PHYS 1441 – Section 002
Lecture #15

Monday, March 18, 2013
Dr. Jaehoon Yu

- Work with friction
- Potential Energy
- Gravitational Potential Energy
- Elastic Potential Energy
- Mechanical Energy Conservation

Announcements

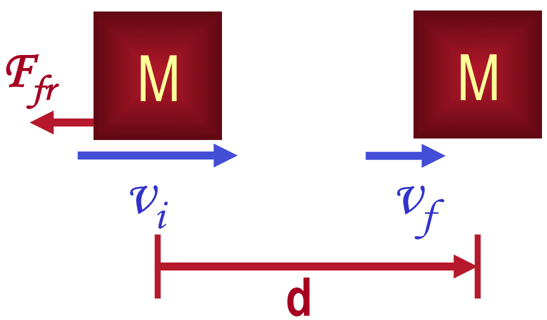
- Midterm comprehensive exam
  - This Wednesday, Mar. 20, in class in SH103
  - Covers CH1.1 through CH6.3 plus Appendices A1 – A8
  - Mixture of multiple choice and free response problems
  - No scantron is necessary
  - Bring your calculator but do NOT input formulae
  - A formula sheet is going to be provided
  - Bring a blank scrap sheet for working out problems
  - Must transfer your work and answers to the exam!!
  - GOOD LUCK!

Reminder: Special Project #4

- Using the fact that g=9.80m/s^2 on the Earth's surface, find the average density of the Earth.
  - Use the following information only but without computing the volume explicitly
    - The gravitational constant $G = 6.67 \times 10^{-11} N \cdot m^2 / kg^2$
    - The radius of the Earth $R_E = 6.37 \times 10^3 km$
- 20 point extra credit
- Due: Monday, Mar. 25
- You must show your OWN, detailed work to obtain any credit!!

Work and Energy Involving Kinetic Friction

- What do you think the work looks like if there is friction?
  - Static friction does not matter! Why? **It isn't there when the object is moving.**
  - Then which friction matters? **Kinetic Friction**



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

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

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

The negative sign means that the work is done on the friction!!

The final kinetic energy of an object, including its initial kinetic energy, work by the friction force and all other sources of work, is

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

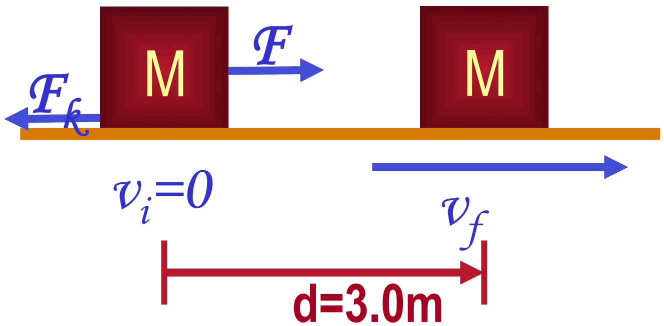
t=0, KE_i

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

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

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

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

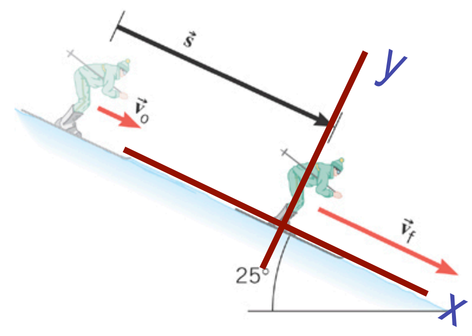
$$W = W_F + W_k = \frac{1}{2}mv_f^2$$

Solving the equation for v_f, we obtain

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

Ex. Downhill Skiing

A 58kg skier is coasting down a 25^o slope. A kinetic frictional force of magnitude f_k=70N opposes her motion. At the top of the slope, the skier's speed is v_0=3.6m/s. Ignoring air resistance, determine the speed v_f at the point that is displaced 57m downhill.



(a)

What are the forces in this motion?

