Physics 121.
Lecture 09.

Navy Lt. Ron Candiloro's F/A-18 Hornet creates a shock wave as he breaks the sound barrier July 7. The shock wave is visible as a large cloud of condensation formed by the cooling of the air. A smaller shock wave can be seen forming on top of the canopy. It is possible for a skilled pilot to work the plane's throttle to move the shock wave forward or aft.

F/A-18 Hornet breaking the sound barrier. Photo by John Gay

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Physics 121.
Lecture 09.

- Topics:
  - Course announcements
  - Quiz
  - Work and Energy:
    - Definition
    - Work done by a Variable Force
    - Kinetic Energy

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Physics 121.
Course announcements.

- Homework set # 4 is due on February 28 at 8.30 am.
  - Note there is written component on this assignment.
  - The most effective way to work on the assignments is to tackle 1 or 2 problems a day.
- On Monday 2/23, you will receive an email with your results of Exam # 1.
- Exam # 1 will be returned during workshops next week.
  - The minimum you should do is to compare the scores shown on your blue booklet with the scores in my email.
  - You should of course compare your solutions with the posted solutions.
  - If you are not happy with the grading of the exam, you need to write down why you feel you deserve more points on a particular question, attach the note to your blue booklet(s), and return them to me before the end of lecture 13 (March 5).

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Some observations on Exam # 1. 13% did not (correctly) enter the ID #.

- Scantron:
  - 14 students did not enter their student ID on the scantron form.
  - 9 students did not enter their student ID correctly.
  - Students entered their solutions incorrectly.
  - Answers not on front.
- This time, I added missing student IDs were possible, but **there will be no adjustments for Exam # 2.** But there were forms where I could not even read the name to determine the student ID.
- Note: your ID has 8 numbers.

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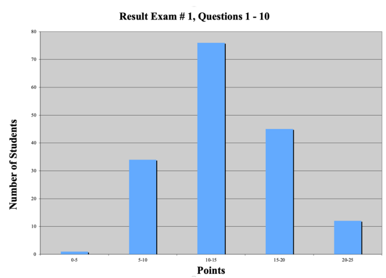
First results Exam # 1. Q1 – Q10.



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Quiz.

- Let's practice what we learned (and read).

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Work and energy.

- In the next few weeks, we will not discuss any new physics, but develop tools to simplify how we use our understanding of the force laws and the laws of motion to understand and/or predict the outcome of experiments.
- We will start with defining the concept of work and the concept of energy.

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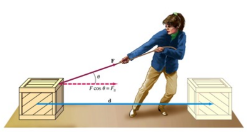
Work and energy.

- When a force F is applied to an object, it may produce a displacement d.
- The work W done by the force F is defined as

$$W = \vec{F} \cdot \vec{d} = Fd\cos\theta$$

where θ is the angle between the force $\vec{F}$ and the displacement $\vec{d}$.



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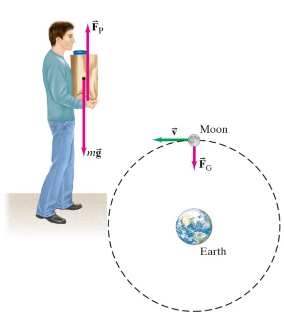
Work.

- Consider the definition of W:

$$W = \vec{F} \cdot \vec{d} = Fd\cos\theta$$

- The work done by the force $\vec{F}$ is zero if:
  - $d = 0$ m (no displacement)
  - $\theta = 90°$ (force perpendicular to the displacement).



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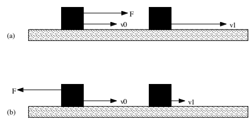
Work.
Positive, zero, or negative.

- Work done by a force can be positive, zero, or negative, depending on the angle θ :
  - When $0° \leq \theta < 90°$ (scalar product between F and d is larger than 0) the speed of the object will increase.
  - When $\theta = 90°$ (scalar product between F and d is 0) the speed of the object will not change.
  - When $90° < \theta \leq 180°$ (scalar product between F and d is smaller than 0) the speed of the object will decrease.



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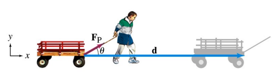
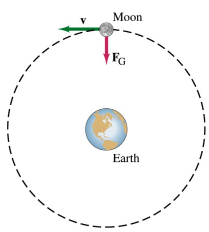
Work: units.

- The unit of work is the Joule (abbreviated J).
- Per definition, 1 J = 1 Nm = 1 kg m^2/s^2.
- There are many important examples of forces that do not do any work. For example, the gravitational force between the earth and the moon does not do any work! Note: in this case, the speed of the moon does not change.





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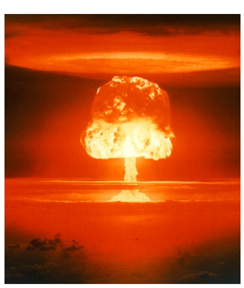
Power.

