1. Running Roller Coasters

Energy

1.1 What makes the fastest coaster?

Thrill parks attract visitors in part by having a variety of rides. Some roller coasters use wooden tracks with lots of hills and turns but no loops. Steel coasters often flip the riders in multiple loops and banked turns. Much of the thrill of any coaster is going fast. Compare the speeds of these coasters at Great America.

Fastest rides at Great America

Coaster	Top Speed (mph)
Raging Bull	72
Eagle	66
Shockwave	65
Iron Wolf	55
Vipor	50
Whizzer	42

What is the key to designing a coaster to make it run very fast? The answer lies ahead!

1.2 Energy - #1 physics concept?

Energy is a term often used to describe people or objects. It's also a powerful physics concept. **Energy** can be defined as the ability to do work. The more energy present in you or any object, the more likely something can be made to happen or change. Amusement park rides possess many kinds of energy. Imagine a bumper car. It is energized by electricity so it has **electrical energy**. All objects in motion have **kinetic energy**. When the bumper car goes forward or backward, it has kinetic energy. A car that is stopped has no kinetic energy. After a while the car wheels warm up due to friction with the ground. Energy associated with heat is called **thermal energy.** The electrical rod touching the ceiling creates examples of **sound energy** (screeches) and **light energy** (sparks). During a collision, the car may bounce so it has spring or **elastic energy**. If the car were jolted off the ground, it would have **potential energy**. Any time you lift an object, you increase its potential energy. There also exists **nuclear energy** inside the atoms making up the car, as well as **chemical energy** between those same atoms. Finally, if the car receives any permanent damage (a dent or scratch), the car has **deformation energy.** ☹ Finally, if you add all the types of energy an object has at any particular moment, the sum is called the **total energy**

1.3 Conservation of Energy

The exciting part of energy is changing from one type to another. As the bumper car moves electrical energy (electricity) is converted to kinetic energy (motion). As a coaster goes down a hill it gives up potential energy (height), and gains kinetic energy (speed). Unfortunately, energy can not be entirely converted to another.

Efficiency is the percent of energy retained (i.e. still available) after an energy conversion. Did you know a typical car is 30% efficient? Only 30% of the chemical energy in gasoline is converted to kinetic energy that moves the car. Where did the rest go? Heat! Whenever energy is changed into another type, heat is also produced. Most of the time heat is undesirable, and it can never be fully converted back to more useful energies. Even so, if you include heat with all other energies present, you will find the total energy of any completely described situation is constant. That's a powerful law called **conservation of energy**.

Energies are not lost or created; they are just converted from one type to another. Think of an object's energy as a shirt having many pockets for different types of energy. An object, for example a marble, can lose or gain certain types of energy by switching pockets, but the total energy stays the same. There is an old saying - "what you get out of something is what you put into it". Does what you just read support this statement?

1.4 PE stands for Potential Energy

Gravity is a force that must be overcome to lift an object. Since energy is put into an object to raise it, that object gains height energy called gravitational **potential energy ("PE")**.

Potential energy depends on three factors: mass, height, and gravity.

The higher an object, the more work it took to get there, and hence the more PE possessed by the object. A coaster has the most PE at the top of the heighest hill. It should also makes common sense that more massive objects will have more potential energy than lighter ones. The PE of a coaster is higher if more people are on board since it takes more work to lift a heavier coaster. Finally, PE depends on gravity since gravity determines the weight of a coaster. Gravity or more accurately, the acceleration of gravity is given the symbol "g", and has a value of about 9.8 m/s^2 on earth.

En garde, I have a sharp equation for you!

PE = m*g*h

PE = potential energy in joules (J)
m = object's mass in kilograms (kg)
h = height of object in meters (m)
g = gravity (about 9.8 m/s^2 on Earth)

The above equation can be used to find the potential energy anywhere along a roller coaster along as the coaster's mass and vertical height are known. The weight of an object is simply its mass multiplied by the acceleration of gravity.

