Lesson 12-Work, Power, and Internal Energy

Work

Work is accomplished through the application of force. Work is defined as the application of force operating through a distance. For example, when we apply a force to a box and slide the box across the floor, we have applied a force and operated on the box to move it through a distance.

$$\text{Work} = \text{force} \cdot \text{displacement}$$

Both force and displacement are vectors. The dot (·) indicates a special type of vector multiplication called a scalar product or dot product. The result of this type of vector multiplication is not a vector but a scalar. Work is a scalar quantity. As long as the two vectors are parallel to each other, the scalar product is just the product of the two magnitudes.

Note, it is not enough to merely apply the force. If the object does not move then no work is accomplished. Furthermore, it is not enough that an object moves through a distance. Perhaps it is moving under its own momentum. Again no work is accomplished. Work is only accomplished when the force "causes" the object to move through the distance.

One important feature of the force is that it must have a component pointing in the direction of the motion or against the direction of the motion. When computing the work done by a given force, we use only the component that is parallel to the motion. The other component accomplishes no work and makes no contribution to the net work.

When multiple forces act on the same object at the same time, we compute the work done by each force separately. When the force has a component in the direction of the motion, that force does positive work. When a force has a component that opposes the direction of the motion, that force does negative work. What we call the net work, W_{net}, is just the arithmetic sum of the works accomplished by all the forces acting on the object.

The unit of work is the N·m, which is also defined as a joule (J). In work, remember, the force (N) and the displacement (m) are parallel. The unit of torque is also the N·m, but in torque calculations the force (N) and the displacement (m) must be perpendicular. The joule (J) is only used to refer to work. Torque is always reported as newton·meters.

Power

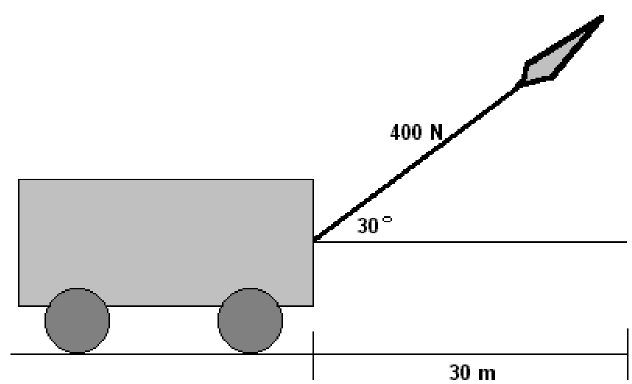
The work calculation says nothing about the amount of time required to complete the motion. Seconds, minutes, eons; it's all the same in the work calculation. Power is the quantity that tells us how fast the work is accomplished. Power is the amount of work performed divided by the time required to achieve it. The unit of power is the watt (watt = W = J/s).

Internal Energy
This refers to the inner state of an object, most often to a machine, and provides some information about the machines ability to perform work. A machine converts internal energy to work. Both energy and work are reported in joules. In order to perform 50 joules of work, an engine must lose at least 50 joules of its internal energy. It may lose more than 50 joules if it also has to overcome its own internal resistance or suffers from other limitations on its ability to convert energy into work. Every machine needs to have its internal energy replenished or it will eventually run out of energy and stop running.

We will have a lot more to say about internal energy and the conversion of energy into work in later chapters. The general topic is called Thermodynamics.

Energy in its various forms provides one of the key organizing principles of modern science. Energy considerations inform our understanding of all natural and man-made systems; from the reproduction of bacteria, to the design of nuclear reactors, to the evolution of the stars, to the evolution of the entire universe, etc.

Example I
Ia. *A man pulls a wagon across the floor by pulling on the handle angled 30º above horizontal. The man moves the wagon 30 m by pulling with a force of 400 N. How much work does the man do on the cart during this move?*



First, find the component of the force parallel to the displacement.

$F_{\parallel}$ = 400 cos 30º = 400 (0.866) = 346.4 N = 350 N (2 SF)

Work = W = 346.4 N x 30 m = 10,392 N·m = 10, 392 J = 1.0E4 J (2 SF)

Ib. *If it took him 1 minute and 10 s to move the wagon 30 m, what was the average power he applied to the wagon during the move?*

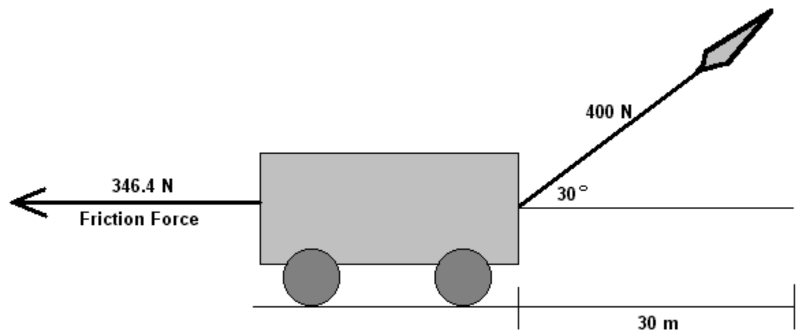
Power = Work/time = 10,393 J / 70 s = 148.5 J/s = 148.5 W = 150 W (2 SF)

Ic. *How much internal energy did the man convert to work? Were there other changes in the internal energy of the man while moving the wagon? If so, what were they? If not, how can you tell?*

10,000 J of internal energy were converted to work. Internal energy was also lost to pulling up on the handle, running his biological systems, and moving the man himself.

Example II

This time the wagon comes rolling up to the starting line and the man prepares to apply his 400 N force on the handle just as in the first example. Except this time the wheels lock up just as the man starts to pull. As it turns out, the friction force created by the dragging tires is exactly equal to the horizontal component of the man's pull on the handle; that is 346.4 N pointing to the left in our new diagram.



Since the two opposing horizontal forces are exactly equal and opposite, there is no net force and no acceleration. The cart keeps whatever residual velocity it had just before the wheels locked up and the man started to pull. Because the forces are equal and opposite, the velocity remains constant as long as the man keeps pulling.

IIa. *How much work does the man do on the wagon?*

$Work_{man} = W_{man}$ = 346.4 N x 30 m = 10,392 N·m = 10, 392 J = 1.0E4 J (2 SF)

IIb. *How much work does the friction force do on the wagon?*

$Work_{Friction} = W_F$ = 346.4 N x (–30 m)= –10,392 N·m = –10, 392 J = –1.0E4 J (2 SF)

IIc. *What is the net work done on the wagon?*

$Work_{net} = W_{net} = W_{man} + W_F$ = 10, 392 J + (–10, 392 J) = zero J

IId. *Because the wheels locked up and the wagon had a very slow initial velocity, it takes the man 22 minutes to move the wagon 30 m. What is the average power expenditure by the man in moving the wagon?*

Power = Work/time = 10,393 J / (22 x 60) s = 7.873 J/s = 7.873 W = 7.9 W (2 SF)

IIe. *Would the man say it was easier to pull the cart with the wheels locked or with the wheels rotating and why would he say so?*

Even though the average power expenditure was smaller during the second pull, it was actually harder because it was necessary to sustain the pull for a much longer time and all his other energy demands had to be maintained for that extended period. The man said it was harder because he lost more internal energy during the second move.