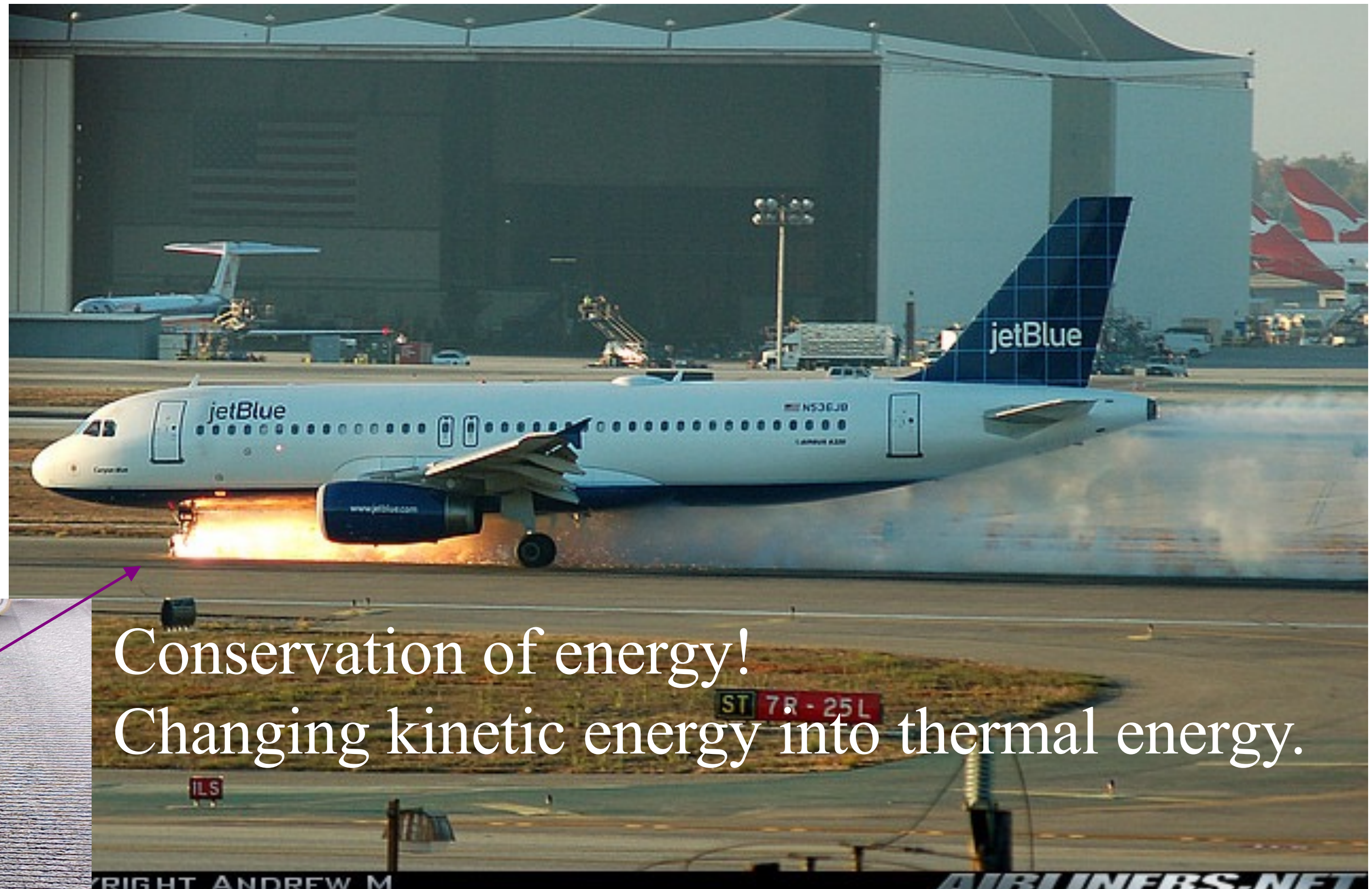
Physics 121.
Lecture 10.



Conservation of energy!
Changing kinetic energy into thermal energy.

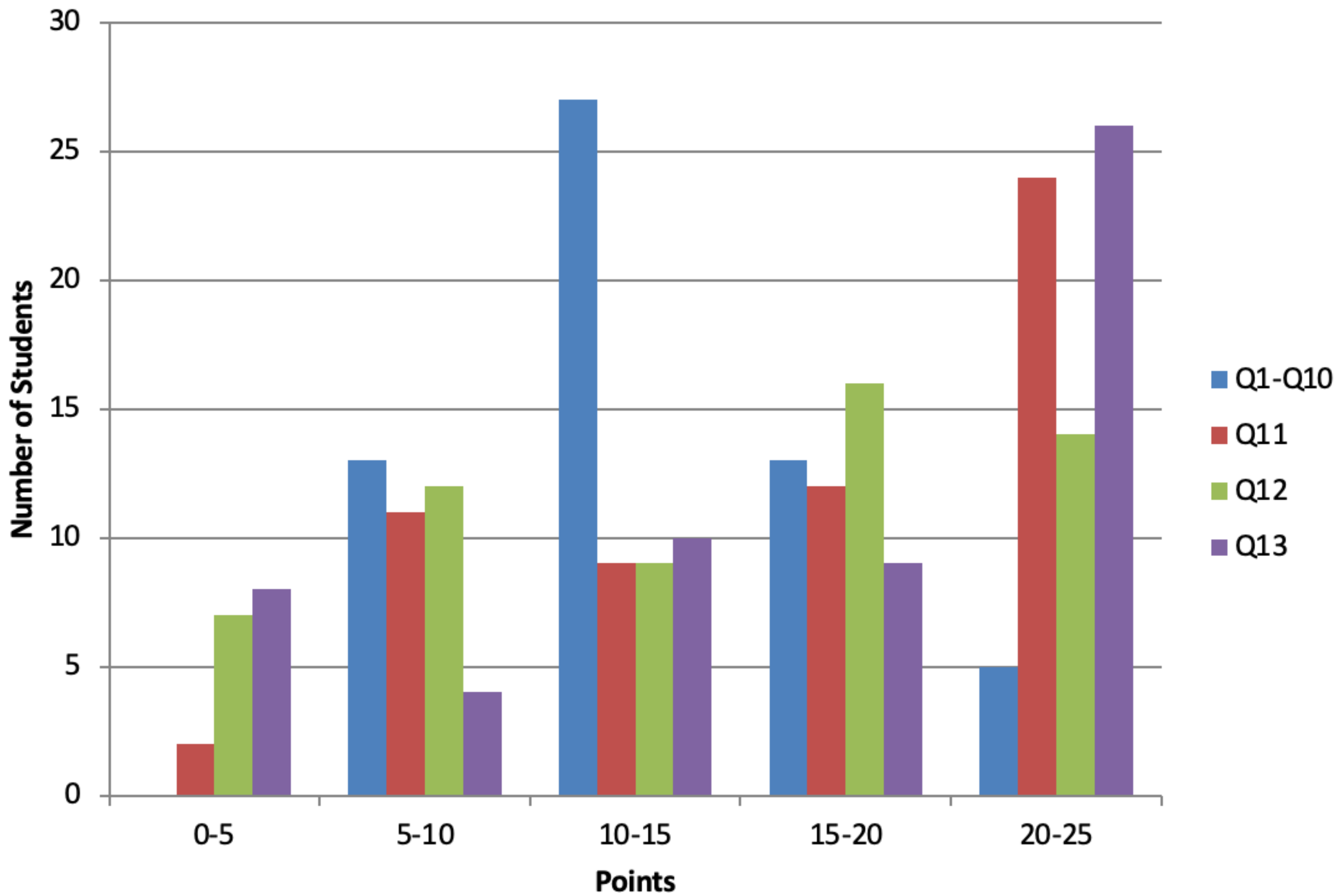
Physics 121.
Lecture 10.

