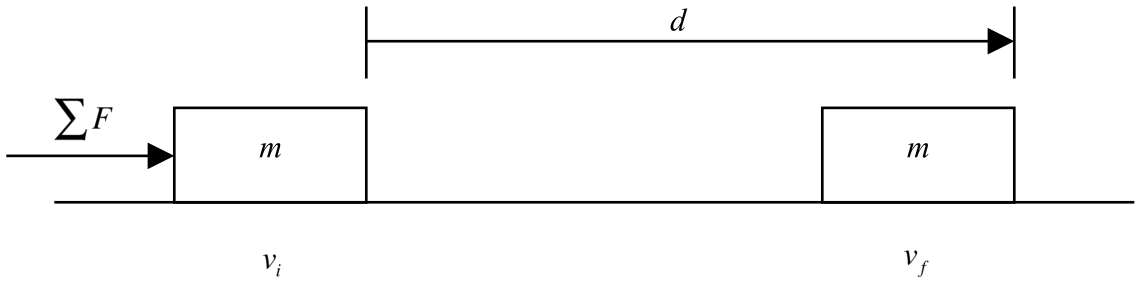
Kinetic Energy and the Work-Energy Principle

Energy is the ability to do work. A moving object can do work on another object it strikes. For example, a hammer does work on a nail it drives into wood. Since an object in motion has the ability to do work, it is said to have energy. The energy of motion is called **kinetic energy**.

Consider an object of mass m that is moving in a straight line with an initial speed v_i. To accelerate it uniformly to a speed v_f, a constant net force $\sum F$ is exerted on it parallel to its motion over a displacement d.



We define the quantity $\frac{1}{2}mv^2$ to be the **translational kinetic energy** of the object.

$$E_k = \frac{1}{2}mv^2$$

Notice that the kinetic energy is directly proportional to the mass of the object, but proportional to the *square* of the speed. Thus, if the mass is doubled, the kinetic energy is doubled. However, if the speed is doubled, the object has four times as much kinetic energy (and is capable of doing four times as much work).

Also, the work above leads to an important result known as the **work-energy principle**. This can be stated in words:

The net work done on an object is equal to the change in the object's kinetic energy.

$$\sum W = \Delta E_k$$

The work-energy principle tells us that if positive net work W is done on a body, its kinetic energy increases by an amount W. If negative net work W is done on a body, its kinetic energy decreases by an amount W.

Because of the connection between work and energy, energy is measured in the same units as work: joules.

Example 1 KE and work done on a baseball.

A 145 g baseball is thrown with a speed of 25 $m \cdot s^{-1}$. (a) What is its kinetic energy? (b) What was the net work done on the ball to make it reach this speed, if it started from rest?

Example 2 Work on a car, to increase its KE.
How much net work is required to accelerate a $1250\ kg$ car from $20.0\ m \cdot s^{-1}$ to $30.0\ m \cdot s^{-1}$?

Example 3 Work to stop a car.
A car traveling $60\ km \cdot h^{-1}$ can brake to a stop within a distance of $20\ m$. If the car is going twice as fast, $120\ km \cdot h^{-1}$, what is the stopping distance? Assume the braking force is constant.

Homework
Energy Worksheet #2

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1. What is the initial kinetic energy of a $0.50\ mg$ flea that leaves the ground at a speed of $30\ cm/s$? ($2.25\times10^{-8}\ J$)

2. A carbon atom of mass $1.99\times10^{-26}\ kg$ has $4.64\times10^{-19}\ J$ of kinetic energy. How fast is it moving? ($6.83\times10^{3}\ m/s$)

3. If the kinetic energy of a particle is doubled, by what factor has its speed increased? ($\sqrt{2}$)

4. If the speed of a particle is doubled, by what factor does its kinetic energy increase? (4)

5. How much work does it take to accelerate an electron ($m = 9.11\times10^{-31}\ kg$) from rest to $5.0\times10^{6}\ m/s$? ($1.14\times10^{-17}\ J$)

6. How much work must be done to stop a $1000\ kg$ car traveling at $100\ km/h$? ($-3.86\times10^{5}\ J$)

7. A baseball ($m = 140\ g$) traveling $30\ m/s$ moves a fielder's glove backward $15\ cm$ when the ball is caught. What was the average force exerted by the ball on the glove? ($-420\ N$)

8. If the speed of a car is increased by 50%, by what factor will its minimum braking distance be increased, assuming all else is the same? Ignore the driver's reaction time. ($9/4$)

9. In 1955 a paratrooper fell $370\ m$ after jumping from an aircraft without his parachute opening. He landed in a snowbank, creating a crater $1.1\ m$ deep, but survived with only minor injuries. Assuming the paratrooper's mass was $80\ kg$ and his terminal velocity was $50\ m/s$, estimate
   a. the work done by the snow in bringing him to rest. ($-1.0\times10^{5}\ J$)
   b. the average force exerted on him by the snow to stop him. ($9.1\times10^{4}\ N\ [up]$)
   c. the work done on him by air resistance as he fell. ($-2.9\times10^{5}\ J$)

10. A $180\ kg$ load is lifted $23.0\ m$ vertically with an acceleration $a = 0.150g$ by a single cable. Determine
    a. the tension in the cable. ($2029\ N$)
    b. the net work done on the load. ($6086\ J$)
    c. the work done by the cable on the load. ($4.67\times10^{4}\ J$)
    d. the work done by gravity on the load. ($-4.06\times10^{4}\ J$)
    e. the final speed of the load assuming it started from rest. ($8.2\ m/s$)

11. One car has twice the mass of a second car, but only half as much kinetic energy. When both cars increase their speed by $5.0\ m/s$, they have the same kinetic energy. What were the original speeds of the two cars? ($3.6\ m/s$, $7.1\ m/s$)