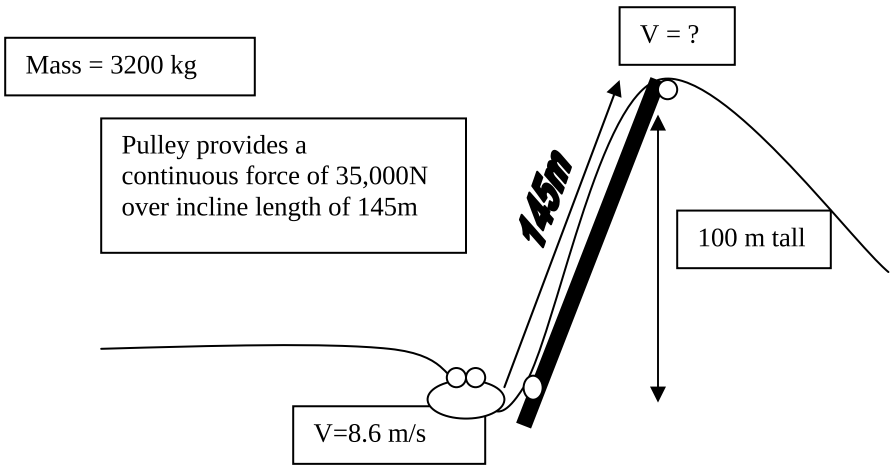
So KE at bottom = total at dock = 1.2×10^5

then KE = 1/2 *3200 * v^2 = 1.2×10^5

answer: v = 8.7 m/sec

II. Climbing the first hill – finding speed after a pulley does work

After the coaster is catapulted from the loading platform, it moves down the track until it reaches the bottom of the mechanically assisted incline. A hook called a **chain dog** , grips the coaster producing a very memorable clanking sound of interlocking raw steel. The coaster is then pulled on a chain up the incline to the top of the first hill. The main result of this positive work is a huge increase in potential energy. There is also commonly a small increase in kinetic energy. The coaster will usually be moving slightly faster after climbing the hill. It is very important to accurately determine the speed of the coaster at the top of the hill since the total energy of the coaster equals the PE and KE at the top of the first hill. Once again, conservation of energy can be invoked to determine the speed at the top of the hill.



At the bottom of the incline:

Total Energy = Work + KE + PE

Work = Fd = 35,000N * 145m = 5.1 x 10^6
KE = 1/2mv^2 = ½*3200*8.7^2 = 1.2 x 10^5
PE = mgh = 3200 kg * 9.8 * 2m= 63,000

Total Energy = 5.3 x 10^6

At the top of the incline:

Total Energy = Work + KE + PE

Work = 0 J
KE = ½ * 3200 * v^2 = ???
PE = mgh = 3200*9.8 * 100m = 3.2 x 10^6

Total Energy = 5.3 x 10^6 (same as at bottom)

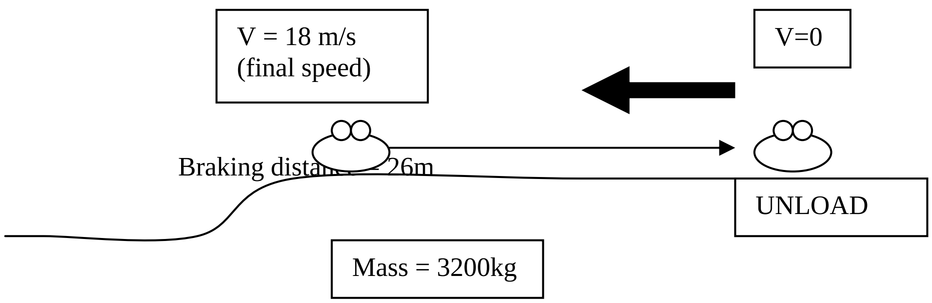
So KE = Total - PE = 5.3 x 10^6 – 3.2 x 10^6 = 2.1 x 10^6

then KE = 1/2 *3200 * v^2 = 2.1 x 10^6
answer: v = 36 m/sec (that's an insanely fast starting speed!)

