7.1: Introduction- Work and Impulse

In physics, "work" (or "doing work") is what we call the process through which a force changes the energy of an object it acts on (or the energy of a system to which the object belongs). It is, therefore, a very technical term with a very specific meaning that may seem counterintuitive at times.

For instance, as it turns out, in order to change the energy of an object on which it acts, the force needs to be at least partly in line with the displacement of the object during the time it is acting. A force that is perpendicular to the displacement does no work—it does not change the object's energy.

Imagine a satellite in a circular orbit around the earth. The earth is constantly pulling on it with a force (gravity) directed towards the center of the orbit at any given time. This force is always perpendicular to the displacement, which is along the orbit, and so it does no work: the satellite moves always at the same speed, so its kinetic energy does not change.

The force *does* change the satellite's momentum, however: it keeps bending the trajectory, and therefore changing the direction (albeit not the magnitude) of the satellite's momentum vector. Of course, it is obvious that a force must change an object's momentum, because that is pretty much how we defined force anyway. Recall Equation (6.1.1) for the average force on an object: $\vec{F}_{av} = \Delta\vec{p}/\Delta t$. We can rearrange this to read

$$\Delta\vec{p} = \vec{F}_{av}\Delta t. \tag{7.1.1}$$

For a constant force, the product of the force and the time over which it is acting is called the *impulse*, usually denoted as $\vec{J}$

$$\vec{J} = \vec{F}\Delta t. \tag{7.1.2}$$

Clearly, the impulse given by a force to an object is equal to the change in the object's momentum (by Equation (7.1.1)), as long as it is the only force (or, alternatively, the net force) acting on it. If the force is not constant, we break up the time interval Δt into smaller subintervals and add all the pieces, pretty much as we did with Figure 1.2.5 in Chapter 1 in order to calculate the displacement for a variable velocity. Formally this results in an integral:

$$\vec{J} = \int_{t_i}^{t_f} \vec{F}(t)dt. \tag{7.1.3}$$

Graphically, the x component of the impulse is equal to the area under the curve of F_x versus time, and similarly for the other components. You will get to see how it works in a lab experiment this semester.

There is not a whole lot more to be said about impulse. The main lesson to be learned from Equation (7.1.1) is that one can get a desired change in momentum—bring an object to a stop, for instance—either by using a large force over a short time, or a smaller force over a longer time. It is easy to see how different circumstances may call for different strategies: sometimes you may want to make the force as small as possible, if the object on which you are acting is particularly fragile; other times you may just need to make the time as short as possible instead.

Of course, to bring something to a stop you not only need to remove its momentum, but also its (kinetic) energy. If the former task takes time, the latter, it turns out, takes *distance*. Work is a much richer subject than impulse, not only because, as I have indicated above, the actual work done depends on the relative orientation of the force and displacement vectors, but also because there is only one kind of momentum, but many different kinds of energy, and one of the things that typically happens when work is done is the *conversion* of one type of energy into another.

So there is a lot of ground to cover, but we'll start small, in the next section, with the simplest kind of system, and the simplest kind of energy.