Gravitational force: F_g Normal force: F_N Kinetic frictional force: f_k

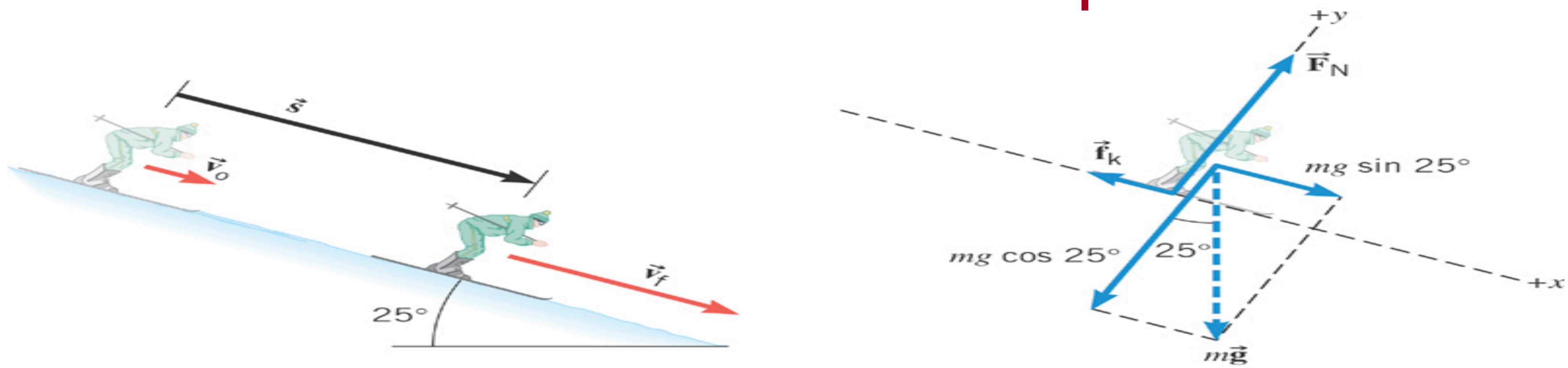
What are the X and Y component of the net force in this motion?

Y component $$\sum F_y = F_{gy} + F_N = -mg\cos 25^o + F_N = 0$$

From this we obtain $$F_N = mg\cos 25^o = 58 \cdot 9.8 \cdot \cos 25^o = 515N$$

What is the coefficient of kinetic friction? $$f_k = \mu_k F_N \Rightarrow \mu_k = \frac{f_k}{F_N} = \frac{70}{515} = 0.14$$

Ex. Now with the X component



(a) (b) Free-body diagram for the skier

X component $\sum F_x = F_{gx} - f_k = mg\sin 25^{o} - f_k = \left(58\cdot 9.8\cdot \sin 25^{o} - 70\right) = 170N = ma$

Total work by this force $W = \left(\sum F_x\right)\cdot s = \left(mg\sin 25^{\circ} - f_k\right)\cdot s = \left(58\cdot 9.8\cdot \sin 25^{o} - 70\right)\cdot 57 = 9700J$

From work-kinetic energy theorem $W = KE_f - KE_i \Rightarrow KE_f = \frac{1}{2}mv_f^2 = W + KE_i = W + \frac{1}{2}mv_0^2$

Solving for v_f $\quad v_f^2 = \frac{2W + mv_0^2}{m} \Rightarrow v_f = \sqrt{\frac{2W + mv_0^2}{m}} = \sqrt{\frac{2\cdot 9700 + 58\cdot (3.6)^2}{58}} = 19\, m/s$

What is her acceleration? $\sum F_x = ma \Rightarrow a = \frac{\sum F_x}{m} = \frac{170}{58} = 2.93\, m/s^2$

Potential Energy

Energy associated with a system of objects → Stored energy which has the potential or the possibility to work or to convert to kinetic energy

What does this mean?

In order to describe potential energy, U, a system must be defined.

The concept of potential energy can only be used under the special class of forces called the conservative force which results in the principle of ***conservation of mechanical energy.***

$$E_M \equiv KE_i + PE_i = KE_f + PE_f$$

What are other forms of energies in the universe?

Mechanical Energy *Chemical Energy* *Biological Energy*

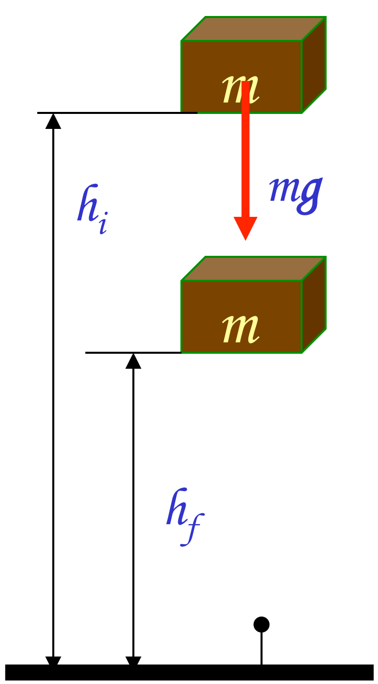
Electromagnetic Energy *Nuclear Energy* *Thermal Energy*

These different types of energies are stored in the universe in many different forms!!!

If one takes into account ALL forms of energy, the total energy in the entire universe is conserved. It just transforms from one form to another.