III. Stopping the coaster – finding the force needed to brake

Brakes are needed at the end of the ride to bring the coaster to a safe stop. All of the coaster's kinetic energy at the end of the ride is converted to heat energy. Typically the unloading dock is at the same elevation as the loading platform so there has been no net change in PE from start to finish. The change in energy is thus well defined, it's just the coaster's final KE. The key to stopping a coaster is to pick an adequate breaking distance so the braking force is adequate, but not so excessive that passengers would be hurt or thrown out of the car☹. Once again, the conservation of energy method can be used to determine the work due to braking and then the force can be determined using the work equation. The final speed before braking is either given, or determined from the previous hill using conservation of energy methods.

What force is needed to stop this coaster?



End of ride: | At the loading platform:

Total Energy = Work + KE + PE | Total Energy = Work + KE + PE

Work = Fd = 0 | Work = F* d = ??
KE = 1/2mv^2 = ½*3200*18^2 = 5.2 x 10^5 | KE = 0
PE = 0 | PE = 0

Total Energy = 5.2 x 10^5 | Total Energy = 5.2 x 10^5 (same)

So W = F*d = 5.2 x10^5 J

answer: F = W / d
= 5.2 x10^5 J / 26 m
= 2.0 x 10^4 N (a reasonable force but a lot of Newton burgers!)

Review Questions:

1. List in chronological order the 6 stages of a typical coaster such as the Viper?

2. In your opinion, which of the 6 stages is the most thrilling?

3. For which ride(s) at Great America is the "car" you get into already moving?

4. What is a chain dog?

5. What sort of brakes are used in water coasters like Splashwater Falls?

6. About how long does it typically take to climb a roller coaster hill?

7. Name the 6 simple machines

8. How do machines make life easier since they don't actually change the amount of work done?

9. How does a coaster get its PE at the top of the first hill?

10. At the end of a ride a coaster comes to a complete stop. Why is this not a violation of the conservation of energy?

11. What are the units of work?

12. How do you if the work done is positive or negative work?

13. Check off for which activities do you do work on your backpack?

    a.picking it up ___ b. holding it __
    c. dropping it ____ d. throwing it__
    e. walking with it on your back
    f. flying in a plane with it on your lap__
    g. crushing it in a garbage compactor__
    h. floating in space with it on your back__

14. How does work depend on time?

15. How much force is needed to lift (at constant speed) a book which weighs 2 N?

16. If you lift the book twice as high as your friend, you do _____ as much work.

17. How does work change if you double the force used for the same distance?

18. A child uses 5 Joules of work to lift his 10 Newton toy bag. How high did he lift it?

19. How much energy does a garbage can have after a disgruntled worker kicks it 12 meters using 5.5 Newtons of kicking force?

20. How much work is done on the floor when you stand on it? (assume m = 95 kg)

21. How much more work does it take to brake a coaster to a stop if it goes twice as fast?

22. How much work is achieved on Giant Drop to lift a total mass of 25,000 kg to the top of the ride (30m high)?

23. Why would a longer cannon shoot out a human cannon ball faster than a shorter one

24. What is the final KE of a 3500 kg car if 120,000 J of work are done on it to move it from rest along a flat track?

?

25. What force is produced by the catapult which causes a coaster to move 12m and gain 12,000 J of energy?

26. How much work is it for a 50 kg student to get into a .85m high bed? How much work to get out again?

27. Why are the extended body movements used in “follow through” effective in batting sports such as baseball, tennis, etc

28. What is measured in Newton-meters (Nm)

29. A ice cream cone of 0.25 kg falls from a height of 0.6 m. Calculate the work of deformation☹ (assume stops on impact)

30. A plastic ice cream cone of .25 kg falls from a height of 0.6m and bounces up to 0.3 m. How much work did the ground do on the cone ? (hint: consider the change in energy)

31. Two bumper cars (each 5500 kg and moving at 15 m/sec collide head on and stop.). How much work of deformation did each car do onto the other?

