Velocity, Speed, and Motion... Oh My!

Velocity equals distance divided by time. Velocity and speed are very similar ideas, but velocity is a vector, and speed is not. Suppose we knew that someone was driving at thirty-five kilometers an hour (35 km/hr), but the direction wasn't given. How would you draw an arrow to represent a vector? You can't know how to draw the vector if you only have one value (either amount or direction). In this example, you were never told about the direction. Physicists would say that the speed is thirty-five kilometers an hour (35 km/hr), but the velocity is unknown. On the other hand, if you're moving at 35 km/hr in a northern direction, then you would have an arrow pointing north with a length of 35. Physicists would say that the velocity is 35 km/hr north.

Velocity is the rate of motion in a specific direction. I'm going that-a-way at 30 kilometers per hour. My velocity is 30 kilometers per hour that-a-way. Average speed is described as a measure of distance divided by time. Velocity can be constant, or it can change (acceleration). Speed with a direction is velocity.

Remember vectors? You will use a lot of vectors when you work with velocity. Our real world example of navigation on the ocean used velocity for every vector. Velocity is a vector measurement because it has an amount and a direction. Speed is only an amount (a scalar). Speed doesn't tell the whole story to a physicist. Think of it another way. If I tell you I'm driving north and ask you how long until we get to the city. You can't know the answer since you don't know my speed. You need both values.

One Moment in Time

Instantaneous velocity measures one moment in time. There is a special thing called instantaneous velocity. That's the velocity at a split second in time. Above, we were talking about your speed and direction over a long period of time. Why would you need to measure a velocity at one moment? Think about the moment you drove over the manhole. It's important to know if you were going 1 km/hr when you drove over the manhole, or 60 km/hr. It wouldn't help you to know that your average speed was 30 km/hr.

The term "instantaneous" refers to something physicists call a limit. Scientists "limit" the amount of time they do the measurement. When the "limit" moves to zero, that limit is one tiny moment in time. A physicist would measure your velocity as the "limit for a period of time", zero, to get the instantaneous velocity.

Changing Your Velocity

When velocity is changing, the word acceleration is used. Acceleration is also a vector. You speed up if the acceleration and velocity point in the same direction. You slow down (also referred to as decelerating) if the acceleration and velocity point in opposite directions. When you accelerate or decelerate, you change your velocity by a specific amount over a specific amount of time.

Just as with velocity, there is something called instantaneous acceleration. Instantaneous means scientists measure your acceleration for a specific moment of time. That way they can say he was accelerating at exactly this amount at this point during his trip.

Constant Acceleration

There are a few special situations where acceleration may be constant. This type of acceleration happens when there is a constant net force applied. The best example is gravity. Gravity's pull on objects is a constant here on Earth and it always pulls toward the center of the planet (Note: Gravity decreases as you move far away from the surface of the planet.). The gravities of other planets are different from Earth's gravity because they may have different masses and/or sizes. Even though the gravity may be smaller or larger, it will still create a constant acceleration near the surface of each planet.

Momentum Basics

Momentum is equal to the mass multiplied by the velocity. Momentum is another vector measurement. Momentum is in the same direction as velocity. Scientists calculate momentum by multiplying the mass of the object by the velocity of the object. It is an indication of how hard it would be to stop the object. If you were running, you might have a mass of 50 kilograms and a velocity of 10 meters per second west (really fast). Your momentum would be 500 kg-m/sec west. Easy as pi.

Remember Newton's First Law? It said that any object moving will continue moving unless it is interfered with. That idea applies to momentum as well. The momentum of an object will never change if it is left alone. If the 'm' value and the 'v' value remain the same, the momentum value will be constant.

Momentum increases as either mass or velocity increase. The momentum of an object, or set of objects (system), remains the same if it is left alone. Within such a system, momentum is said to be conserved.

Here's the momentum idea in simpler terms. When you throw a ball at someone and it hits him hard, it hurts because it was difficult to stop (had momentum).Think about it. If you throw a small ball and a large ball at the same speeds, the large ball will hit a person with a greater momentum, be harder to stop, and hurt more. When the mass is greater (at the same speeds), the momentum is greater.

A bullet is an example of an object with a very small mass that has a lot of momentum because it is moving very quickly. Bullets are therefore difficult to stop; it's a good idea not to try!

