Topic 5: Work and Energy

Source: *Conceptual Physics* Textbook (Chapter 8), CPO textbook (Chapters 3 and 4), *Conceptual Physics* lab book (#21, 22, 23, 24, 25, 26, 27, 28) and CPO labs 3A, 3B, 4A, and 4B

Types of Materials: Textbooks, laboratory manuals, demonstrations, worksheets and activities

Building on: Once vectors, distance, displacement, speed, velocity and net force have been studied, this allows for the study of work (force x displacement) and the study of gravitational potential energy and kinetic energy through the use of laboratories.

Leading to: When students understand the conservation of work and energy, seeing connections of all topics from one through four becomes real. Also, the important topic of energy plays a very important role in today's world and needs to be explored by students in depth.

Links to Physics: Energy is probably the most important topic studied in physics and other physical sciences. Without understanding it, propelling cars down the road or astronauts to the moon and back would not be possible. Heating and cooling our homes in an efficient manor has become extremely important considering the short supply and cost of fuel.

Links to Chemistry: The world of chemistry relies heavily on the understanding of energy transfer. One example is the extraction of gasoline from crude oil to run motorized vehicles. Another example involves using corn in the fabrication of ethanol or the making of some breakfast cereals. Chemists produce products that are exothermic and endothermic in nature such as heating pads to keep the hands warm in winter of ice packs to place on a sprained knee. Understanding of energy release by chemicals can result in the formation of companies or just helping out in the kitchen.

Links to Biology: People eat food to obtain the energy it possesses from chemical reactions that allow the person to breathe, walk and run. Plants that grow from the earth extract energy from the soil's nutrients that come from the sun itself.

Materials:

(a) Hewitt
1. Lab 21 – Making the Grade
2. Lab 22 – Muscle Up
3. Lab 23 – Cut Short
4. Lab 24 – Conserving Your Energy
5. Lab 25 – How Hot Are Your Hot Wheels?
6. Lab 26 – Wrap Your Energy in a Bow

7. Lab 27 – On a Roll
8. Lab 28: Releasing Your Potential

(b) Hsu
1. Lab 3A – Momentum and the 3rd Law
2. Lab 3B – Conservation of Energy
3. Lab 4A – Force, Work and Machines
4. Lab 4B – Work and Energy

(c) My Labs
Car Up and Down Ramp

(d) Worksheets
Work and Energy

(e) Demonstrations
1. Bend Wire
2. Lead Shot in Cardboard Tube
3. Pulley and Lever
4. Jumping Disk
5. Energy Transfer #1
6. Energy Transfer #2

(f) Videos and Websites
1. ESPN SportsFigures "The Gear Game" Video Guide (Mountain Biking)
2. Funderstanding 3-D Coaster Lab Sim (Shockwave)
3. ESPN SportsFigures "Perpetual Motion" Video Guide (Tony Hawk Skateboarding)
4. The Skater Dude Lab Sim (Java)
5. http://video.google.com/videoplay?docid=-8943205214784769158
   (This website challenges current thinking in physics in some instances and may be not totally true in others, but I feel it is good (in part) to show parts and have a class discussion. I feel it should generate class interest and perhaps give a spark to that quiet thinker to get hooked on science). A 1 hr. 50-min. video is too long, so showing parts would be appropriate.
6. http://ShopHistoryChannel.com
   (The Modern Marvel TV series, Renewable Energy DVD, $24.95, is a wonderful presentation of the new technology being worked on to supplement oil energy. Examples include wind, solar, etc., with current knowledge being applied.
7. http://www.history.com/media.do?action=clip&id=tdih_0127
   Shows old footage of inventor of the TV.

(g) Good Stories:
1. The Household Match
2. James Joule

Topic 5: Energy Lab – Work Input and Output Energy

Purpose: To compare the work input when a car is pulled up an incline to the output energy that is put into the car-earth system. Thus, calculate the energies and efficiencies of the setup.

Theory: An inclined plane is one of the six simple machines and input work and output energy can be easily calculated. The input work can be calculated by multiplying the input force needed to pull the car up the incline times the distance traveled up the incline. The output energy is equal to the gain in gravitational potential energy (GPE) if no energy is lost. So,

Input = Output

And, with friction,

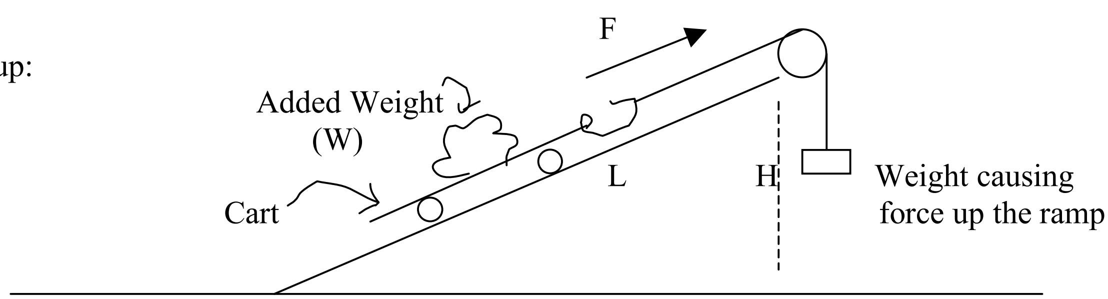
Input = Output + Energy lost by friction.

The efficiency of a machine is the comparison of output to input, or

Efficiency = Output/Input.

To make this percent efficiency, just multiply by 100%.

Setup:



Procedure: Car = ______________________N

1. Use a small angle of 15 degrees or so, and pull the cart with a loaded small weight the length of the incline with slotted weights that pull down but go around a movable pulley that changes the direction of the force up the ramp. The amount of slotted weights should be enough to keep the cart going at a constant speed while moving up the ramp (fine-tuning of the weights will be necessary).