32. How much work is needed to bring a 4000.kg coaster moving at 10 m/sec to rest?

33. A 85 kg student sprints from rest to 7 m/sec in 12 seconds. How much work did he do?

34. How much work does it take to lift a box that weighs 3.0 Newtons a height of 4.0m?

35. How is work different from power?

36. How much work does a 100 Watt light bulb do in 5 minutes?

37. How many kilowatts is produced by a machine that produces 25,000 J of energy every 10 seconds?

38. What is the power of a coaster brake that brings a 950 kg car moving at 20 m/sec to rest in 20 seconds? Give answer in both watts and horsepower!

39. A 75 kg student jumps up 2m in 1.5 sec. How many watts did she demonstrate?

40. How do two machines compare if the first one lifts a coaster in 90 seconds while the second does the same work in 30 seconds?

41. What are the advantages and disadvantages to having powerful machines to reduce the time needed to climb the first hill and to bring a coaster to a stop?

42. A new ride requires 20 kw for each ride which lasts for 5 minutes. If the cost of electricity is 8cents per kilowatt-hour, how much does it cost to power each ride?

43. A certain pulley has a chain speed of 0.10 m/sec and the hill is 40 m long. How much power does the pulley produce if it uses 10,000 N of force to pull up a coaster?

44. How fast is a 5000 kg loaded coaster moving after a catapult uses 25,000 Joules to start the coaster moving from rest?
(assume heat energy can be ignored)

45. A coaster moves 12.5m and gains 110,000 J of energy from a catapult machine. What was the force of propulsion?

46. How fast is a 2400 kg coaster moving at the top of a 80 m high incline if the coaster started at 2m/sec when a 19,000 N pulley began to pull the coaster a track distance of 120m? (draw a picture if you're not sure!)

47. What minimum braking force is needed to stop a 4400 kg moving at 12 m/sec within a braking distance of 20m?

3. Kiddy Land

Fun machines using materials that don't break

3.1 Alternatives to roller coasters

Not every can or wants to ride a roller coaster. Most of the bigger, scarier rides are marketed to teens and young adults. Typically, kids under 54 inches are not even allowed to try. Adults who have medical conditions such as bad backs, pregnancy, or heart conditions are not advised to

ride. Forget jumping into a coaster if you have a broken leg, or difficulty moving. Owners of theme parks can make more money if they can entice all members of the family to come along and paid admission. . So how do theme parks accommodate young kids, kids who don't like moving rides, or older adults who can't enjoy fast rides? One method is to devote part of the park grounds to a "kiddy land" – an area having only non-thrill playground like attractions. Just look at the success of Disney World, a park almost exclusively devoted to kids with very few fast moving rides. In this section we will discover how to design simple fun attractions that are kid friendly and kid tough. Your theme park must also include a kid attraction, so don't forget to jot down and discuss with your partners any ideas or questions that come to mind ☺

3.2 Types of kiddy land attractions

Designing a kiddy land is not so difficult. Just go to the playground park in your neighborhood, then make everything the same but bigger and more complicated. Some playground equipment is fun because kids can get the feeling of moving fast, like on slides, merry-go-rounds, and swings. We will focus on rides that are fun because they make kids feel stronger, braver, or bigger than they really are. For example, kids can't resist the challenge of climbing to the top of tall structures. So build a really big gentle ramp so even the smallest kids and slowest grand parents can make it to the top. But also include a difficult short cut to the top – make a steeper ramp, a climbing net wall, or a knotted swinging rope. Kids also love to make things "work". So create some pretend devices having some sort of gears or pulleys to lift or pull heavy objects like a huge bucket of sand. The time tested teeter-totter is also a kid favorite, maybe since two friends can play together. How about a "smarter" bigger teeter totter that helps kids figure out where to sit so many kids of different sizes can teeter-totter at the same time. Whatever type of ride you choose for your own theme park, you will need something that lets kids do things easier. Such a device is called a machine. Every complicated machine is build out of one of 6 simple machines. We will focus on only three – ramp, pulley, and lever. Of course you can also use one of the other three- screw, gears, and wedge.

3.3 Machines – mechanical advantage

Stairs, power tools, a hinge, a bicycle, curtain drawstrings, a computer – which of these are machines? Actually they all are! You may think of a machine as anything that you plug in and does something for you. Certainly that's true, but more generally what is a machine?

A machine is a device that changes the size or direction of a force.

