PHYS 1441 – Section 001
Lecture #11

Tuesday, June 30, 2015

Dr. Jaehoon Yu

- Newton's Law of Universal Gravitation
- Weightlessness
- Work done by a constant force
- Multiplication of Vectors
- Work-Kinetic Energy Theorem

Today's homework is homework #7, due 11pm, Friday, July 3!!

Announcements

- Term exam #2
  - In class this Thursday, July 2
  - Non-comprehensive exam
  - Covers CH 4.6 to what we finish tomorrow Wednesday, July 1
  - Bring your calculator but DO NOT input formula into it!
    - Your phones or portable computers are NOT allowed as a replacement!
  - You can prepare a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam → no solutions, derivations, word definitions or key methods for solutions
    - No additional formulae or values of constants will be provided!
- I am in physics chair's office (SH108) through the remainder of this course

Reminder: Special Project #4

1. Compute the gravitational force between two protons separates by 1m. (10 points)
2. Compute the electric force between the two protons separated by 1m. (10 points)
3. Express the electric force in #2 above in terms of the gravitational force in #1. (5 points)

- You must look up the mass of the proton, the electrical charge of the proton in coulombs, electrical force constant, electric force formula, etc, and clearly write them on your project report
- You MUST have your own, independent answers to the above three questions even if you worked together with others. All those who share the answers will get 0 credit if copied.
- Due for the submission is Monday, July 6!