- In many cases, the work done by a tool is less important than the the rate with which the work can be done.
- For example, explosive devices get their properties from being able to do a lot of work over a very short period in time. The same amount of work done over a longer period of time might not lead to destruction.



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Power: units.

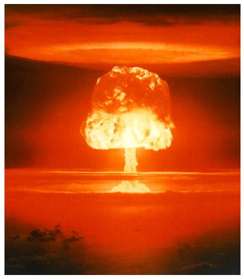
- Power of defined as work per unit time:

$$P = \frac{dW}{dt}$$

- The unit of power is the Watt, abbreviated by a W.
- Per definition:

$$1\ \text{W} = 1\ \text{J/s} = 1\ \text{kg m}^2/\text{s}^3$$

- The power you consume at home is often expressed in terms of kWh, which is the use of 1 kW of power for 1 hour.

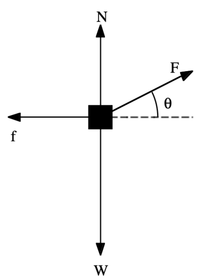


Work. An example problem.

A block of mass M is drawn at constant speed a distance d along a horizontal floor by a rope exerting a force $\vec{F}$ at and angle θ above the horizontal. Compute

(a) the work done by the rope on the block.

(b) the coefficient of kinetic friction between block and floor.



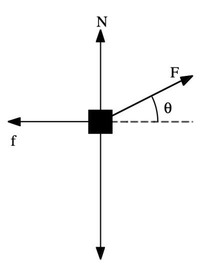
Work. An example problem: step 1.

- The requirement that the object moved with constant speed tells us that the net force acting on it must be 0 N.
- Thus, the net forces in the x and y directions:

$$\sum F_x = F\cos\theta - f_k$$

$$\sum F_y = N + F\cos\theta - Mg$$

…….. must be zero.



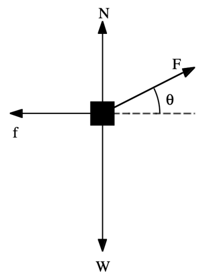
Work.
An example problem: step 2.

- The normal force N can be determined based on the fact that the net force in the vertical direction must be zero:

$$N = Mg - F\cos\theta$$

- Based on the now know normal force N we can determine the frictional force f (kinetic friction since the block is moving):

$$f_k = \mu_k N = \mu_k(Mg - F\cos\theta)$$



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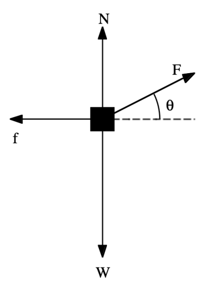
Work.
An example problem: step 3.

- The friction force is also directly related to the applied force F by considering net force in the horizontal direction, which has to be zero.
- This requires that

$$f_k = F\cos\theta$$

- The work done by the friction force is negative (since direction and displacement are in opposite directions):

$$W_f = \vec{f}_k \cdot \vec{d} = -f_k d = Fd\cos\theta$$



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Work.
An example problem: step 4.

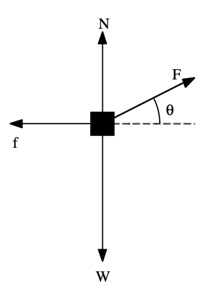
- The work done by the applied force F is equal to

$$W_F = \vec{F} \cdot \vec{d} = Fd\cos\theta$$

- The net work done (due to the applied force and the friction force) is equal to zero.

$$W_{total} = \sum W_i = W_F + W_f = 0$$

- This is not really a surprise …. since the net force on the object is equal to zero.



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4 Minute 9 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 4 minute 9 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWork problem.
  - Go asleep, as long as you wake up in 4 minutes and 9 seconds.

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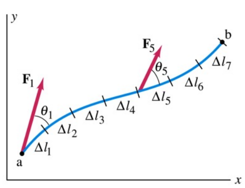
Work done by a varying force.

- In most realistic cases, we need to consider the work done when the force is varying (both in magnitude and direction) as function of time and/or position.

- In this case, we can still use the same approach as we just discussed by breaking up the motion into small intervals such that the path is linear and the force is constant during the intervals considered.



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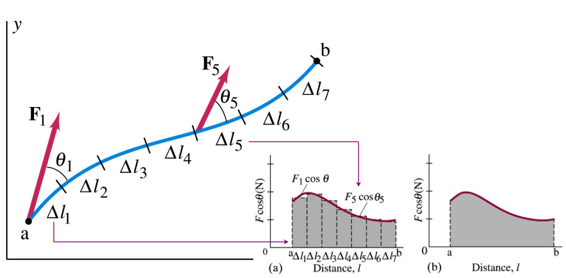
Work done by a varying force.