That means you can use a machine to increase, decrease, or turn how much you want to push or pull something. Your force is called the effort force; the machine produces a resistance force, since it trying to do something difficult (resistive). If a machine increases the effort force you apply, the machine makes it easier for you to move or lift objects that normally are too heavy. Such a machine is said to have a positive mechanical advantage (MA > 1). If a machine makes it harder for you, it creates a disadvantage and has a negative mechanical advantage.

$MA = F_r / F_e$

MA = mechanical advantage
F_r = resistance force out of machine
F_e = effort force put into machine

Any machine:

Positive mechanical advantage (MA > 1):

machine force F_r is larger than yours F_e
but your distance d_e is longer than machine d_r

Negative mechanical advantage (MA < 1):

machine force F_r is smaller than yours F_e
your distance d_e is shorter than machine d_r

Why would you want a machine with a negative mechanical advantage? One reason is you actually want to make it hard for yourself. For example, weight training and conditioning machines with a MA < 1 will help you bulk up by building muscle. Another reason is that by applying a larger force, you don't have to exert yourself over such a long distance to do the same work. Remember, work = force * distance. So if you are working in a cramped space like under a car hood, you might rather use a machine that requires more force, but over less distance.

3.4 Ideal Machines --100 % efficient!

Machines are all about changing force, and transferring the work. Ideally you would want a device that would use all the energy you gave it to do something useful. Unfortunately such machines exist only in the fantasy dreams of engineers and high school teachers! Some energy is always converted to heat due to the omnipotent presence of friction. Hence, perpetual motion machines cannot exist. Did you know a car is only about 30% efficient? That's why cars tend to run very hot. Here is an easy method to calculate the efficiency of a simple machine:

Eff = Work out/work in *100%

Most of our calculations will falsely assume we are using an **ideal machine** – one that is 100% efficient so that all of our energy is transferred with no heat produced. There do exist machines with very smooth slippery surfaces that are close to 100% efficient. Maybe you have seen one in a novelty or hobby store? In any case, ideal machines are a lot easier to analyze as follows:

Ideal machines:

pretend no friction so

Eff = 100%

work in = work out

$F_e * d_e = F_r * d_r$

So if rearrange both sides:

$MA = F_r / F_e = d_e / d_r$

Real machines can be analyzed too:

Real machines:

friction & heat energy produced

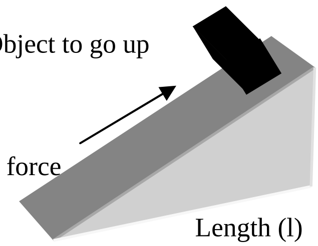
Eff < 100%

work in > work out

$F_e * d_e < F_r * d_r$

Only can use forces:

$MA = F_r / F_e$



3.5 Ramps – how to get to the top!

Ramps can be either smooth, called inclined planes, or stepped, called stairs. Ramps are probably one of the most overlooked simple machines, but can be found everywhere at a theme park. Most roller coasters start on a small boarding hill so the cars can immediately roll down to the lift hill. That means people have to walk up the small hill to board, usually using an inclined plane. You can probably guess at least two reasons why elevators are not practical. It's also the law that you must make public buildings wheel chair accessible. Again you can find lots of little curb ramps and bigger corkscrew shape ramps to wheel up chair bound people as well as heavy equipment. At kiddy land, you will usually find tall castles or other fantasy structures that can be climbed directly vertically or more easily using some sort of ramp.

3.6 Ramp Physics –the juicy part!

But what is exactly easier about a ramp? Whether you use it or not, you get to the same height. So you get to the same energy. So you used up the same amount of work. But isn't easier mean less work? NO! Easier means less force. Easier means without the ramp you have to use a lot more muscle to get to the top. Easier does not mean it takes less time. Someone who can climb the same wall faster is more powerful since he does the same amount of work to get the same amount of energy but in less time. Someone who does the same amount of work with less force is thinking smart. But what is the trade off? How can you do the same work with less force? Go back and look at the definition of work to see if you can figure it out. Try!

In the case of a ramp, you or some device pushes or pull along the length of the ramp so that an object is raised a certain height. The object could be you walking up a hill or an entire coaster train being pulled up the lift hill.