Period of a Satellite in an Orbit

Speed of the satellite $$v = \sqrt{\frac{GM_E}{r}} = \frac{2\pi r}{T}$$

$$\frac{GM_E}{r} = \left(\frac{2\pi r}{T}\right)^2$$

Square either side and solve for T2

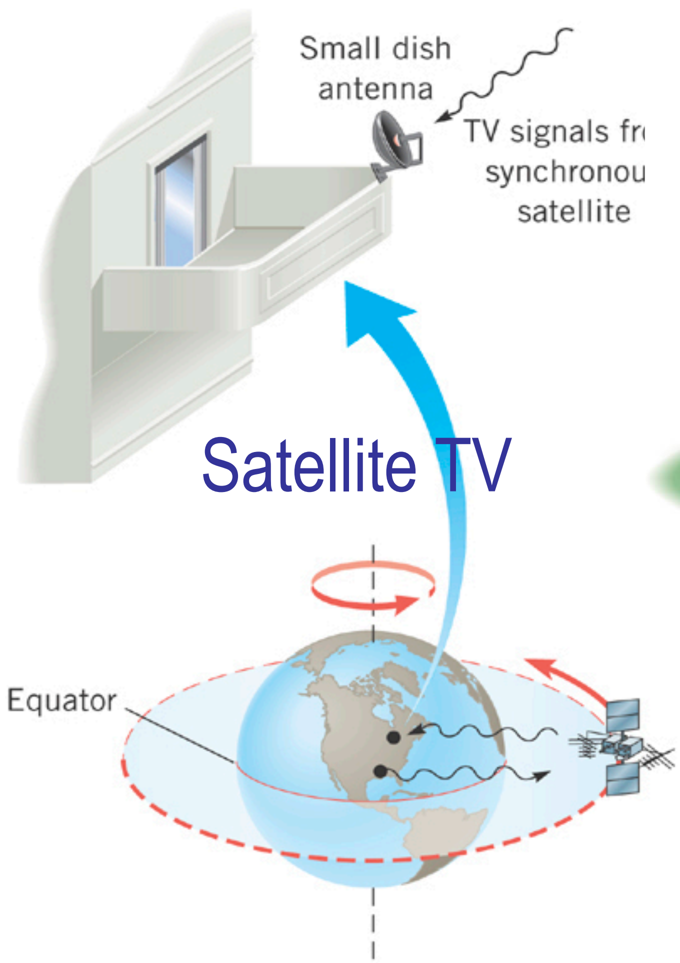
$$T^2 = \frac{(2\pi)^2 r^3}{GM_E}$$

Period of a satellite $$T = \frac{2\pi r^{3/2}}{\sqrt{GM_E}}$$

Kepler's 3rd Law

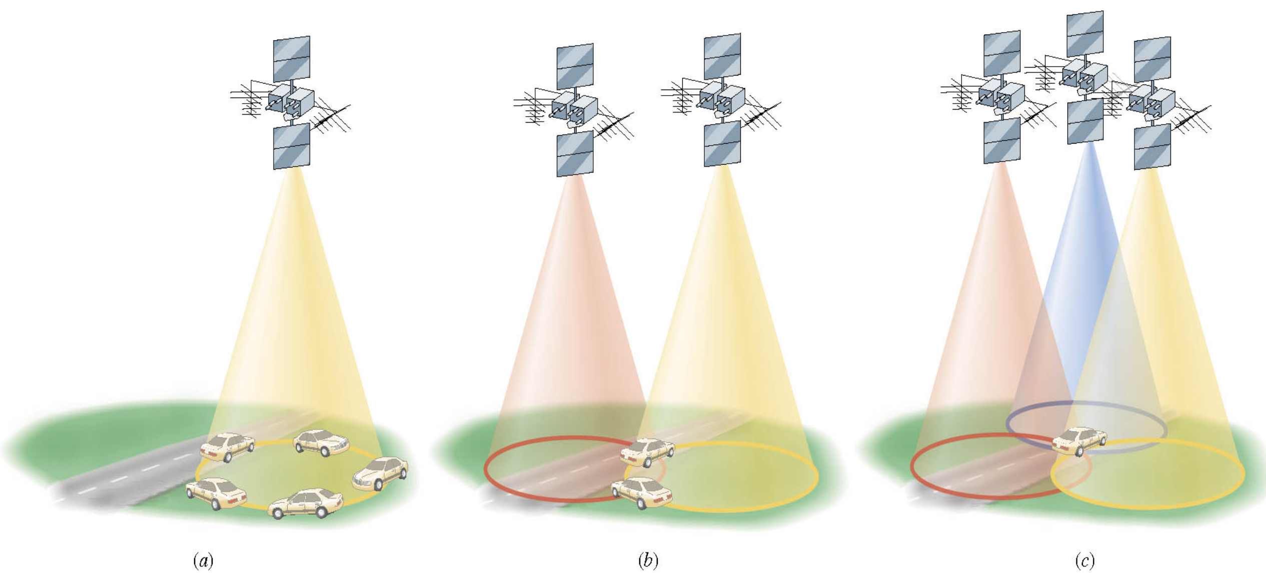
This is applicable to any satellite or even for planets and moons.

Geo-synchronous Satellites



Satellite TV

Global Positioning System (GPS)