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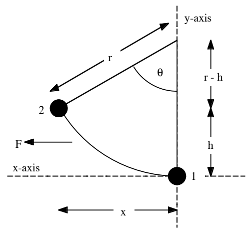
Calculating work. Do less work by thinking before starting!

- Consider the work done by all forces acting on the pendulum when it moves from position 1 to position 2.
- During this motion, the angle between the path and the net force changes. What am I to do?

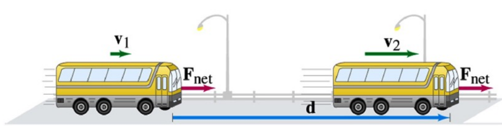


$$W = \vec{F}_t \cdot \vec{d} = (\vec{F} + \vec{F}_g) \cdot \vec{d}$$

$$\vec{F} \cdot \vec{d} = Fx = F\sqrt{h(2r - h)}$$

$$\vec{F}_g \cdot \vec{d} = -F_g h = -mgh$$

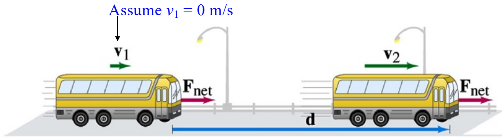
The work-energy theorem.



- We have already seen that there is a connection between the work done by a force and the change in the speed of the object:
  - If W > 0 J: speed increases
  - If W = 0 J: speed remains constant
  - If W < 0 J: speed decreases

The work-energy theorem.

Assume $v_1 = 0$ m/s



- Consider the bus starting from rest (v_1 = 0 m/s) and having an acceleration $a = F/m$ (assume $v << c$). The velocity at a later time t will be equal to

$$v(t) = v_0 + at = at$$

- This relation can be used to determine the time t at which the bus reaches a certain velocity v_2:

$$t = \frac{v_2}{a}$$

The work-energy theorem.

Assume v_1 = 0 m/s

- The displacement at this time t is equal to

$$d = x\left(t = \frac{v_2}{a}\right) = x_0 + v_0 t + \frac{1}{2}at^2 = \frac{1}{2}a\left(\frac{v_2}{a}\right)^2 = \frac{1}{2}\frac{v_2^2}{a}$$

- The work done by the force F during this period is equal to

$$W = \vec{F} \cdot \vec{d} = ma\left(\frac{1}{2}\frac{v_2^2}{a}\right) = \boxed{\frac{1}{2}mv_2^2} \leftarrow \text{Kinetic energy K}$$

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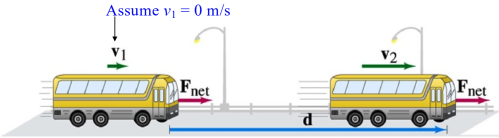
The work-energy theorem.

Assume v_1 = 0 m/s



- Assuming that there is no heat flow in or out of the bus, we conclude that for low velocities (non-relativistic velocities):

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

- In the case of the bus: $F_{net}d = \Delta E = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

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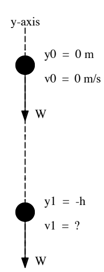
The energy principle. Example 1.

- An object with mass m is at rest at time t = 0 s. It falls under the influence of gravity through a distance h. What is its velocity at that point?



- Solution:
  - Assume $Q = 0$.
  - Work done by the gravitational force = mgh.
  - Change in energy = change in kinetic energy = $(1/2)mv_1^2$.
  - The Energy Principle ($Q = 0$): $mgh = (1/2)mv_1^2$ or $v_1 = \sqrt{(2gh)}$

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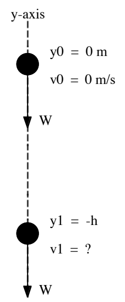
The work-energy theorem. An application.

- An object with mass m is at rest at time $t = 0$ s. It falls under the influence of gravity through a distance h. What is its velocity at that point?
- Solution:
  - Initial kinetic energy: $K_i = 0$ J.
  - Work done by the gravitational force: $W = mgh$.
  - Change in kinetic energy: $K_f - K_i = \frac{1}{2}mv_1^2$.
  - Work-Energy theorem:

$$mgh = \frac{1}{2}mv_1^2$$

or

$$v_1 = \sqrt{2gh}$$



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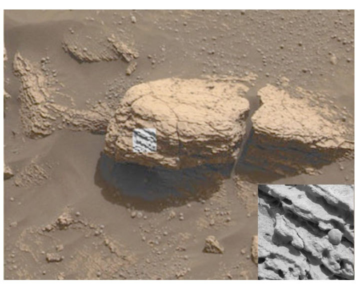
That’s all! Next week: conservation of energy.



Unusual Spherules on Mars
Credit: Mars Exploration Rover Mission, JPL, USGS, NASA

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