Conserving Momentum

Elastic collisions have constant momentum while inelastic collisions lose momentum. We already told you that the momentum of an isolated object (or system of objects) is conserved. If the net force acting on an object is zero, then the linear momentum is constant. In an elastic collision (such as a superball hitting and rebounding from the ground), no kinetic energy is lost. All of that energy is still in the object, so we say that energy was conserved. If the kinetic energy didn't change, then neither did the value of the momentum (The momentum vector, however, DID change, since the direction of momentum changed.). Energy is a scalar, not a vector, so a direction change doesn't matter.

What about an inelastic collision? In an inelastic collision, some of the energy will be lost to heat or sound or light or some other energy. The thing to remember is that the total energy didn't change, but some of it escaped into the air, ground, etc. The object would then have less energy when it rebounded, so the KE and momentum would be less. The total energy is the same, but the energy of the object did not remain the same. The energy of the object was not conserved, but the total energy was.

Try throwing a piece of clay on the ground. When the clay slams into the ground, some of the kinetic energy of the clay was lost as heat and sound to the ground and air, and some of the heat remains in the clay. Since the velocity became zero, so did the momentum. The energy is still around, but divided up in different places.

Friction Basics

Friction is a force that acts in an opposite direction to movement. Friction is a force that holds back the movement of a sliding object. That's it. Friction is just that simple.

You will find friction everywhere that objects come into contact with each other. The force acts in the opposite direction to the way an object wants to slide. If a car needs to stop at a stop sign, it slows because of the friction between the brakes and the wheels. If you run down the sidewalk and stop quickly, you can stop because of the friction between your shoes and the cement.

What happens if you run down the sidewalk and you try to stop on a puddle? Friction is still there, but the liquid makes the surfaces smoother and the friction a lot less. Less friction means it is harder to stop. The low friction thing happens to cars when it rains. That's why there are often so many accidents. Even though the friction of the brakes is still there, the brakes may be wet, and the wheels are not in as much contact with the ground. Cars hydroplane when they go too fast on puddles of water.

Friction and Gases

Air resistance of the atmosphere heats the bottom of the shuttle. Friction only happens with solid objects, but you do get resistance to motion in both liquids and gases. This doesn't involve sliding surfaces like friction does, but is instead the kind of resistance you get if you try to push your way through a crowd. It's a colliding situation, not a sliding one. If the gas is air, this is referred to as air resistance.

If you were in the space shuttle and re-entering the atmosphere, the bottom of the shuttle would be getting very hot. The collisions that occur between the molecules of the air being compressed by the shuttle, heat up the air AND the shuttle itself. The temperature on the top of the shuttle is also warm, but nowhere near the temperatures found on the bottom.

Friction and Liquids

Although liquids offer resistance to objects moving through them, they also smooth surfaces and reduce friction. Liquids tend to get thinner (less viscous) as they are heated. Yes, that's like the viscosity of the oil you put in your car. Car engines have a lot of moving parts, and they rub on each other. The rubbing produces friction and the result is heat. When oil is added to a car engine, the oil sticks to surfaces, and helps to decrease the amount of friction and wear on the parts of the engine. An engine that runs hotter requires a more viscous oil in order for it to stick to the surfaces properly.

Measuring Friction

Higher coefficient of friction compared to lower coefficient of friction. Measures of friction are based on the type of materials that are in contact. Concrete on concrete has a very high coefficient of friction. That coefficient is a measure of how easily one object moves in relationship to another. When you have a high coefficient of friction, you have a lot of friction between the materials. Concrete on concrete has a very high coefficient, and Teflon on most things has a very low coefficient. Teflon is used on surfaces where we don't want things to stick; such as pots and pans.

Scientists have discovered that there is even less friction in your joints than in Teflon! It is one more example at how efficient living organisms can be.

Forces of Attraction

Gravity of the Earth pulls objects towards the center of the planet. Gravity or gravitational forces are forces of attraction. We're not talking about finding someone really cute and adorable. It's like the Earth pulling on you and keeping you on the ground. That pull is gravity at work.

Every object in the universe that has mass exerts a gravitational pull, or force, on every other mass. The size of the pull depends on the masses of the objects. You exert a gravitational force on the people around you, but that force isn't very strong, since people aren't very massive. When you look at really large masses, like the Earth and Moon, the gravitational pull becomes very impressive. The gravitational force between the Earth and the molecules of gas in the atmosphere is strong enough to hold the atmosphere close to our surface. Smaller planets, that have less mass, may not be able to hold an atmosphere.