- Topics:
  - Course information
  - Review of the concept of work and kinetic energy.
  - Conservation laws: why do we care?
  - Conservative and non-conservative forces.
  - Potential energy.

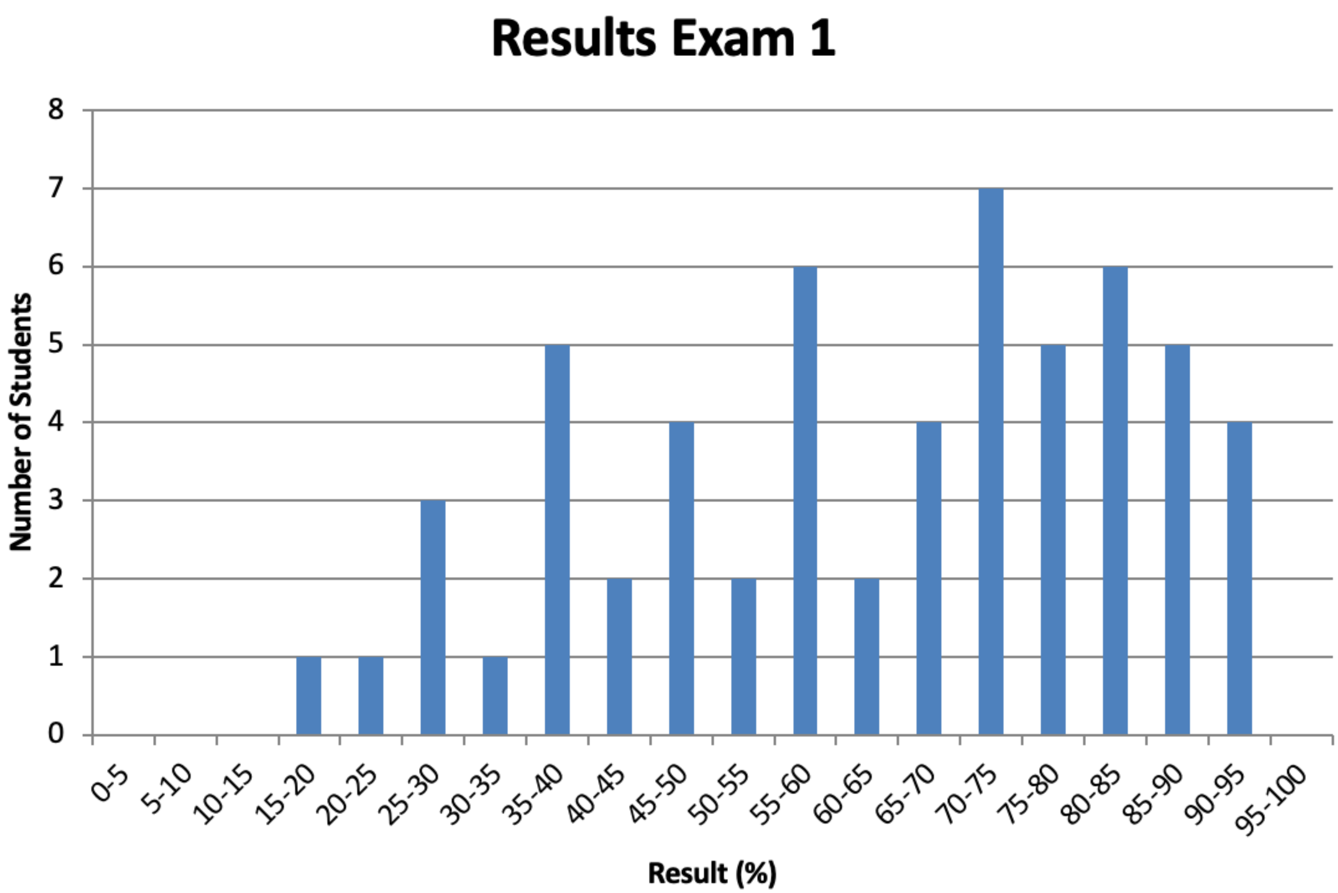
Course information.
Homework assignments.

- Homework set # 4 is due on February 28 at 8.30 am.
- Exam # 1 will be returned during workshops this 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).

