PHYS 1441 – Section 004
Lecture #11

Wednesday, Mar. 3, 2004

Dr. Jaehoon Yu

- Work done by a constant force
- Kinetic Energy and Work-Energy theorem
- Power
- Potential Energies ➔ gravitational and elastic
- Conservative Forces

Today's homework is homework #7, due 1pm, next Wednesday!!

Announcements

- Homework site is down.
  - The due will be extended till 5pm tomorrow.
  - If the site does not work by noon tomorrow, I will extend again for another day
- Two worst homework will be dropped
- Exam Results
  - Class average: 56
  - Top score: 80.5
- Final grades will be assigned on a sliding scale
- Exam can be easily made up by other credits
- There will be a quiz on March 10
  - Sections 5.6 – 6.10

Newton's Law of Universal Gravitation

People have been very curious about the stars in the sky, making observations for a long time. But the data people collected have not been explained until Newton has discovered the law of gravitation.

Every object in the Universe attracts every other objects with a force that is directly ***proportional to the product of their masses*** *and* ***inversely proportional to the square of the distance*** *between them.*

How would you write this principle mathematically?

$$F_g \propto \frac{m_1 m_2}{r_{12}^2}$$

With G

$$F_g = G\frac{m_1 m_2}{r_{12}^2}$$

G is the universal gravitational constant, and its value is

$$G = 6.673 \times 10^{-11}$$

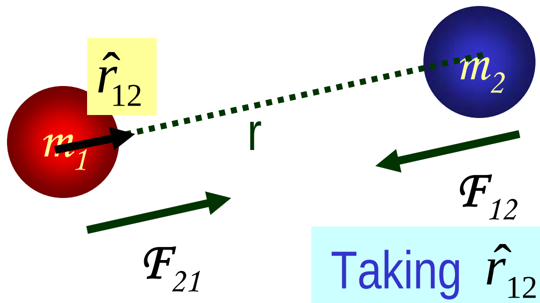
Unit? $N \cdot m^2 / kg^2$

This constant is not given by the theory but must be measured by experiment.

This form of forces is known as an inverse-square law, because the magnitude of the force is inversely proportional to the square of the distances between the objects.

More on Law of Universal Gravitation

Consider two particles exerting gravitational forces to each other.



Two objects exert gravitational force on each other following Newton's 3rd law.

Taking $\hat{r}_{12}$ as the unit vector, we can write the force m_2 experiences as

$$\vec{F}_{12} = -G\frac{m_1 m_2}{r^2}\hat{r}_{12}$$

What do you think the negative sign mean?

It means that the force exerted on the particle 2 by particle 1 is attractive force, pulling #2 toward #1.

Gravitational force is a field force: Forces act on object without physical contact between the objects at all times, independent of medium between them.

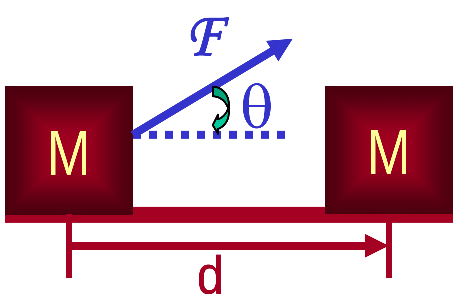
The gravitational force exerted by a finite size, spherically symmetric mass distribution on a particle outside the distribution is the same as if the entire mass of the distributions was concentrated at the center.

How do you think the gravitational force on the surface of the earth look?

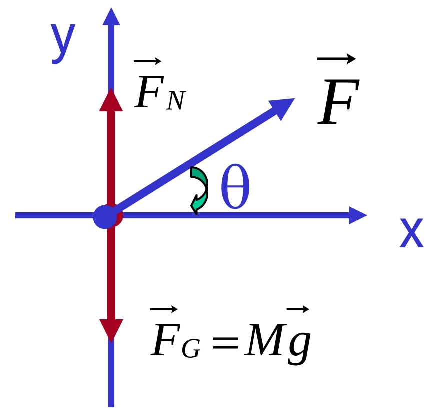
$$F_g = G\frac{M_E m}{R_E^2}$$

Work Done by a Constant Force

Work in physics is done only when the SUM of forces exerted on an object caused a motion to the object.