Weight = m*g

So also

PE = Weight * height

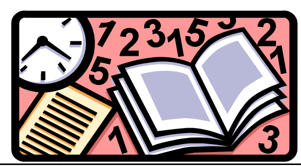
How about Great America on the moon?

On the moon, the acceleration of gravity is only 1.6 m/s^2. All objects have the same mass, but weight about six times less! . A moon ride would take much less work to lift up to the first hill, but it would also have much less potential energy. In summary, potential energy depends only on weight and vertical height.

Hints:

1. Don't confuse mass (in kilograms) with weight (measured in newtons)
2. Mass is in kilograms (1000 grams = kg)
3. Energy is in Joules (sounds like jewels)

Calculating Potential Energies



1. How much more PE does a 1.0 kg banana have after raising it higher by 3.0 meters?
(BTW, that's a 2 1/4 pound fruit!)

Answer
PE = mgh = 1kg * 9.8 * 3 m = 29 Joules (J)

2. What is the PE of a cheeseburger in your mouth? (assume burger weights 1N, mouth is 1.5 m high)

Answer
PE = Weight * height = 1N * 1.5m = 1.5 Joules (J)

1.5 Who is Rube Goldberg?

Reuben Lucius Goldberg was a cartoonist who poked fun at and designed silly gadgets such as an automatic back scratcher, a self-operating napkin, and a 20-step method to turn off the room lights. His cartoons live on and have inspired many people to invent very complicated gadgets to do very simple things. Some have appeared in movies such as Flubber, Goonies, Back to the Future, and the Nutty Professor. Rube Goldberg- like gadgets are the essence of the Mousetrap board game. There also exist annual contests to create the most excessive gadget to do the simplest task. A competition is held each year for high school students in Chicago. More information can be found out at: http://www.anl.gov/OPA/rube/

Years ago, engineering fraternities at Purdue University sought to win the contest by setting another fraternity's house on fire. The college quickly smothered that competition!

Why should we care about Rube Goldberg?

You may be assigned to create a poster or working model of your own Rube Goldberg design. You will be expected to describe all the changes in energy that would occur in your Goldberg machine. Who knows? Your machine might win in a real contest or even be sold on those late night TV ads. Someone invented the first electric toothbrush; it could have been you!

1.6 Perpetual Motion Machines

The United States Patent Office still has an open application for a perpetual motion machine- some gadget that does something forever. Such a gadget would convert between energy types forever without changing any energy into heat. If heat were created, it would have to be converted back 100% into a practical form of energy. If such a device existed its owners would be very rich. Imagine a car that never needs refueling! Somehow gas fumes and heat would have to be collected and reused over and over.

Can perpetual motion machines exist?

Theoretically it is possible to have perpetual motion. The total energy must stay the same so the conservation of energy law is not violated. However, technically it has been impossible to make or even design on paper such a device. Ultimately some additional energy from outside the machine is needed or the device requires heat to travel from cold to hot, which it can't. For more info, check out http://prisoner.soe.bcit.bc.ca/rjw/pmm

1.7 Kinetic Energy (KE)

Kinetic energy is the energy of motion. It takes energy to make things move, so moving object have kinetic energy. . Students walking to class have KE, while those simply standing in the hallway have no KE. A roller coaster has its greatest KE which it has its greatest speed. Likewise it takes more energy to move more massive objects. If two students fall at the same speed on the Giant Drop ride, the heavier student will have more kinetic energy.

So, kinetic energy depends only on two variables, mass and speed:

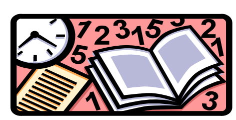
I'm back!!!

$$KE = \frac{1}{2} m * v^2$$

KE = kinetic energy in joules (J)
m = mass in kilograms (kg)
v = velocity in meters/ second (m/s)

Note velocity is speed in a certain direction. For energy calculations, direction is not needed.