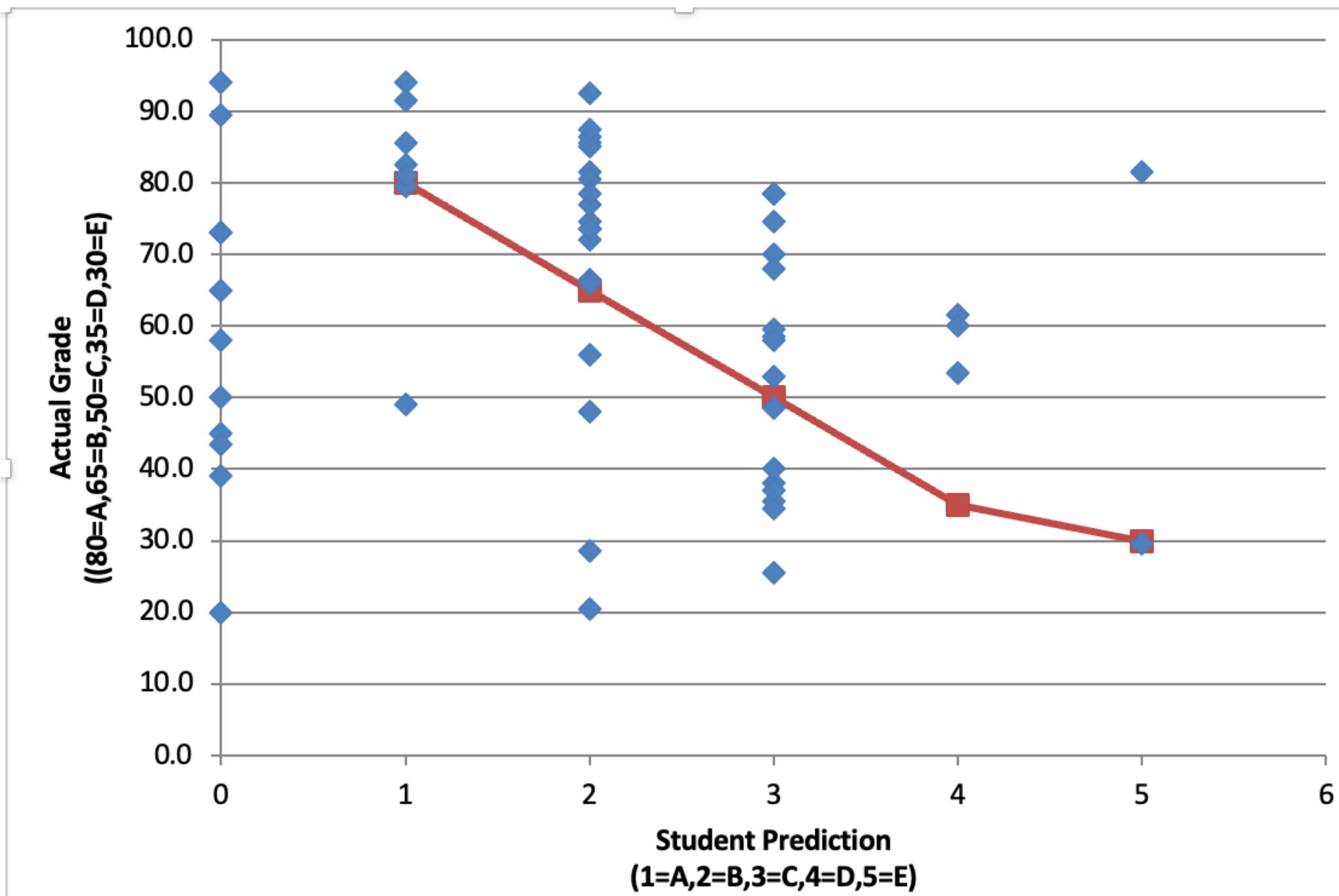
Results Exam # 1



Results Exam # 1



How well did you predict your performance?



Quiz.

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

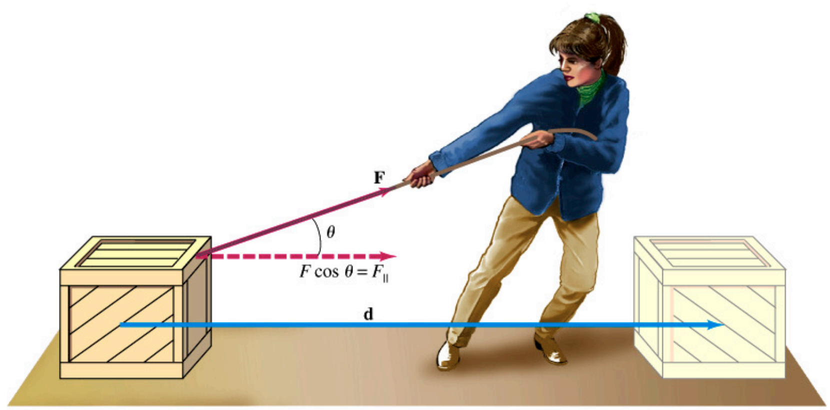
A quick review.
Work and energy.

- 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

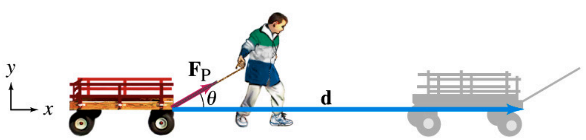
$$W = \vec{F} \cdot \vec{d} = Fd\cos\theta$$

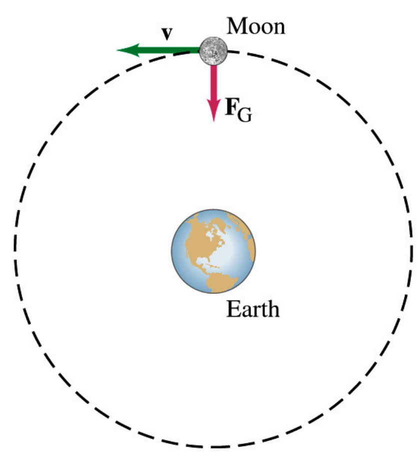
where θ is the angle between the force $\vec{F}$ and the displacement $\vec{d}$.