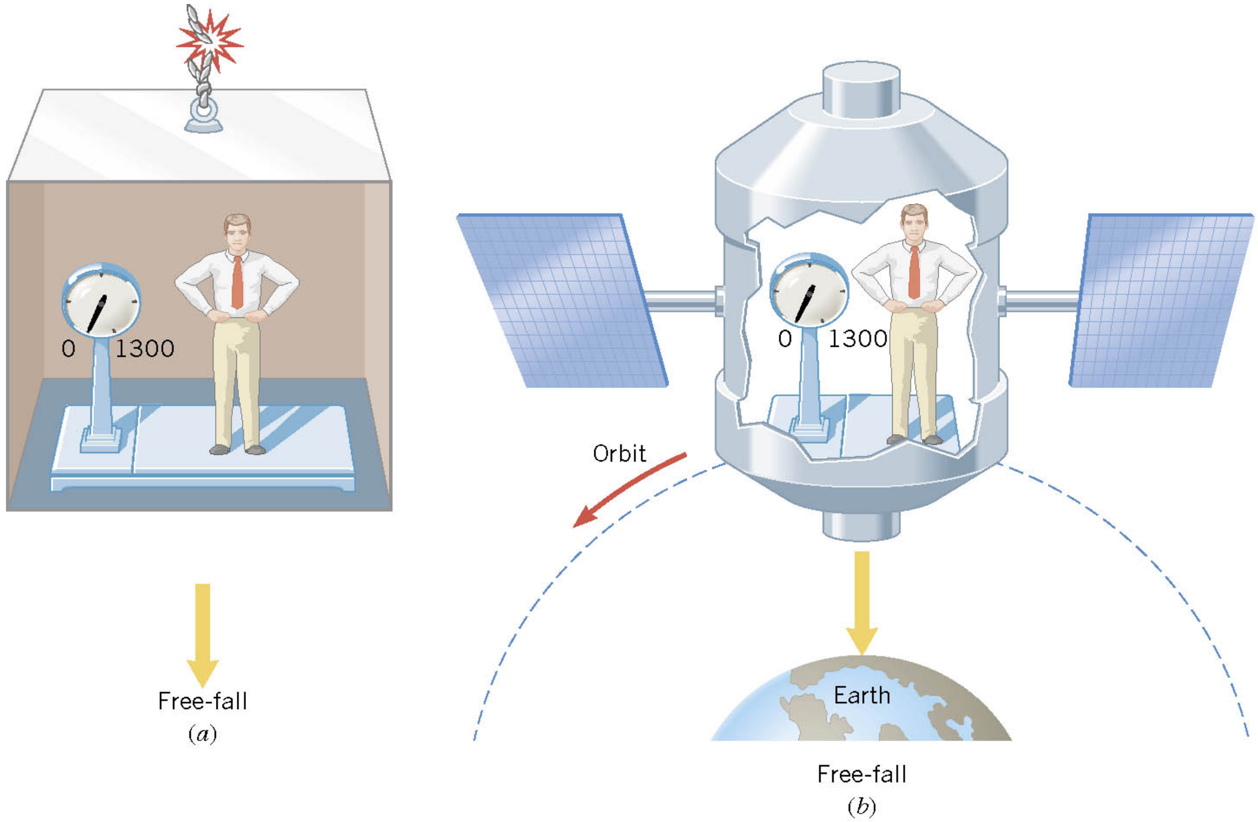


What period should these satellites have?

The same as the earth!! 24 hours

What altitude must they be?

Ex. Apparent Weightlessness and Free Fall



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In each case, what is the weight recorded by the scale?

Ex. Artificial Gravity

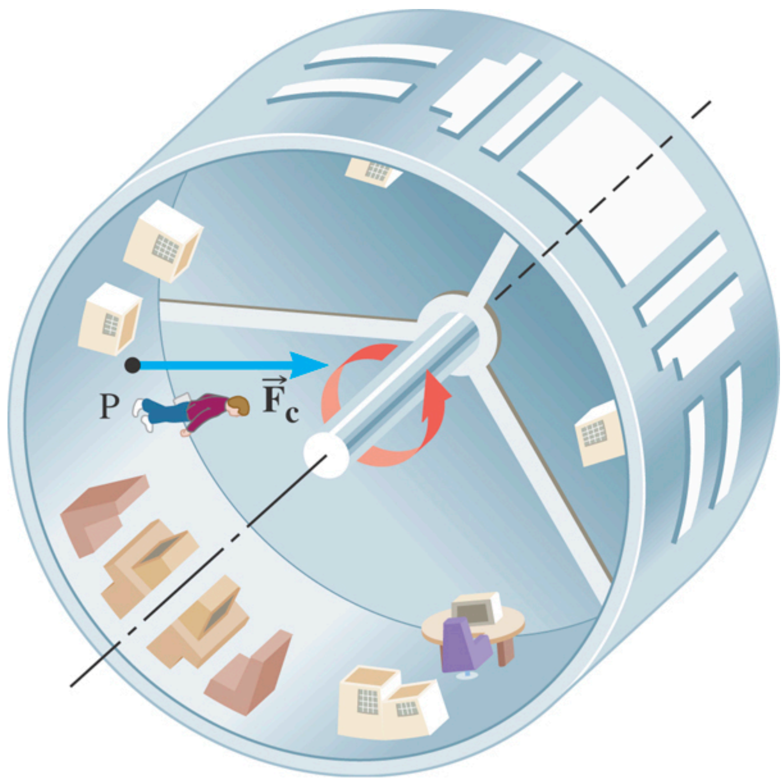
At what speed must the surface of the space station move so that the astronaut experiences a push on his feet equal to his weight on earth? The radius is 1700 m.

$$F_c = m\frac{v^2}{r} = mg$$

$$v = \sqrt{rg}$$

$$= \sqrt{(1700\ \mathrm{m})(9.80\,\mathrm{m/s^2})}$$

$$= 130\,m/s$$



Motion in Resistive Forces

Medium can exert resistive forces on an object moving through it due to viscosity or other types frictional properties of the medium.

