What is power? Power. Not the kind of political power that we see in Washington and elsewhere in the world. This is the way we define power in physics.

It is energy per unit time. Now energy is joules and time is seconds. Energy is work that is Newton meters per second. It's the same thing. We sometimes call this watts. 1 joule per second is one watt. Power is a scalar.

Suppose I move an object with mass m from A to B gravitational field-- gravity is in this direction-- and the vertical separation between A and B is 8. I have to do work in going from A to B. The work energy I have to generate equals, in this case, plus mg h. Remember, Massachusetts General Hospital. Very easy to remember.

If it takes me t seconds to go from A to B, then the average power that I have generated, that I have produced, by Walter Lewin in going from A to B equals mg h divided by t.

If I'm very lazy and I take a long time, then my average power will be low.

If I'm not so lazy and I do it very fast, the average power will be higher. Notice that average power can be negative. If I go from B to A, then the work that I would be doing would be negative. If I go from A to B, the work I do will be positive. So therefore, average power can be both positive as well as negative, depending upon whether I go from A to B or from B to A.

Let's take a mountain climber and take a specific example.

A mountain climber say, has a mass of 70 kilograms. And the mountain climber climbs over a vertical distance of about 3,000 feet, which is very roughly 1,000 meters. So the work done by the mountain climber-- and if I ignore work due to friction with the shoes, just the vertical distance that he's going, if I take only that into account, which is probably the major portion of the work he has to do, it's mg h, so that would be 70 times 1,000 times g. I'll take 10 for g. So that's about 7 times 10 to the 5 joules.

If it takes that person one hour, then average power would be 7 times 10 to the fifth divided by 3,600 seconds. That is about 195 watts. If you round it off, about 200 watts.

If that person takes 5 hours to make the same trip, then the average power will be five times lower, so we'll be about 40 joules per second. So that's about 40 watts. So you see, it depends strongly on how long the trip takes.

An engine, car, plane or an elevator motor does work. The average power is the work that the engine does from the car or the plane or elevator motor. And if it takes t seconds to go from one place to another, then the average power is given by the work done divided by the time t.

What now is the instantaneous power? Instantaneous. Well, I would like to revisit the idea of average velocity and instantaneous velocity. And you can watch a different segment where I discuss that in glorious detail.

Let's take a one-dimensional motion. So we only move in x. Then, the average velocity between time t1 and time t1 is the position of the object at time t2 minus the position of the object at time t1 divided by t2 minus t1. That's average. This bar means average, like this bar means average.

What is the instantaneous velocity at time t? That equals dx dt.

In a very similar way, can we now go to instantaneous power? Instantaneous power at a particular moment in time is dw dt. This is a little bit amount of work done in a very small amount of time. And in the [? limiting ?] case for dt going to 0. So this equals the force at that moment in time dot product dx-- also a vector-- dt. There is your dt. F dx is dw. We have the dt here. And so this becomes the force at that moment in time dot product with the velocity at that moment in time. dx dt is the velocity.

And so you see that force is Newtons, velocity is meters per second. So you get your joules per second and you get your watts. This is scalar. So the instantaneous power is the dot product between the force at that moment in time, dot product with the velocity at that moment in time.

Can the instantaneous power be negative? Of course. It can be negative. It can be positive. It can be 0.

Power is a dot product between force and velocity.

So all that matters is what is the angle between the two vectors?

Suppose the velocity is in this direction and the force is in this direction. This angle is larger than 90 degrees. So, the instantaneous power is negative.

If you allow this force to act on to this object for some time, it's doing negative work.

If the velocity is in this direction, and the force is in this direction, well then, the power is positive.

And if the velocity is in this direction, but the force is exactly at 90 degree angles, then the instantaneous power equals 0.

If you allow this force to act on to this object, as long as the force is perpendicular to v, no work is done by this force.

Let's take a satellite near earth orbit. It has a speed of 8 kilometers per second.

So here is the satellite. And the satellite say, is moving in this direction, velocity v. And that is 8 kilometers per second. 8 times 10 to the 3 meters per second. The satellite has a thruster here, a thruster here, a thruster here, and a thruster here.

And at this moment in time, we fire this thruster. So hot gas is coming out here with high speed. And that will provide a force in this direction. And let the magnitude of that force on the satellite, the magnitude be 1,000 Newton.

The instantaneous power is now the dot product between these two, but since they are in the same direction, cosine of the angle is 1. So we get 8,000 times 1,000 is 8 times 10 to the 6 joules per second. This force will immediately increase the speed, which is the magnitude of this velocity in this direction. Positive power.

By the way, if the satellite were further away from the earth, and its speed were only 1,000 meters per second, then the power would only be 1,000,000 joules per second. So power depends both on force and it depends on velocity. It's obvious because if its speed were eight times lower, then the work done by this force in the same amount of time will be eight times less because the satellite moves over a distance, which is eight times less. But that's rather natural.

Let's go back to our satellite eight kilometers per second. But now it's not firing this thruster, but let's suppose it is firing now this thruster.

So now I'll make a new drawing, Otherwise we get too confused.

So it is going in this direction 8 kilometers per second. And now, this rockets fires. And now the force is in this direction. And let's assume that the magnitude of the force is again, 1,000 Newtons.

What is now the instantaneous power? The instantaneous power is now 0. The force is perpendicular to the direction of the velocity. There's no instantaneous increase in the magnitude of this velocity. As long as this force stays perpendicular to this direction of the vector v, the magnitude of this vector v will not change. The direction of v may change, but the magnitude will not change as long as this is perpendicular to this.