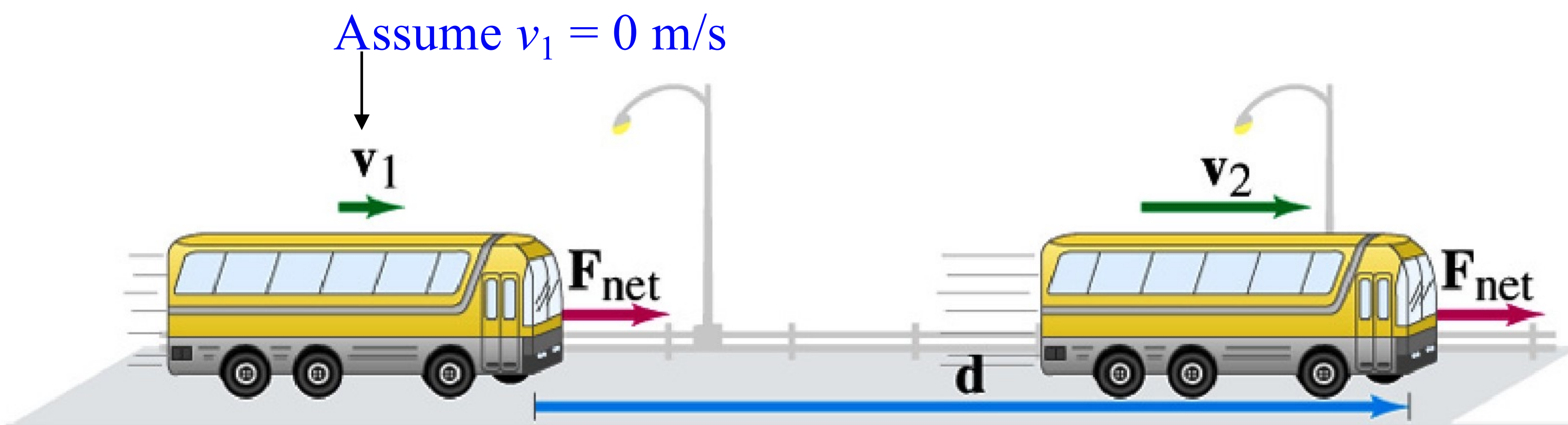
A quick review. Work: positive, zero, or negative.

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





A quick review.
The work-energy theorem.



- 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: $F_{net}d = \Delta E = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

Conservation of energy.

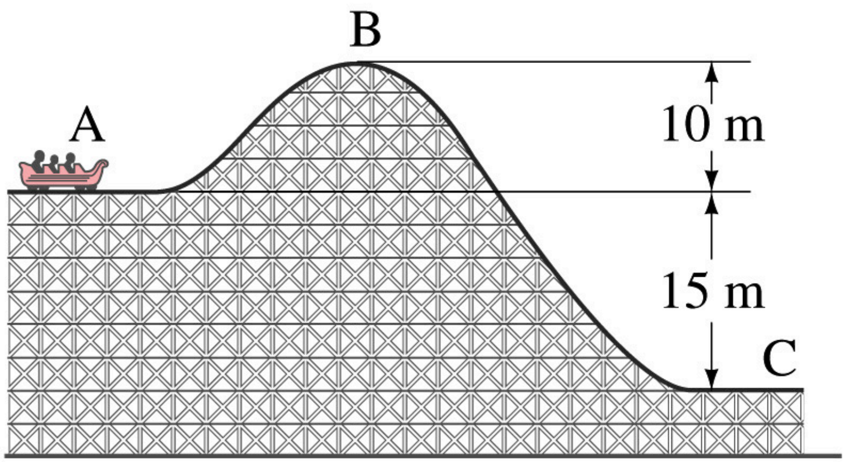
- Conservation laws in physics can be expressed in the following manner:

  "Consider a system of particles, completely isolated from outside influence. As the particles move about and interact with each other, there are certain properties of the system that do not change."

- One of the properties of closed systems that will not change is the total energy of the system. The energy may be converted from one form to another form, but the total will not change. Note: **you never waste energy; you just transform it from a useful form to a useless form when you waste it!**

Conservation of energy.

- Before we can apply conservation of energy, we need to define what the total energy of the system is.
- Clearly, the total energy is not equal to the kinetic energy of the components since this sum is clearly not conserved.
- In addition to kinetic energy, the system must contain potential energy (energy that has the potential to be converted into kinetic energy) in order to be conserved.



Conservation of energy.

- Consider what would happen if we define the mechanical energy of a system to be equal to the sum of the kinetic energy K and the potential energy U:

$$E = K + U$$

- If the total mechanical energy is constant, we must require that $\Delta E = 0$, or

$$\Delta K + \Delta U = 0$$

- We conclude any change in the kinetic energy ΔK must be accompanied by an equal but opposite change in the potential energy ΔU.

Potential energy in one dimension.

- Per definition, the change in potential energy is related to the work done by the force:

$$\Delta U = -W = -\int_{x_0}^{x} F(x')dx'$$

- The potential energy at x can thus be related to the potential energy at a point x_0:

$$U(x) = U(x_0) + \Delta U = U(x_0) - \int_{x_0}^{x} F(x')dx'$$

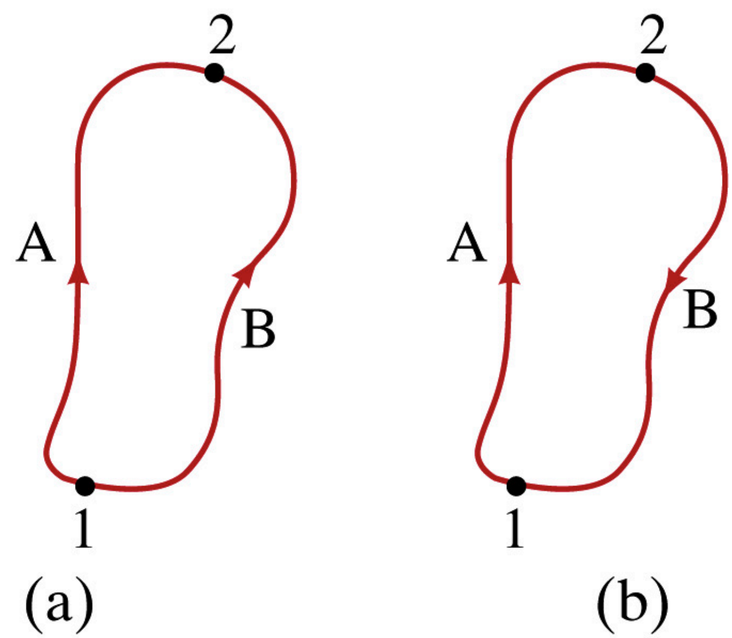
Potential energy in one dimension.

$$U(x) = U(x_0) + \Delta U = U(x_0) - \int_{x_0}^{x} F(x')dx'$$

- When we apply conservation of energy, we are in general only concerned with changes in the potential energy, ΔU, and not the actual value of U.
- We are free to assign a value of 0 J to the potential energy when the system is in its reference configuration.
- **Note**: the units of potential energy are the units of energy (the Joule).