Planetary Gravity

Obviously, gravity is very important on Earth. The Sun's gravitational pull keeps our planet orbiting the Sun. The motion of the Moon is affected by the gravity of the Sun AND the Earth. The Moon's gravity pulls on the Earth and makes the tides rise and fall every day. As the Moon passes over the ocean, there is a swell in the sea level. As the Earth rotates, the Moon passes over new parts of the Earth, causing the swell to move also. The tides are independent of the phase of the moon. The moon has the same amount of pull whether there is a full or new moon. It would still be in the same basic place.

We have to bring up an important idea now. The Earth always produces the same acceleration on every object. If you drop an acorn or a piano, they will gain velocity at the same rate. Although the gravitational force the Earth exerts on the objects is different, their masses are just as different, so the effect we observe (acceleration) is the same for each. The Earth's gravitational force accelerates objects when they fall. It constantly pulls, and the objects constantly speed up.

They Always ask About Feathers

Both the feather and the ball fall at the same speed in a vacuum. People always say, "What about feathers? They fall so slowly." Obviously, there is air all around us. When a feather falls, it falls slowly because the air is in its way. There is a lot of air resistance and that resistance makes the feather move slower. The forces at work are the same. If you dropped a feather in a container with no air (a vacuum), it would drop as fast as a baseball.

What About the Moon?

But what keeps the Moon from falling down, if all of this gravity is so strong? Well, the answer is that the moon IS falling; all the time, but doesn't get any closer to us! Remember that if there wasn't a force acting, the Moon would be traveling in a straight line. Because there IS a force of attraction toward the Earth, the moon "falls" from a straight line into a curve (orbit) around the Earth and ends up revolving around us. The Earth's gravity holds it in orbit, so it can't just go off in a straight line. Think about holding a ball on a string and spinning it in a circle. If you were to cut that string (no more gravity), the ball would fly off in a straight line in the direction it was going when you cut the string. That direction, by the way, is not directly away from your hand, but tangent to the circle. Tangent is a geometry term used to describe a direction that are related to the slope of a curve. Math stuff. The pull of the string inward (toward your hand) is like the Earth's gravitational pull (inward toward the center of the Earth).

All Work and no Play

Work, work, work. You might head off to your job one day, sit at a computer, and type away at the keys. That's all we do here. Is that work? To a physicist, only parts of it are. Work is done when a force that is applied to an object moves that object. The work is calculated by multiplying the force by the amount of movement of an object (W = F \* d). A force of 10 newtons, that moves an object 3 meters, does 30 n-m of work. A newton-meter is the same thing as a joule, so the units for work are the same as those for energy – joules.

Sitting and looking at a computer screen is not work. Tapping on the keyboard and making the keys move is work. Your fingers are applying a force and moving the keys. Driving to your job is not work because you just sit, but the energy your car engine uses to move the car does work. You have to exert a force AND move something to qualify as doing work.

Holding a box does not require work. Raising the box requires work. Imagine that you are holding a brick above the ground. Your arm is straight out in front of you and it's pretty tough to hold. Slowly, your arm gets tired, the brick feels heavier and heavier, and you finally have to stop to let your arm rest. Even though you put forth a lot of effort to hold the brick up, did you do any work on the brick? Nope. The brick didn't move. No work was done if no movement happened. If you lifted the brick again after your arm had rested, that would be work.

Transfer of Energy

Work transfers energy from one object to another. We've already talked about moving objects. What else? Work is also linked to the expansion and compression of gases. When a gas tries to expand, it exerts an increasing force on the surfaces of a container and may make those surfaces move. The gas would then be doing work and transferring energy to the container. If you heat a balloon (carefully), the molecules of air in the balloon gain energy and strike the inner walls of the balloon with greater force. Because the inner surface of the balloon is flexible, that surface moves outward. The air does work, and transfers energy to the balloon. If you compress a balloon, you do work, and transfer energy to the air inside the balloon.

Measuring Work for Gases

When scientists measure the work done on, or by, gases, they look at the system at the beginning and the end of the project. They look at the initial and final states. To figure out the total work done on, or by, a gas system, they use the formula W = P (delta)V. W stands for work, P is the pressure of the system (for gases), and delta V is the change in volume for the system. A variation would be W = V(delta P), where V is volume, and delta P is the change in pressure. The delta values are taken at the beginning and end.

Sometimes they might take measurements while things are happening. Those are measurements of intermediate states. They could then use the intermediate measurements to calculate work, and then total those work values up to figure the total work done.