Free Body Diagram



Which force did the work? Force $\vec{F}$

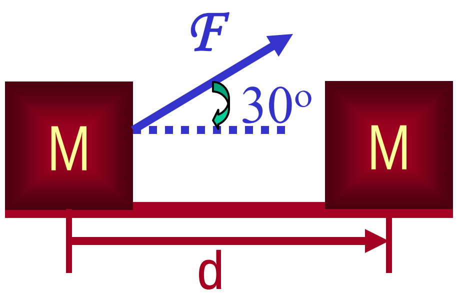
How much work did it do? $W = \left|\sum\left(\vec{F}\right)\right|\left|\vec{d}\right|\cos\theta$ Unit? $N \bullet m$ $= J$ (for Joule)

What does this mean? Physical work is done only by the component of the force along the movement of the object.

Work is energy transfer!!

Example of Work w/ Constant Force

A man cleaning a floor pulls a vacuum cleaner with a force of magnitude F=50.0N at an angle of 30.0º with East. Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced by 3.00m to East.



$$W = \left|\left(\sum \vec{F}\right)\right|\left|\vec{d}\right| \cos\theta$$

$$W = 50.0 \times 3.00 \times \cos 30^{o} = 130J$$

Does work depend on mass of the object being worked on?

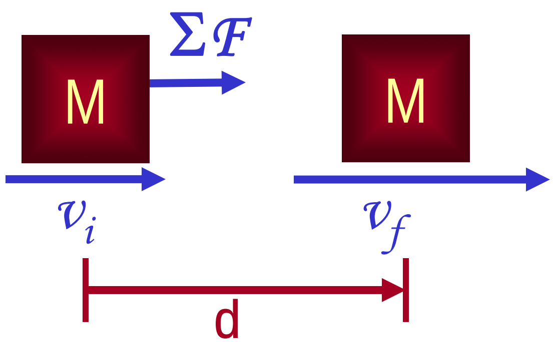
Yes!

Why don't I see the mass term in the work at all then?

It is reflected in the force. If the object has smaller mass, it would take less force to move it the same distance as the heavier object. So it would take less work. Which makes perfect sense, doesn't it?

Kinetic Energy and Work-Kinetic Energy Theorem

- Some problems are hard to solve using Newton's second law
  - If forces exerting on the object during the motion are so complicated
  - Relate the work done on the object by the net force to the change of the speed of the object



Suppose net force $\Sigma\mathcal{F}$ was exerted on an object for displacement d to increase its speed from v_i to v_f.

The work on the object by the net force $\Sigma\mathcal{F}$ is

$$W = Fd\cos\theta = (ma)d\cos 0 = (ma)d$$

Displacement $$d = \frac{1}{2}(v_f + v_i)t$$

Acceleration $$a = \frac{v_f - v_i}{t}$$

Work $$W = (ma)d = \left[m\left(\frac{v_f - v_i}{t}\right)\right]\frac{1}{2}(v_f + v_i)t = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

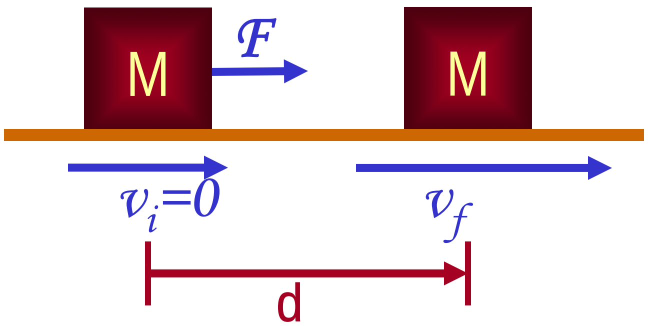
Kinetic Energy $$\boxed{KE = \frac{1}{2}mv^2}$$

Work $$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = KE_f - KE_i = \Delta KE$$

The work done by the net force caused change of object's kinetic energy.