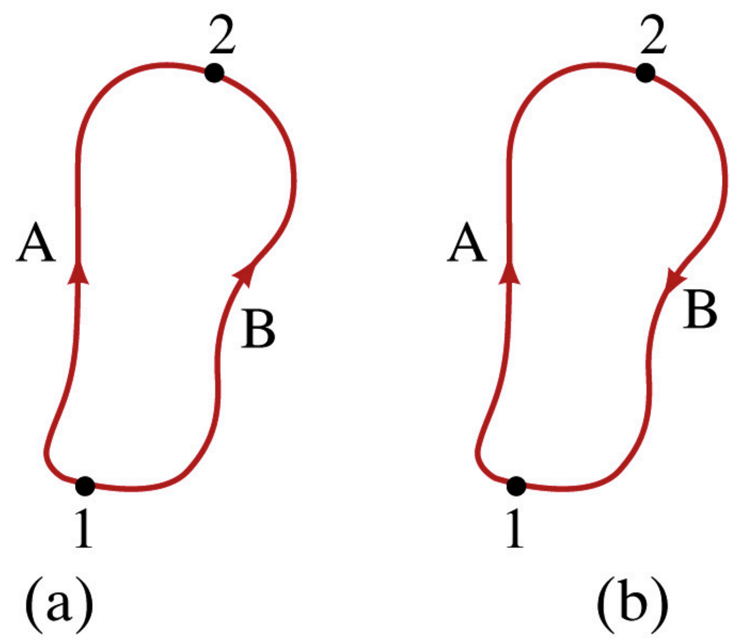
Potential energy. Path dependence.

- The difference between the potential energy at (2) and at (1) depends on the work done by the force F along the path between (1) and (2).
- But ……. we can get from (1) to (2) via path A and via path B. In order to uniquely define the potential at (2) the work done must only depend on the start and end point, and not on the path followed.



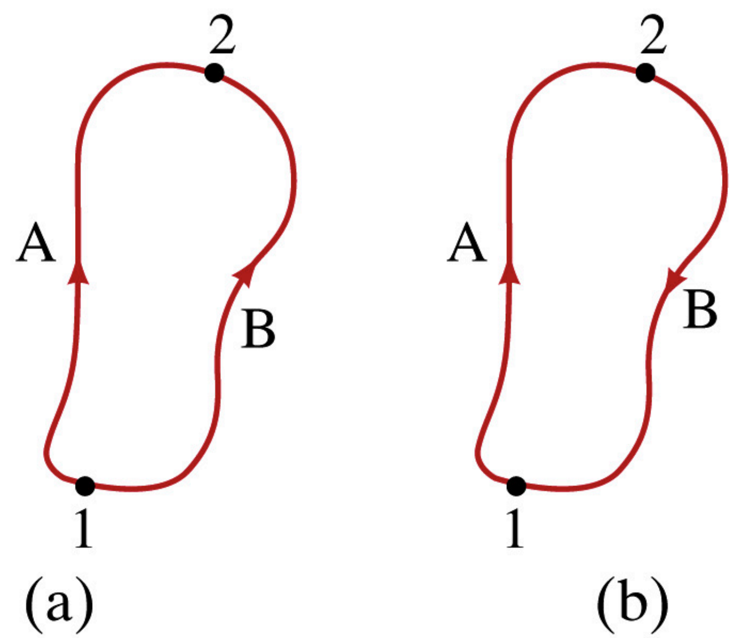
Potential energy. Path dependence.

- The work done must only depend on the start and end point, and not on the path followed.
- This is not true for all forces. For example, the work done by the friction force is always negative. If the friction force is constant in magnitude, the work done by the friction force depends on the path length and is thus path dependent.



Potential energy.
Conservative and non-conservative forces.

- If the work is independent of the path, the work around a closed path will be equal to 0 J.
- A force for which the work is independent of the path is called a **conservative force**.
- A force for which the work depends on the path is called a **non-conservative force**.



4 Minute 29 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 4 minute 29 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 29 seconds.

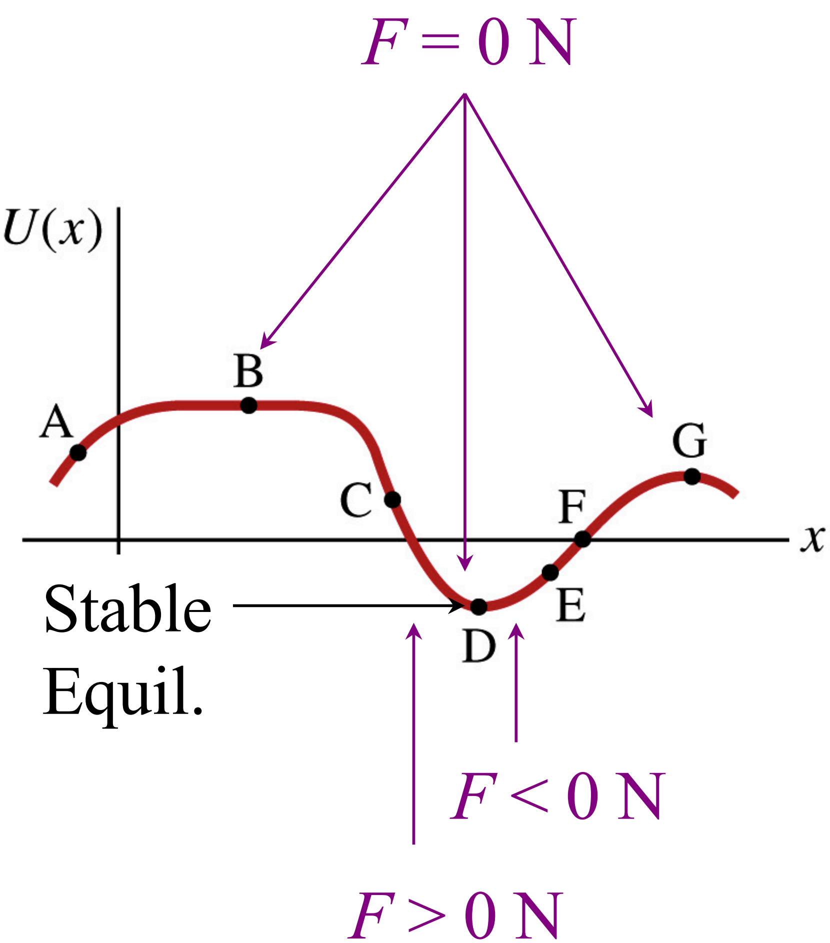
Potential energy in one dimension.