Calculating kinetic Energies



a. What is the KE of a 2 kg bowling ball at rest?
b. What is KE if the same ball is rolling at 6 m/s?

Answer
a. KE = 0 since at rest!

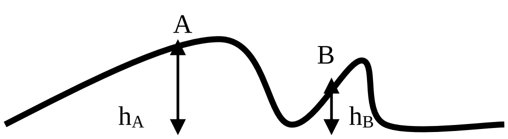
b. $KE = \frac{1}{2} * 2kg * 6^2 = 36$ Joules (J)

So which property explains why one roller coaster is faster than another?

The fastest coaster will have the most kinetic energy. Where did that energy come from? KE was converted from the potential energy of the first hill. So the fastest coaster has the biggest drop. You knew that already, but now you the physic reasons for it. (we ignored air resistance and friction for now). But what about mass? A more massive coaster will have more potential energy at the same height. Be prepared to explain why the coaster's speed doesn't depend on its mass!

1.8 Coaster Problems

There is a simple way to find the speed of a coaster at any height along the ride as long as one knows another speed at a different height. Consider two points "A" and "B" on a roller coaster. We can calculate the total energy at each point by assuming the coaster has only potential and kinetic energy. Minor errors due to effects of friction will be ignored for now.



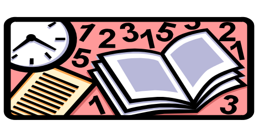
At point A:	At point B:
$PE = mg\,h_A$	$PE = mg\,h_B$
$KE = ½\,mv_A^2$	$KE = 1/2mv_B^2$

We can now invoke the conservation of energy. The total energy at either point is the same.

KE + PE (height A) = KE + PE (height B)

Hence, one can solve for one of the velocities if the other velocity and two heights are known. This method can be used anywhere on the track, not just at the top and bottom of hills.

Coaster Problems



1. A 2000. kg coaster is moving at 4.00 m/sec at the top of a hill having a 20.0 m drop. What is the coaster's speed at the bottom of the drop?

Answer

Find energy at top:

$PE = mgh = 2000*9.8*20 = 392{,}000$ J
$KE = 1/2mv^2 = 1/2*2000*4^2 = 16{,}000$ J
Total Energy = PE + KE = 408,000 J

Find energy at bottom:

$PE = mgh = 2000 *9.8 * 0 = 0$ (at bottom!)
KE = don't know yet
Total Energy = 408,000 J (same as above)

So, KE at bottom = Total energy at top
$1/2*2000*v^2 = 408{,}000$ J
v = 20.2 m/sec (about 44 mph)

2. Your are traveling at 2.0m/sec at the top of a 20. m high hill. What is your coaster's speed when you are at the top of the next hill (10. m high)? Mass of coaster is 2000 kg

Answer

Find energy at 1st hill:

$PE = mgh = 2000*9.8*20 = 392{,}000$ J
$KE = 1/2mv^2 = 1/2*2000*2^2 = 4{,}000$ J
Total Energy = PE + KE = 396,000 J

Find energy at 2nd hill:

$PE = mgh = 2000 *9.8 *10 = 196{,}000$ J
KE = don't know yet
Total Energy = 396,000 J (same as above)

So, 196,000 + KE = Total energy on 1st hill
196,000 + 1/2mv2 = 396,000 J
$1/2*2000*v^2 = 200{,}000$ J
v = 14 m/s

1.9 Summary

Conservation of *total* energy
(super important!)

You can't make or destroy energy, only change it to another type of energy!

KE + PE (height A) = KE + PE (height B)

Efficiency (% not lost to heat)

Eff =(Energy out/ Energy in)*100

Unit Conversions

1 m/sec = 2.24 mph.