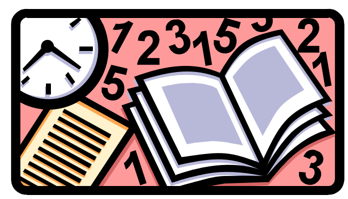
Input to ramp:

Fe = force applied along ramp
De = distance object moves up ramp
(equal to entire length if goes to top)

Output to ramp:

Fr = force machine overcomes (object's weight)
Dr = vertical distance object moves
(equal to ramp height if goes to top)

Ramp question s & notes



1. Why are ramps useful?
2. What shaped ramps are the most useful?
3. What is the efficiency of an ideal ramp?
4. Find 3 ways to find mechanical advantage using forces, distances, & ramp dimensions:

MA =

MA =

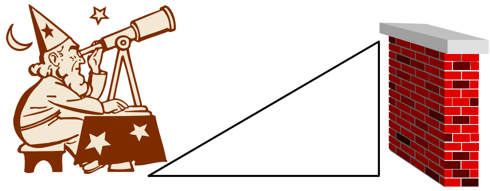
MA =

Sample problem:

an ideal ramp is 6 m long, 2 m high:

5. What is the above ramp's MA?
6. What force would be needed to lift a 60 N object without the ramp?
7. How much work would it take to lift the same object a height of 2 m without the ramp?
8. How much work if you did use this ramp?

9. What force would be needed to lift the object to the top using the ramp?



3.7 Ramp This! - a mini-lab!

Goal: apply the equations of an ideal ramp

Method: set up a board ramp of your choice!

Clue: keep all measurements the same units

3.8 Pulleys - counting strings is easy!

One of the most popular events in kiddy land may be wall climbing for kids. Most kids don't make it to the top and appear they will fall. Fortunately they are held up by a safety rope by someone else is pulling down on. How can that be that someone can hold up the entire weight of a climber by pulling down? The answer of course is the pulley. Pulleys are easy to spot since they always have a rope or chain somehow attached. Every coaster uses one on the lift hill. The calculations for pulleys are easy, but really seeing how they work is a different matter. We will consider only non-moving pulleys fixed to a wall or ceiling. The secret to understanding is thinking of each rope as having another person pulling on it, except for the first rope that is tied to the pulley. If you have two ropes, then only one rope is holding all the weight. This kind of pulley switches the direction of force, but doesn't reduce it☹. If you have 3 ropes, that's like having 2 ropes holding up the weight – so you only need to use1/2 of the force☺. You can still use the ideal machine equations involving forces and distances:

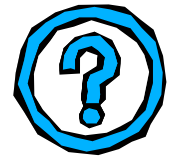
Ideal Pulley

Work in = Force you pull * length you pull

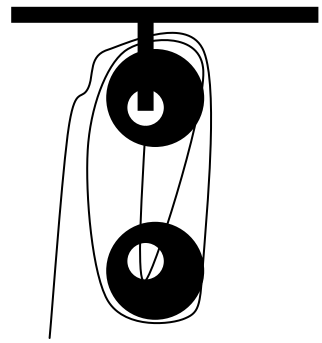
Work out = object weight * height object moved

MA = total strands of rope/chain - 1

Sample Problems



Practice these tricky pulley problems



1. What is the MA of this pulley?

2. How much force would you need to pull up a 1000N ten year old boy?

3. If the boy went up by 4 meters, how many meters of string do you have to pull?

4. How much work did you do all together

5. How much PE does the boy have now?

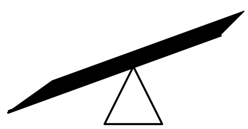
6. If you lifted him in 40 seconds, what is your power?

3.9 Levers – it's all balance

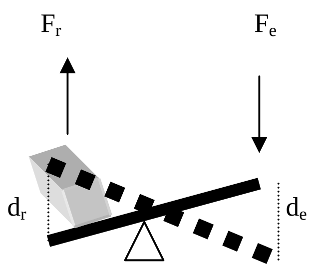
Levers are probably the most common machine. The simplest kind is the teeter-totter. But there are actually two more kinds that describe how everyday objects like hinges, crowbars, and body joints work. The common feature of all levers is a pivot point, called a fulcrum. . Like other machines, levers can be used to change the size or direction of force. Likewise levers do not change the energy or work needed to do a job.