- The potential energy is directly related to the force acting on the object.
  - If we know the force, we can calculate the change ΔU:

$$\Delta U = -W = -\int_{x_0}^{x} F(x')dx'$$

  - If we know the change dU, we can calculate the force F:

$$F(x) = -\frac{dU}{dx}$$



Potential energy.
Examples: the spring force.

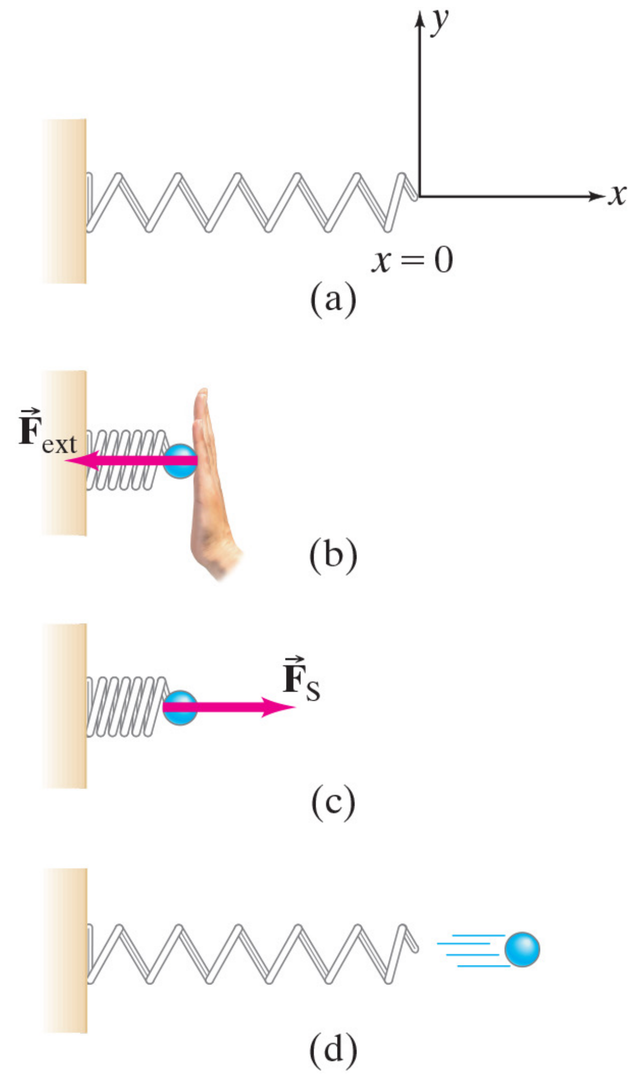
- The force exerted by a spring is given by Hooke's Law:

$$F(x) = -kx$$

- Consider the potential energy at x, taking the rest position as our reference point (where $U = 0$ J):

$$U(x) = -\int_{x_0}^{x} -kx'dx' = \frac{1}{2}kx^2$$

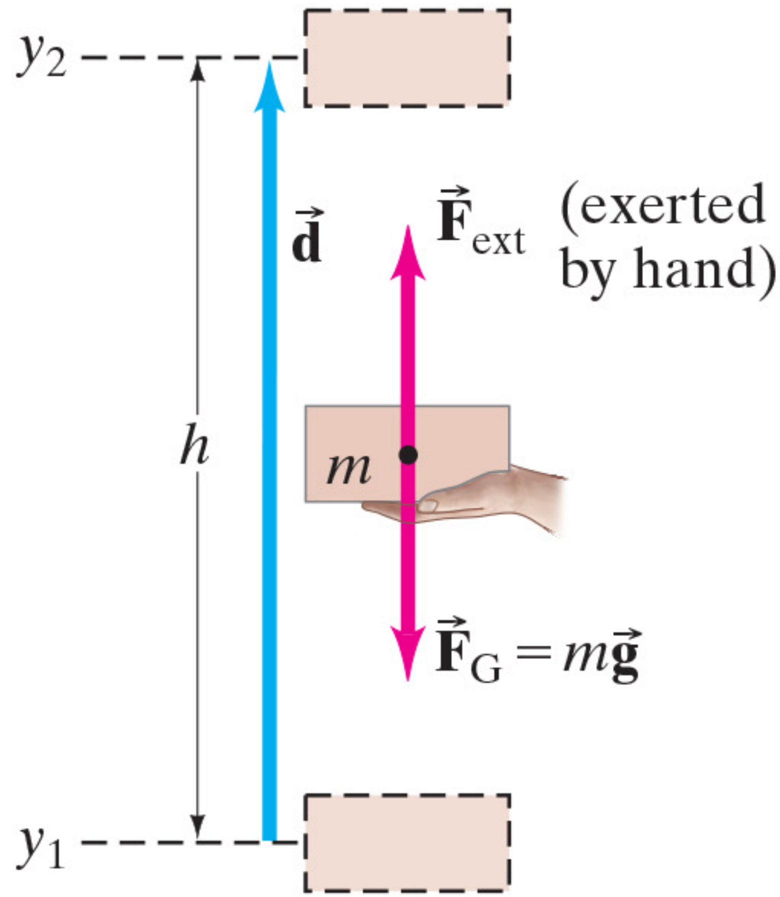
- We see that the potential energy has a minimum when $x = 0$ m.



Potential energy. Examples: the gravitational force.

- Consider what happens when we increase the height of an object of mass m by h.
- The work done by the gravitational force is negative (force and displacement point in opposite directions) and equal in magnitude to mgh.
- The potential energy due to the gravitational force at position 2 is thus equal to

$$U(y_2) = U(y_1) - W = U(y_1) + mgh$$



Usually, the potential energy on the surface is taken to be 0 J.