1 kg = 2.22 lbs

1 mile = 1610 m

1 ft = 0.305 m

1 hr = 3600 sec

Potential energy (height energy)

$$PE = m*g*h$$

-doubles if double mass
-doubles if double height

Also note: $Weight = m*g$

Kinetic Energy (motion energy)

$$KE = \frac{1}{2} m * v^2$$

-doubles if double mass
-*quadruples if double speed*

Simple Roller Coaster Equation

Assumes only force is gravity
So no friction or external work done

1.10 Review Questions

Energy

1. Name 3 differences between the older coaster ride Eagle, and the new Raging Bull
2. What in your opinion is the most important question to answer when creating a new ride?
3. Define energy in your own words
4. Give an example of kinetic energy
5. You may have heard the phrase: you have a lot of potential! Explain using physics
6. What type of energy is associated with the bonding between atoms to form molecules?
7. Why would you want sport shoes to have stored elastic energy?
8. The fission or breaking apart of atoms is an example of __________ energy being used.
9. A toaster or hair dryer needs ________ energy to provide __________ energy.
10. If a brittle object is dropped on the floor, it may suffer _____________ energy.
11. Which energy types are often maximized at rock concerts?
12. Which energy allows you to read this page, pick up radio signals, or microwave food?:
13. List the types of energy in the order you used them to get to school today:

Conservation of Energy

14. Which energy (PE,KE, or total) is constant?
15. How is energy conservation like recycling?
16. Why is heat energy often called the graveyard for energy conversions?

Potential energy

17. What does the symbol g stand for?
18. How could a bowling ball and tennis ball have the same potential energy?
19. When is your PE higher, when in social studies on the second floor or math on the first floor?
20. What is the weight of a 70 kg student?
21. What is the potential energy of a 1/2 pound hamburger in your mouth (assume your standing so your mouth is 1.5m high above the ground)?
22. How much energy must you expend to raise yourself another 2.0 m while on a ladder? Assume your mass is 55kg
23. You stand at the top of a staircase which is 4 meters tall (about 12 feet). All of a sudden you trip and fall all the way down, plowing into an unwary freshman at the bottom. If you have 80 kg of mass, how much energy do you give the unlucky freshman?
24. Tricky one! How much energy would a 60 kg person have if he hiked up a 20 meter crater on the moon, where gravity is only 1/6 as strong as it is on the Earth?
25. What is the hidden source of energy in those perpetual motion balancing toys that seem to rock back and forth forever?

Kinetic Energy

26. Calculate the kinetic energy of a100 kg student walking at 0.8 m/sec to class
27. What happens to an object's kinetic energy if its velocity is doubled? Tripled?
28. What happens to an object's kinetic energy if its mass is doubled? Tripled?

29. What happens to an object's kinetic energy if both its mass and velocity are doubled ?

30. What is the velocity of a Viper car if it has a mass of 1000 kg and its KE is 310,000 J ?

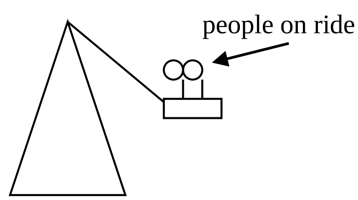
Coaster Problems

31. What is the total energy of a 65 kg student on the Giant drop at the moment she is screaming 20 m above the ground and moving at 9 m/sec?

32. Where on a roller coaster is your kinetic energy at its maximum?

33. Where on a roller coaster is your potential energy at its maximum value?

34. Mark on the swing ride below where the maximum KE and maximum PE are experienced



35. If a 10 kg object drops from rest from height of 5m, how much PE does it have to start?

36. For the same object, how much KE will it have just as it hits the ground? (ignore all forms of friction including air resistance)

37. What is the speed of a 200 kg water sled at the bottom of a 20 m hill, if it is moving forward at 3 m/sec at the top of the hill just before falling?

38. American Eagle ride has a 147 foot drop. If you are traveling at 2 m/sec at the top of the drop, what is your speed at the bottom of the drop? (you don't need mass!).