Now, if we take a situation-- you guessed it. Here's this satellite and it's going in this direction. Again, 8 kilometers per second. But now I fire this rocket. Remember, we had four rockets. Gas comes out, hot gas is spewed out. And so now we have a force in this direction. So the dot product now gives me a minus 1. The cosine of the angle between them is minus 1. So now the instantaneous power is negative. And the magnitude of the velocity, which we call the speed, will decrease as a result of this force.

Now the mean power over the entire excursion. First we were firing rocket number one, which increased the speed. Then we were firing the rocket so that the force was perpendicular to the velocity vector. And then we were firing a rocket so that the force was in opposite direction as the velocity vector. I call that all together one excursion. I could arrange things in such a way that the average power during this excursion is 0. Because we have one portion where we have positive power, we 0 power, and we have negative power.

So, even though the instantaneous power was only 0 for one brief [INAUDIBLE], the special [INAUDIBLE] when the two were 90 degrees with respect to each other. In our other cases, the instantaneous power was not 0. But yet, the average power can be 0. So never confuse average power with instantaneous power, just as you should never confuse average velocity with instantaneous velocity.

Let's take a satellite in a circular orbit around the earth. So here's the earth. It is a circular orbit. And the gravitational force onto a satellite with mass little m is like so. The velocity of the satellite is like so. The velocity changes all the time. The direction changes. The magnitude does not change. The magnitude of a velocity vector, we call that the speed. The speed itself is a scalar. So the speed never changes, but the direction of the velocity changes. So the velocity vector does change.

What happens with F-- this is the gravitational force-- dot v? Well, that is always 0 because no matter where you are in a circular orbit, this is always at angle 90 degrees. The angle here is 90 degrees. So the instantaneous power is always 0, therefore this force will never change the magnitude of this velocity vector. It will therefore, never change the speed. This force is doing no work on this satellite. During this entire circular orbit, this force is never doing any work on the satellite. That's why the speed of the satellite does not change.

However, the direction of the velocity does change under influence of that force. Give this some thought. None of these concepts are easy. So if you find it difficult, you're not alone; don't feel bad about it.

So a common unit of power in Newtonian mechanics is joules per second, which we watts. However, very often you were also see as a unit of power the horsepower. And 1 horsepower is approximately 746 watts-- joules per second.

In the case off the mountaineer that we dealt with, he was going up-- he or she was going up 1,000 meters in one hour and we calculated that the average power generated by this mountaineer was about 195 watts. If you want to express that in terms of horsepower, and you round things off a little bit, then it's about one quarter of a horsepower.

Let's take an elevator. The elevator itself has a mass of 200 kilograms. It carries 4 people. Let's assume this is the mass of the elevator, that the mass of the people, the 4 people together-- 250, 300 kilograms. Let's just round it off nicely-- 300 kilograms.

It goes up 4 floors. It starts here and stops here. And these are 4 floors-- the vertical distance. And let's say that 4 floors is roughly 10 meters, about 2 and 1/2 meters per floor. That's not unreasonable.

So what is the work done by the motor of the elevator? Well, it is the mass that is 500 times g. That is the gravitational acceleration. Times the distance. Remember, Mg h. So that is 5 times 10 to be 4 joules. It does this in 10 seconds. So the average power is then 50,000 divided by 10. It is the work done divided by the time that it takes. So that is 5,000 joules per second. 5,000 watts. And if you express that in terms of horsepower, it would be about 6.7 horsepower. Not an reasonable number for an elevator.

It is kind of interesting to compare power of the various appliances and the various objects that our so common in our lives.

Electric toothbrush-- if you're so lucky to have one. That's only a few watts I would think. Electric toothbrush. A few watts.

A light bulb. They come of course, in a large variety. But 100 watt light bulb is quite common. I'm sure you have those in your dormitory.

What is interesting that the body heat of a person is also about 100 watts It comes out mostly in the form of infrared radiation. Not visible light. When you turn off the light when it's dark you can't see someone. If you had infrared detectors, you could see someone because you are radiating infrared radiation. And you're doing that roughly at a rate of 100 joules per second.

Compare the body heat of 100 watts with that of electric blankets. You can compare that for efficiency.

Well, a warm body is as good as two electric blankets. So think about it before you buy electric blankets. A car. Oh, let's put the body heat down. Body heat also roughly 100 watts. Equivalent to two electric blankets.

A car. Well, a large variety of course. Typical number 200,000 watts, which is about 270 horsepower. In fact, I've never heard the power of a car being expressed in terms-- all these values of course are average powers. I've never heard a car power being expressed in terms of watts. You would always do it in terms of horsepower. I think cars come in the range from 150 to 300, maybe 400 horsepower and maybe more.

A Boeing 747 is about 200 billion watts. So that would be about 270,000 horsepower.

If you take the average consumption in the United States, all people together, cars, electricity, anything you can think of. So it's the average consumption that we have. How many joules per second that we consume in United States? It is all energy, all energy in the U.S. on average is about 2 times 10 to the 12th watts.

The sun. The sun's power is about 4 times 10 to the 26 watts. That is how many joules per second the sun produces.

And if you know the distance from the sun to the earth, you can calculate how much of that power arrives at the earth at every square meter at the earth, outside the earth's atmosphere. And that number comes out to be approximately 1 kilowatts. And that's an important number. 1 kilowatts per square meter. Very roughly rounded off. It's important because if you ever want to harvest solar energy, that is the very maximum you can ever do.

All right, so much for power and average power.