Conservation of Mechanical Energy

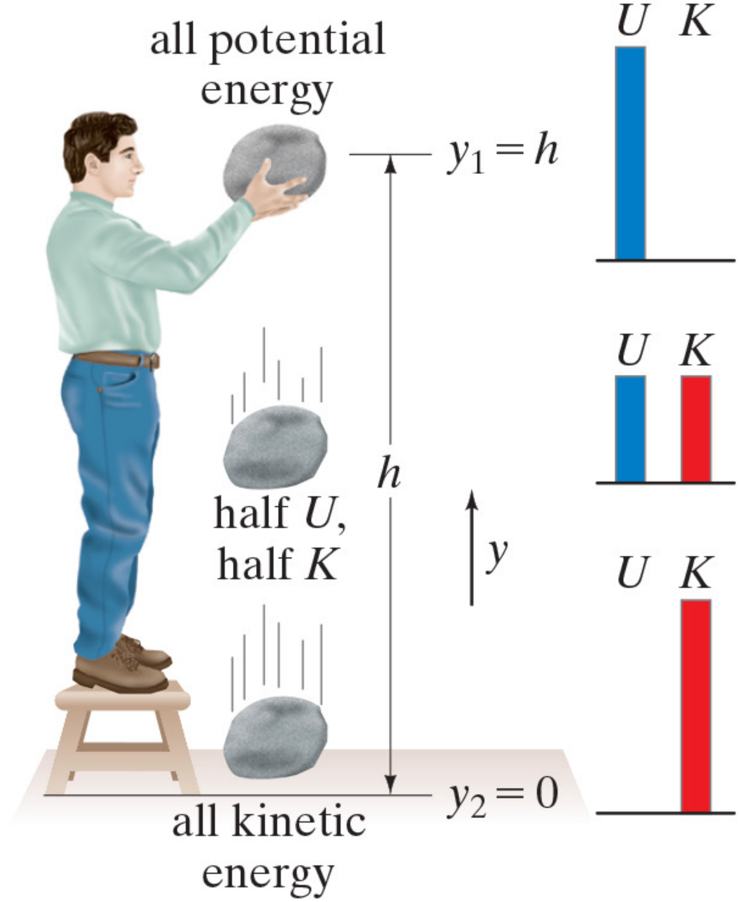
- When we drop an object, the potential energy of the object is converted to kinetic energy.
- At a height h, the total mechanical energy is mgh.
- At ground level, the total mechanical energy is $\frac{1}{2}mv^2$.
- If mechanical energy is conserved, we conclude that

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

or

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

which is independent of m.

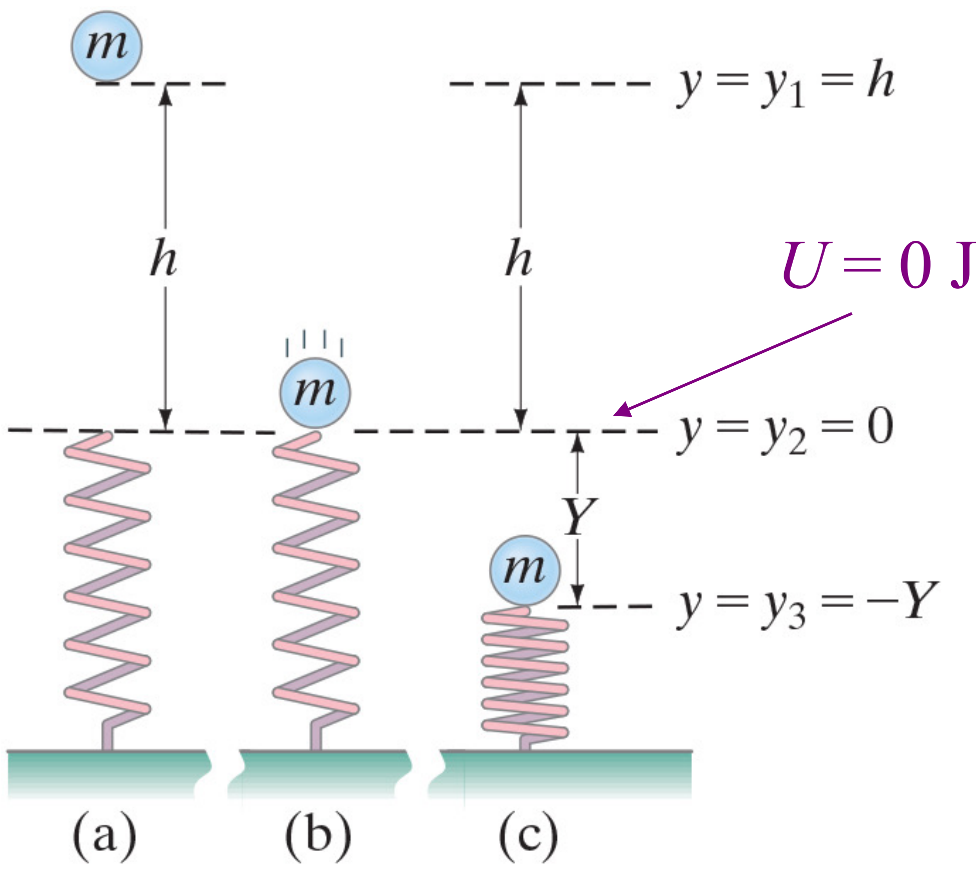


Note: you could also use the equations of motion to find v.