Example for Work-KE Theorem

A 6.0kg block initially at rest is pulled to East along a horizontal, frictionless surface by a constant horizontal force of 12N. Find the speed of the block after it has moved 3.0m.



Work done by the force $\mathcal{F}$ is

$$W = \left|\vec{F}\right|\left|\vec{d}\right|\cos\theta = 12\times 3.0\cos 0 = 36(J)$$

From the work-kinetic energy theorem, we know

$$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Since initial speed is 0, the above equation becomes

$$W = \frac{1}{2}mv_f^2$$

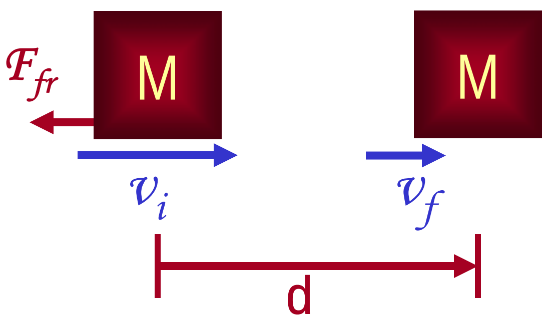
Solving the equation for v_f, we obtain

$$v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2\times 36}{6.0}} = 3.5m/s$$

Work and Energy Involving Kinetic Friction

- Some How do you think the work looks like if there is friction?
  - Why doesn't static friction matter?

Because it isn't there while the object is moving.



Friction force $\mathcal{F}_{fr}$ works on the object to slow down

The work on the object by the friction $\mathcal{F}_{fr}$ is

$$W_{fr} = F_{fr} d \cos(180) = -F_{fr} d \quad \Delta KE = -F_{fr} d$$

The final kinetic energy of an object, taking into account the initial kinetic energy, friction force and other sources of work, is

$$KE_f = KE_i + \sum W - F_{fr} d$$

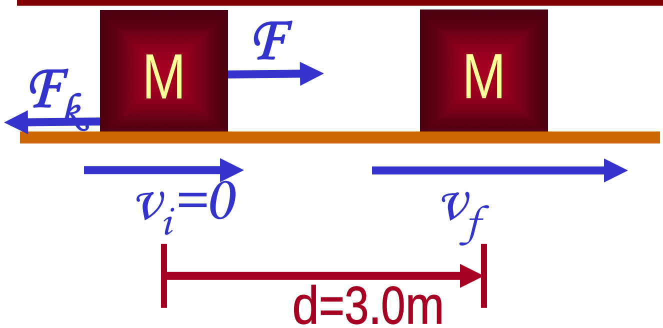
t=0, KE_i

Friction
Engine work

t=T, KE_f

Example of Work Under Friction

A 6.0kg block initially at rest is pulled to East along a horizontal surface with coefficient of kinetic friction μ_k=0.15 by a constant horizontal force of 12N. Find the speed of the block after it has moved 3.0m.



Work done by the force $\mathcal{F}$ is

$$W_F = \left|\vec{F}\right|\left|\vec{d}\right|\cos\theta = 12\times 3.0\cos 0 = 36\,(J)$$

Work done by friction $\mathcal{F}_k$ is

$$W_k = \left|\vec{F}_k\right|\left|\vec{d}\right|\cos\theta = \left|\mu_k mg\right|\left|\vec{d}\right|\cos\theta$$

$$= 0.15\times 6.0\times 9.8\times 3.0\cos 180 = -26\,(J)$$

Thus the total work is

$$W = W_F + W_k = 36 - 26 = 10(J)$$

Using work-kinetic energy theorem and the fact that initial speed is 0, we obtain

$$W = W_F + W_k = \frac{1}{2}mv_f^2$$

Solving the equation for v_f, we obtain

$$v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2\times 10}{6.0}} = 1.8\,m/s$$