Some examples?

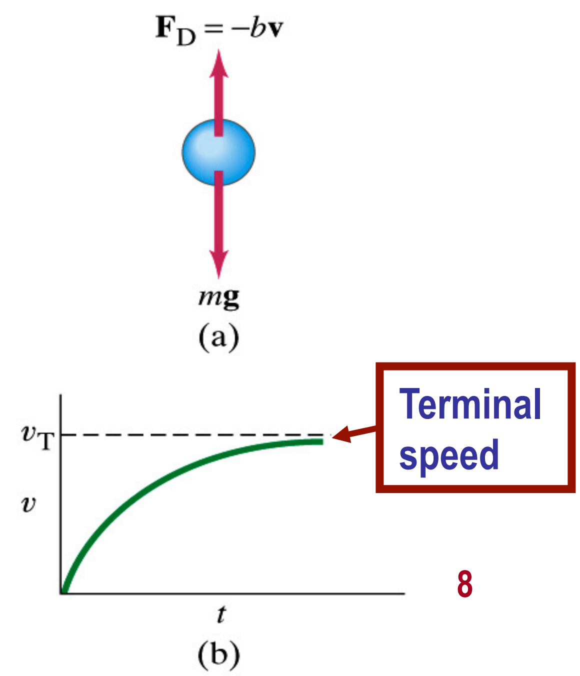
Air resistance, viscous force of liquid, etc

These forces are exerted on moving objects in opposite direction of the movement.

These forces are proportional to such factors as speed. They almost always increase with increasing speed.

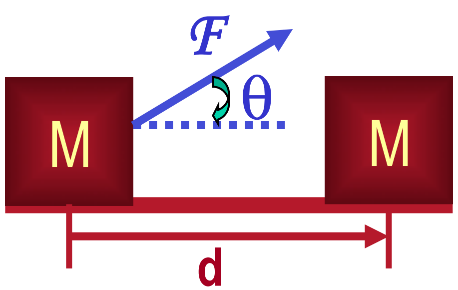
Two different cases of proportionality:

1. Forces linearly proportional to speed: Slowly moving or very small objects
2. Forces proportional to square of speed: Large objects w/ reasonable speed

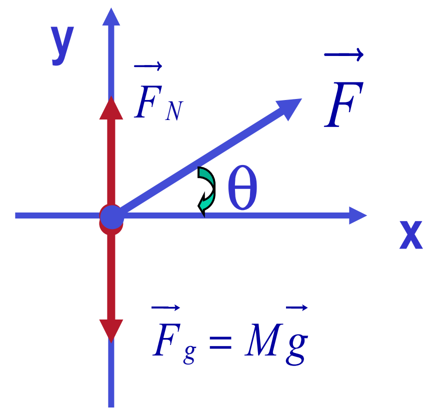


Work Done by a Constant Force

A meaningful work in physics is done only when the net forces exerted on an object changes the energy of the object.



Free Body Diagram



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

What kind? Scalar

How much work did it do? $W = \left(\sum \vec{F}\right) \cdot \vec{d} = Fd\cos\theta$