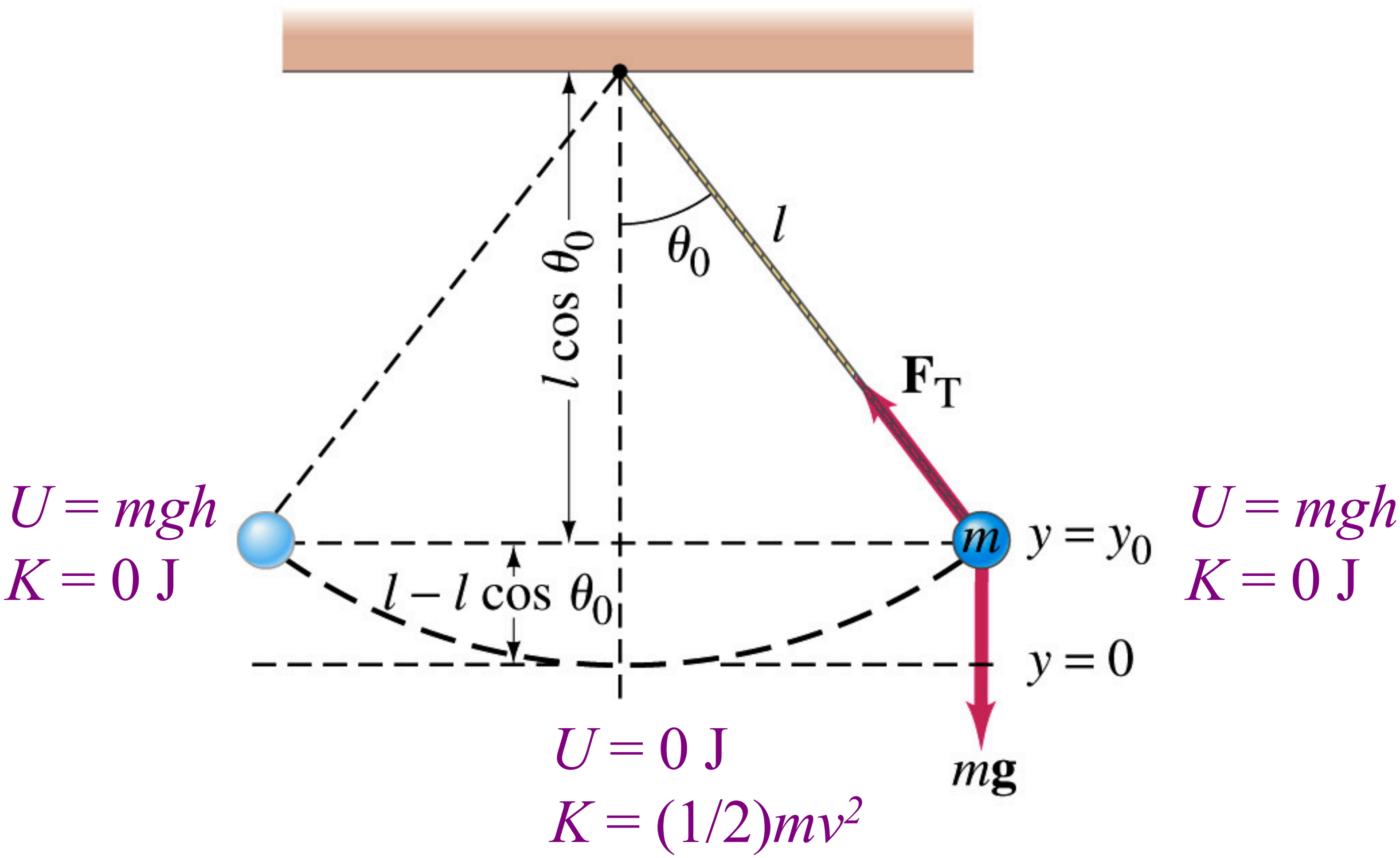
Conservation of mechanical energy.

- In this example we convert potential energy to mechanical energy and back to potential energy.
- The initial mechanical energy is all in the form of gravitational potential energy and is equal to mgh.
- The final mechanical energy is the sum of the gravitational potential energy and the potential energy associated with the compressed spring and is equal to

$$\frac{1}{2}kY^2 = mg(h + Y)$$



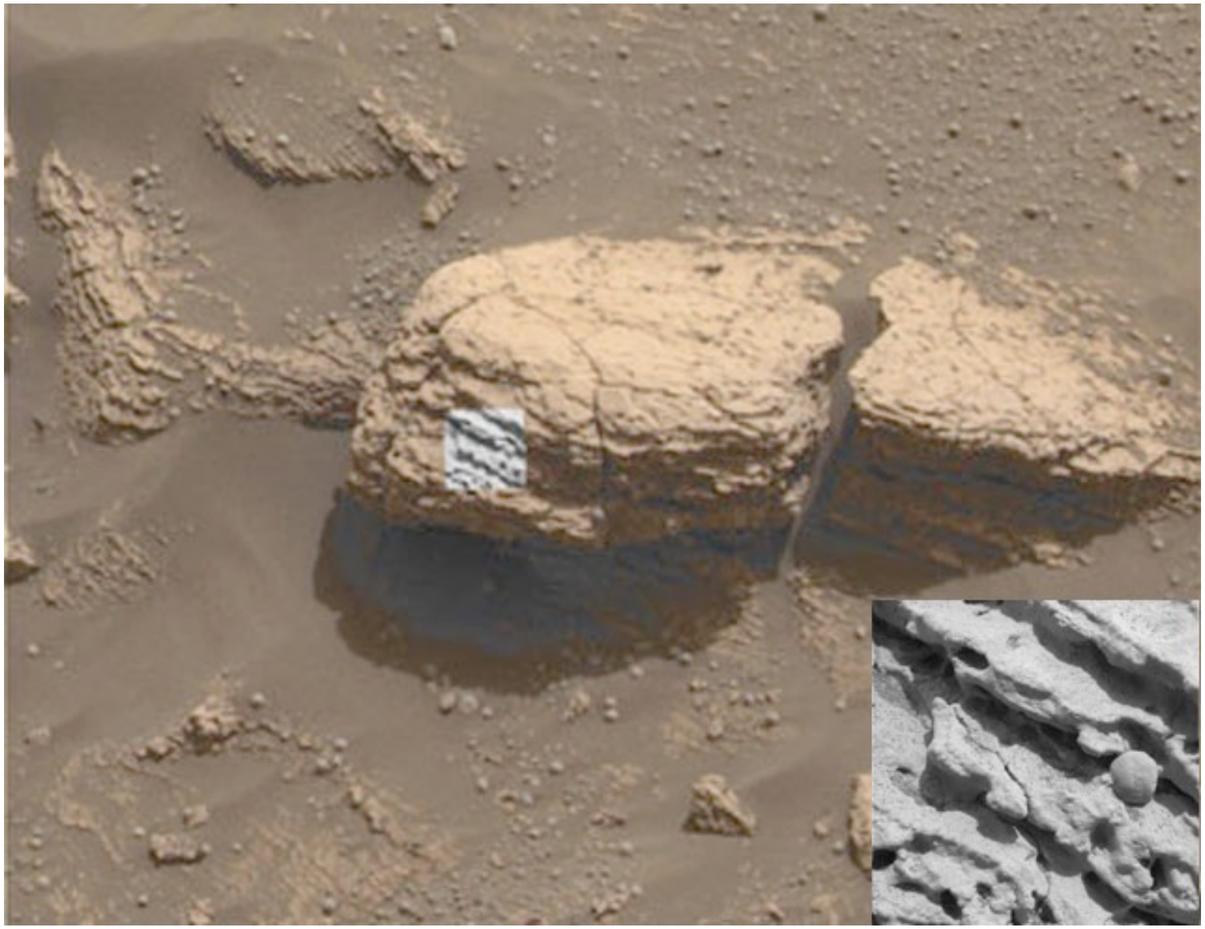
Conservation of mechanical energy.



Conceptual questions.

Let's test our understanding of the concepts of mechanical energy and work by working on the following concept problems:

That's all!
Next week: more on conservation of energy.



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