Gravitational Potential Energy

This potential energy is given to an object by the gravitational field in the system of Earth by virtue of the object's height from an arbitrary zero level



*When an object is falling, the gravitational force, M**g**, performs the work on the object, increasing the object's kinetic energy. So the potential energy of an object at a height y, **the potential to do work**, is expressed as*

$$PE = \vec{F}_g \cdot \vec{y} = \left|\vec{F}_g\right|\left|\vec{y}\right|\cos\theta = \left|\vec{F}_g\right|\left|\vec{y}\right| = mgh \qquad PE \equiv mgh$$

The work done on the object by the gravitational force as the brick drops from y_i to y_f is:

$$W_g = PE_i - PE_f$$
$$= mgh_i - mgh_f = -\Delta PE$$

$$\left(\text{since } \Delta PE = PE_f - PE_i\right)$$

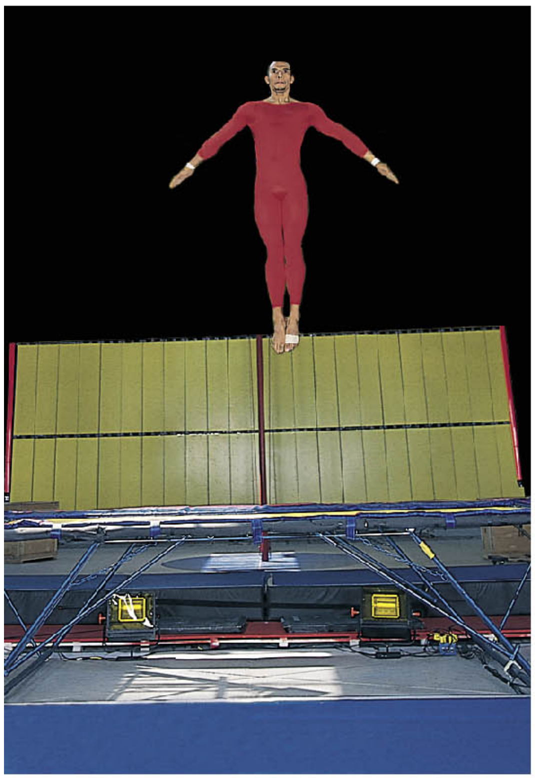
What does this mean?

Work by the gravitational force as the brick drops from y_i to y_f is the negative change of the system's potential energy

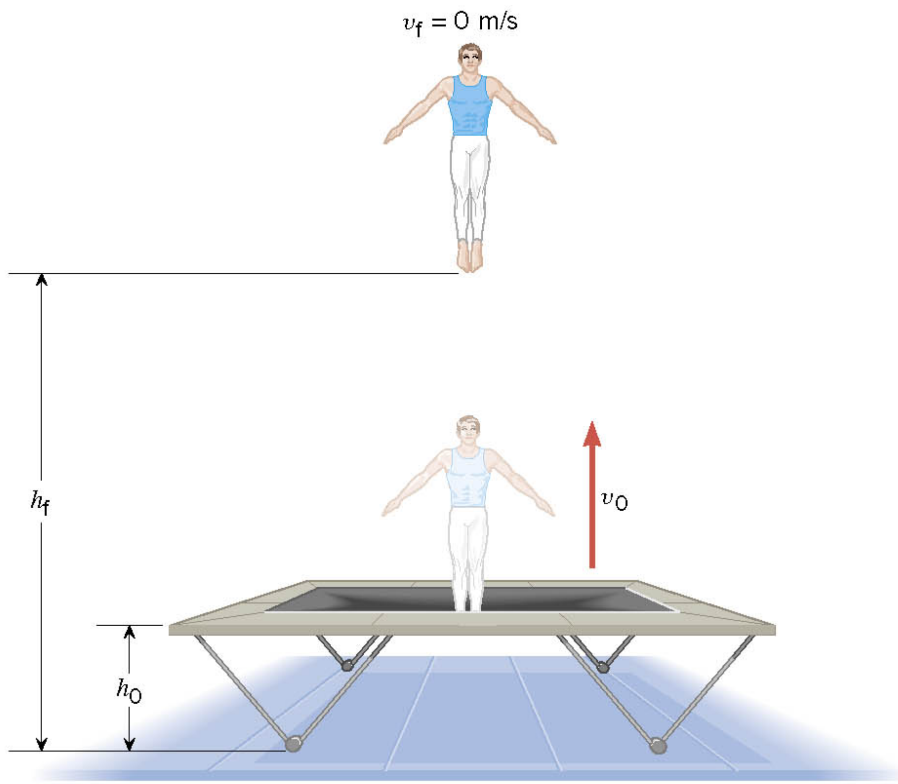
➔ Potential energy was spent in order for the gravitational force to increase the brick's kinetic energy.

Ex. A Gymnast on a Trampoline

A gymnast leaves the trampoline at an initial height of 1.20 m and reaches a maximum height of 4.80 m before falling back down. What was the initial speed of the gymnast?