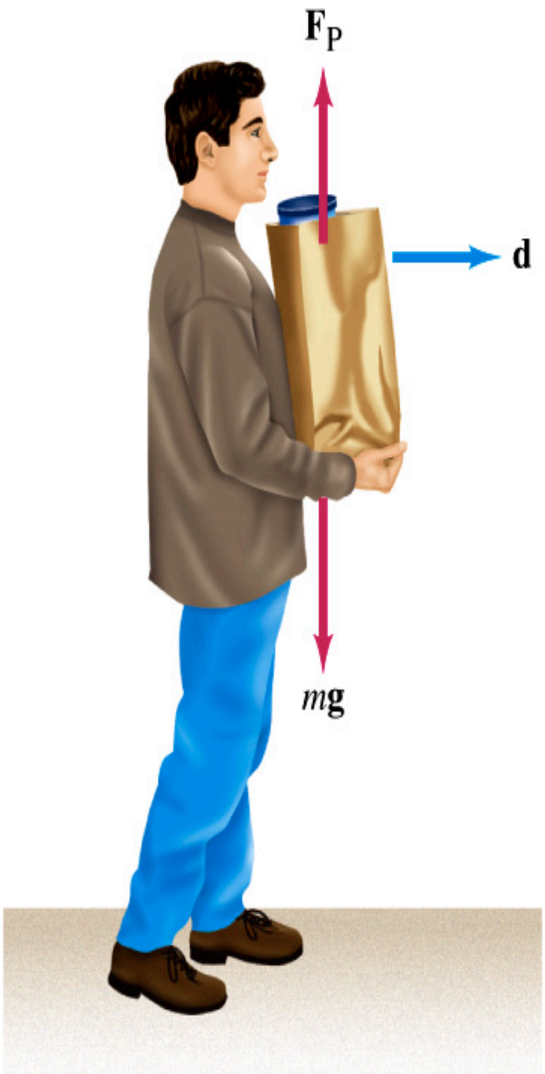
Unit? $N \cdot m$
$= J$ (for Joule)

What does this mean?

Physically meaningful work is done only by the component of the force along the movement of the object.

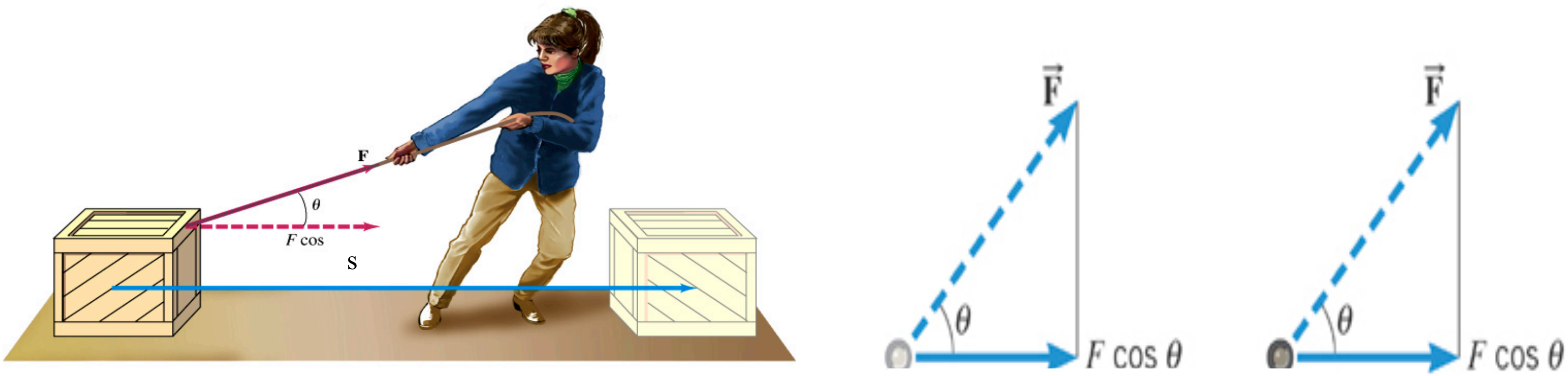
Work is an energy transfer!!

Let's think about the meaning of work!



- A person is holding a grocery bag and walking at a constant velocity.
- Are his hands doing any work ON the bag?
  - No
  - Why not?
  - Because the force hands exert on the bag, F_p, is perpendicular to the displacement!!
  - This means that hands are not adding any energy to the bag.
- So what does this mean?
  - In order for a force to perform any meaningful work, the energy of the object the force exerts on must change due to that force!!
- What happened to the person?
  - He spends his energy just to keep the bag up but did not perform any work on the bag.