Kiddy land will undoubtedly have lots of levers so kids can turn secret doorways, balance another, and lift heavy objects. All the equations for machines are valid for levers. We will assume the levers are ideal; that is, there is no friction at the pivot point. We will also assume that we push or pull vertically on the lever, when in reality we do so along an arc path. But in this way we can quickly draw triangles to aid in measuring distances. It's only a small error!

Fill in the missing details for the 3 types of levers. The first lever is done for you!



Teeter-totter - Type 1 lever



1. Fe = your push/pull
   Fr = force applied by lever

2. de = distance you push
   dr = distance box goes up

3. The forces are located :

opposite sides of fulcrum

4. The sizes of the forces are:

Less, more, or can be equal

5. The direction of forces are:

Opposite of each other

6. mechanical advantage is:

1, >1, or can be <1

7. more examples:
   scissors, balances

Hinge – Type II lever

1. Fe = force you pull up
   Fr = up force on box

2. de =
   dr =

3. The forces are located:

same side of fulcrum

4. The sizes of the forces are:

5. The direction of forces are:

6. mechanical advantage is:

7. more examples:

Joints – Type III lever

1. Fe = force you pull up
   Fr = up force on box

2. de =
   dr =

3. The forces are located :

same side but reversed order

4. The sizes of the forces are:
your force is always bigger

5. The direction of forces are:
same

6. mechanical advantage is:

7. more examples:
tennis racket

3.10 Teeter-totter lab

Goal: learn the art & physics of balance

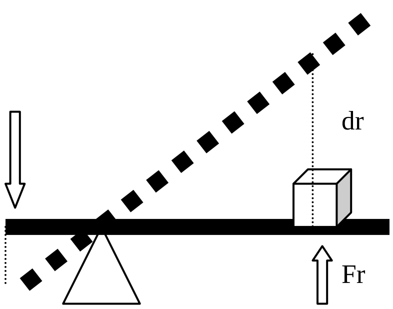
Method: balancing coins of same weight
measure distances moved

Clue: f * D = F * d

(little wt times big distance equals big wt times little distance)

3.11 Drawing lever triangles

Imagination is the key to calculating levers. Imagine pushing on the lever so that it stays attached but pivots on the fulcrum. Then draw the new lever over the old one. Just make sure you don't shift the lever or change its size. It doesn't matter how much to push on your lever since the ratios of distances will be kept the same by the solid location of the pivot. After drawing in your new lever, draw down or up from where the forces are on the lever to make triangles. It's just really trigonometry with a physics purpose! You get the distances by measuring on paper with a ruler. Fr is the weight of the object.



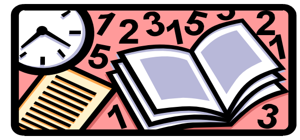
Ideal levers (all types)

Work in = work out

Fe * de = Fr * dr

MA = Fr / Fe = de/dr

Lever questions to ponder



(use physics to back up your answers!)

1. Why is it easier to pry a nail with a longer hammer than a shorter one?

2. Can you hit a ball harder with a longer or shorter racket and why is that?

3. Draw a picture of scissors made so "strong" that can cut through thin sheets of metal:

4. What force is needed to lift a 100N milk crate using an ideal lever having an MA= 5?

5. For the same lever, how far do you have to push if you want the crate to move by 5 m?

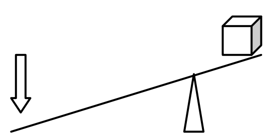
6. Who did more work, you or the milk crate?

7. You rescue your favorite soccer ball under your 5000 N car using a long board. You lift the board .2 meters, the car moves .04 meters. What force did you exert?

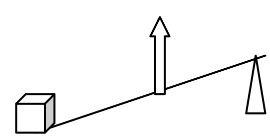
8. Using a board twice as long, how high could you lift the car with the same force?

9. Find the mechanical advantage of the levers:

A.



B.



C.