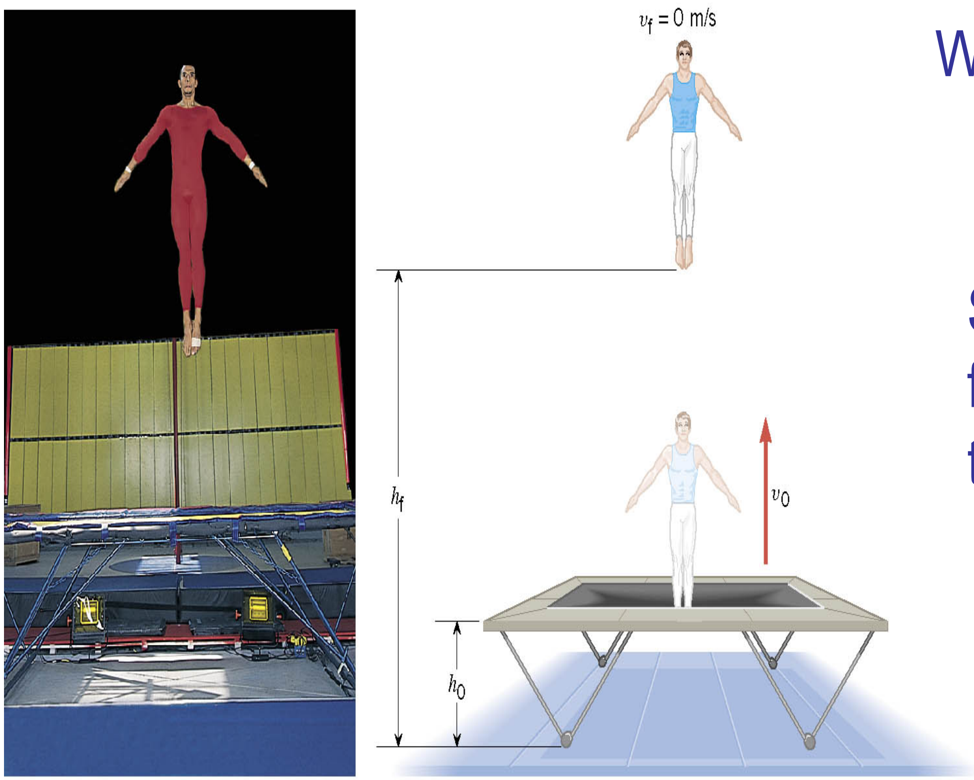
(a)



(b)

Ex. Continued

From the work-kinetic energy theorem $\mathrm{W} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_o^2$



(a) (b)

Work done by the gravitational force

$$W_{\text{gravity}} = mg\left(h_o - h_f\right)$$

Since at the maximum height, the final speed is 0. Using work-KE theorem, we obtain

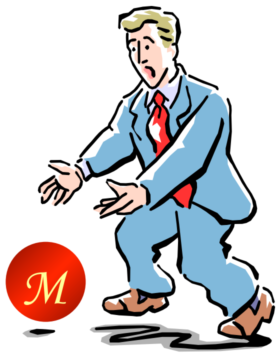
$$\cancel{m}g\left(h_o - h_f\right) = -\tfrac{1}{2}\cancel{m}v_o^2$$

$$v_o = \sqrt{-2g\left(h_o - h_f\right)}$$

$$\therefore v_o = \sqrt{-2\left(9.80\,\mathrm{m/s^2}\right)\left(1.20\ \mathrm{m} - 4.80\ \mathrm{m}\right)} = 8.40\,\mathrm{m/s}$$

Example for Potential Energy

A bowler drops bowling ball of mass 7kg on his toe. Choosing the floor level as y=0, estimate the total work done on the ball by the gravitational force as the ball falls on the toe.



Let's assume the top of the toe is 0.03m from the floor and the hand was 0.5m above the floor.

$$U_i = mgy_i = 7\times 9.8\times 0.5 = 34.3J \quad U_f = mgy_f = 7\times 9.8\times 0.03 = 2.06J$$

$$W_g = -\Delta U = -\left(U_f - U_i\right) = 32.24J \cong 30J$$

b) Perform the same calculation using the top of the bowler's head as the origin.

What has to change?

First we must re-compute the positions of the ball in his hand and on his toe.

Assuming the bowler's height is 1.8m, the ball's original position is –1.3m, and the toe is at –1.77m.

$$U_i = mgy_i = 7\times 9.8\times(-1.3) = -89.2J \quad U_f = mgy_f = 7\times 9.8\times(-1.77) = -121.4J$$

$$W_g = -\Delta U = -\left(U_f - U_i\right) = 32.2J \cong 30J$$