Work done by a constant force



(a) (b)

$$W = \vec{F} \cdot \vec{s}$$
$$= \left(F \cos\theta\right) s$$

$$\cos 0^{o} = 1$$
$$\cos 90^{o} = 0$$
$$\cos 180^{o} = -1$$

Scalar Product of Two Vectors

- Product of magnitude of the two vectors and the cosine of the angle between them $\vec{A}\cdot\vec{B} \equiv \left|\vec{A}\right|\left|\vec{B}\right|\cos\theta$
- Operation is commutative $\vec{A}\cdot\vec{B} = \left|\vec{A}\right|\left|\vec{B}\right|\cos\theta = \left|\vec{B}\right|\left|\vec{A}\right|\cos\theta = \vec{B}\cdot\vec{A}$
- Operation follows the distribution law of multiplication $\vec{A}\cdot\left(\vec{B}+\vec{C}\right) = \vec{A}\cdot\vec{B} + \vec{A}\cdot\vec{C}$
- Scalar products of Unit Vectors $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1 \quad \hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$
- How does scalar product look in terms of components?

$$\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k} \qquad \vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$$

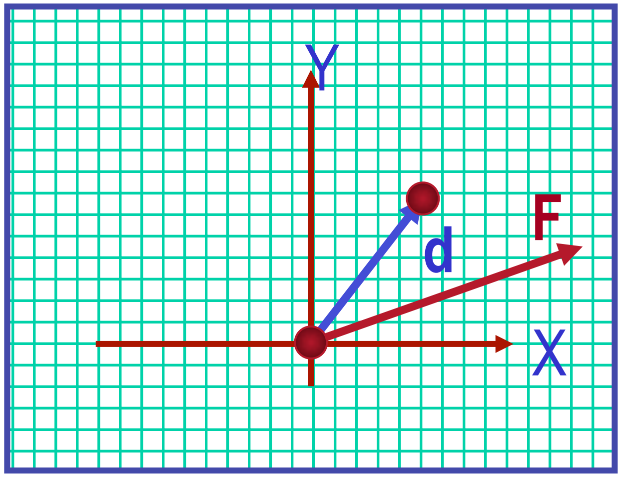
$$\vec{A}\cdot\vec{B} = \left(A_x\hat{i} + A_y\hat{j} + A_z\hat{k}\right)\cdot\left(B_x\hat{i} + B_y\hat{j} + B_z\hat{k}\right) = \left(A_xB_x\,\hat{i}\cdot\hat{i} + A_yB_y\,\hat{j}\cdot\hat{j} + A_zB_z\,\hat{k}\cdot\hat{k}\right) + cross\ terms$$

cross terms =0

$$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$$

Example of Work by the Scalar Product

A particle moving on the xy plane undergoes a displacement **d**=(2.0**i**+3.0**j**)m as a constant force **F**=(5.0**i**+2.0**j**) N acts on the particle.



a) Calculate the magnitude of the displacement and that of the force.

$$\left|\vec{d}\right| = \sqrt{d_x^2 + d_y^2} = \sqrt{(2.0)^2 + (3.0)^2} = 3.6m$$

$$\left|\vec{F}\right| = \sqrt{F_x^2 + F_y^2} = \sqrt{(5.0)^2 + (2.0)^2} = 5.4N$$

b) Calculate the work done by the force F.

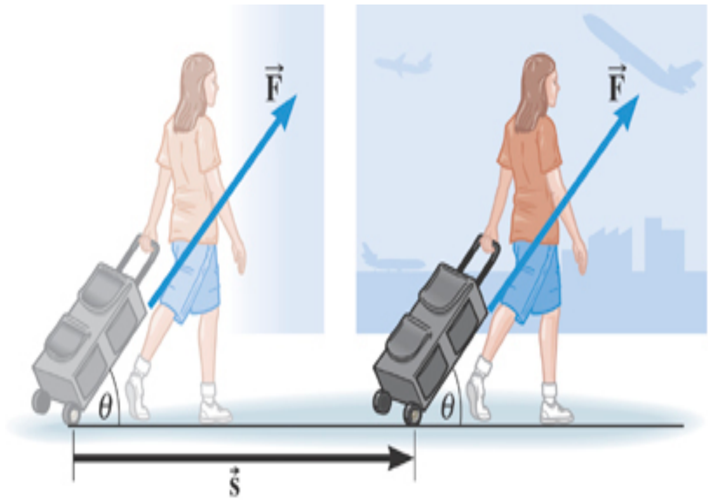
$$W = \vec{F} \cdot \vec{d} = \left(2.0\hat{i} + 3.0\hat{j}\right) \cdot \left(5.0\hat{i} + 2.0\hat{j}\right) = 2.0 \times 5.0\,\hat{i} \cdot \hat{i} + 3.0 \times 2.0\,\hat{j} \cdot \hat{j} = 10 + 6 = 16(J)$$

Can you do this using the magnitudes and the angle between **d** and **F**?

$$W = \vec{F} \cdot \vec{d} = \left|\vec{F}\right|\left|\vec{d}\right|\cos\theta$$

Ex. Pulling A Suitcase-on-Wheel

Find the work done by a 45.0N force in pulling the suitcase in the figure at an angle 50.0º for a distance s=75.0m.



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

$$= \left(45.0 \cdot \cos 50^{\circ}\right) \cdot 75.0 = 2170J$$

Does work done by the same force depend on mass of the object being worked on?

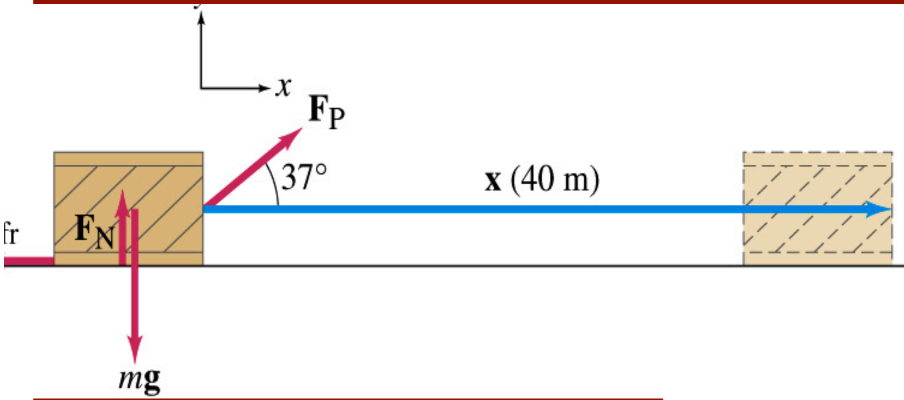
NO

What does the mass do then?

Since the force is the same, the amount of the work done by the force on the object through the same displacement is the same. The only difference by the mass is the time needed to reach the same displacement.

Ex. 6.1 Work done on a crate

A person pulls a 50kg crate 40m along a horizontal floor by a constant force F_p=100N, which acts at a 37° angle as shown in the figure. The floor is rough and exerts a friction force F_{fr}=50N. Determine (a) the work done by each force and (b) the net work done on the crate.



What are the forces exerting on the crate?

F_p | F_{fr} | F_G=-mg | F_N=+mg

Which force performs the work on the crate?

F_p | F_{fr}

Work done on the crate by F_G

$$W_G = \vec{F}_G \cdot \vec{x} = -mg\cos\left(-90^\circ\right)\cdot\left|\vec{x}\right| = 0J$$

Work done on the crate by F_N

$$W_N = \vec{F}_N \cdot \vec{x} = mg\cos 90^\circ \cdot \left|\vec{x}\right| = 100\cdot\cos 90^\circ \cdot 40 = 0J$$

Work done on the crate by F_p:

$$W_p = \vec{F}_p \cdot \vec{x} = \left|\vec{F}_p\right|\cos 37^\circ \cdot \left|\vec{x}\right| = 100\cdot\cos 37^\circ \cdot 40 = 3200J$$

Work done on the crate by F_{fr}:

$$W_{fr} = \vec{F}_{fr} \cdot \vec{x} = \left|\vec{F}_{fr}\right|\cos 180^\circ \cdot \left|\vec{x}\right| = 50\cdot\cos 180^\circ \cdot 40 = -2000J$$

So the net work on the crate

$$W_{net} = W_N + W_G + W_p + W_{fr} = 0 + 0 + 3200 - 2000 = 1200(J)$$

This is the same as

$$W_{net} = \sum\left(\vec{F}\cdot\vec{x}\right) = \left(\vec{F}_N\cdot\vec{x} + \vec{F}_G\cdot\vec{x} + \vec{F}_p\cdot\vec{x} + \vec{F}_{fr}\cdot\vec{x}\right)$$