2. Record in the following table:
   - The force up the incline (equals the slotted weights in N).
   - The length (L) of the incline in (m).
   - The weight (W) in (N), car and added weights that you are lifting.
   - The vertical height (H) in (m) that the weight was lifted.

3. Repeat procedures 1 and 2 with a heavier weight in the car two more times.

Principle of Work

Trial	Force Up Incline (N)	Length of Incline (m)	Total Weight Lifted (N)	Vertical Height (m)
1				
2				
3				

Use the above data to calculate input work and output energy and put in the table below.
Also do the percent efficiency.

Trial	Input Work (J)	Output Energy (J)	Efficiency in %
1			
2			
3			

Questions:

1. What happened to the input work values and why, for trials 1, 2 and 3?

2. What happened to the output energy values and why, for trials 1, 2 and 3?

3. Is the efficiency in trial #1 100%? Why or why not?

4. Look at the efficiencies in trials 1, 2 and 3 and explain the outcome.

Topic 5: Energy Lab – Work Input and Output Energy Answer Sheet

Sample Data in Table

Trial	Force Up Incline (N)	Length of Incline (m)	Total Weight Lifted (N)	Vertical Height (m)
1	6	1.0	10	0.5
2	16	1.0	20	0.5
3	23	1.0	30	0.5

Trial	Input Work (J)	Output Energy (J)	Efficiency in %
1	6 x 1 = 6	10 x 0.5 = 5	5/6 x 100% = 83%
2	8	10	80%
3	11	15	73%

Questions:

1. The input work values go up because more weight is rolled up the ramp.

2. Likewise, the output work values go up because more weight is lifted.

3. The efficiency of the three trials will depend on friction. If little friction is present, the efficiencies can approach 100%, but will probably be in the 90's. For example, if a metal-wheeled cart with little friction rolls on hard wood, 90% plus can be expected.

4. Trials 2 and 3 will go down in efficiencies because the friction gets greater as the weight goes up. (See sample data.)

Topic 5: Work and Energy Worksheet

(A) WORK is accomplished when a force moves an object through a distance. Energy is added to a system when an external force moves a body. We can say that work is one form of energy. When a force acts from within a system, energy is removed from the system. One example is stretching a rubber band. When you supply the force to stretch the rubber band, work/energy is added, but when you let go, the internal force of the rubber band contracts and moves the mass, so work/energy is removed from the system. Another example is the gravitational force. If you lift a mass upward against gravity, work/energy is added and when the mass is dropped, work/energy is removed from the mass-earth system.

Mathematically, Work = force times displacement

$$\text{Or, } W = \vec{F}\vec{d}$$

Force and displacement are vectors, but without explanation—take my word for it—the multiplication of these vectors is called a dot product and the result for work is a SCALAR and has no direction. This makes for easier problem solving. So, work can be expressed as $W = F \times d_{11}$, with the distance being parallel to, or in the direction of the force.

(B) <u>Gravitational Potential Energy (GPE) and Kinetic Energy (KE)</u>
Gravitational Potential Energy, a scalar, is stored in the force field between two masses such as the earth and what's above it. The three physical quantities that determine the strength of the field are mass, change in position and the acceleration of gravity. Thus,

$$GPE = mg\,\Delta h$$

With m in Kg, g = 9.8 m/s/s and Δh is the change in position parallel to the gravitational field lines. If a mass moves perpendicular to the field lines no energy change results such as carrying a book at 1 m above the ground while you walk around. The GPE would remain the same.

<u>Kinetic Energy (KE)</u>
Kinetic energy is a scalar and energy of motion. Only the mass and speed of a body alter a body's motion energy with speed being the greater effect. So an example would be the baseball question, "Should I use a heavy bat or lighter bat that I can swing faster?" Since the equation for KE is:

$$KE = \tfrac{1}{2} mv^2$$

The lighter bat swung faster transfers more KE to the ball. If the light bat is swung 2x faster than the heavy bat, then it has 4x the KE but only a small decrease in KE due to the smaller mass.

Questions and Problems:

1. (a) If a box is slid across a horizontal floor for 1 m by a horizontal force of 1 N, how much work was done on the box-earth system?
   (b) After the pushing force on the box is removed after the 1 m, the box stops. Where did the work/energy go?

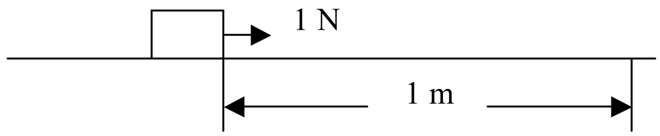
2. You lift a 2 kg dumbbell from the floor over your head to a height of 2 m.
   (a) How much work did you do to lift this weight?
   (b) Where did the work/energy go after lifting the dumbbell above your head?
   (c) How much energy does the dumbbell-earth system have when above you head?
   (d) If you drop the weight, what type of energy does the system have halfway down?
   (e) What type of energy does the system have just before impact?
   (f) After impact, where is the energy?

3. (a) What is the GPE of a 1 kg body at 1m above the earth's surface?
   (b) If the mass is raised to 2 m above the earth, what is the GPE?
   (c) If the same mass were taken to the moon and placed 1m above the moon's surface, compare the GPE to that of being on earth.

4. (a) If a 1 kg mass is moving at 1m/s at 1m above the earth, how much KE is in the mass-earth system?
   (b) What is the total energy of the mass-earth system when the 1 kg mass is moving at 1 m/s at 1 m above the earth?
   (c) How many times greater is the KE when a 1 kg mass doubles its speed?

Topic 5: Work and Energy Worksheet Answer Sheet

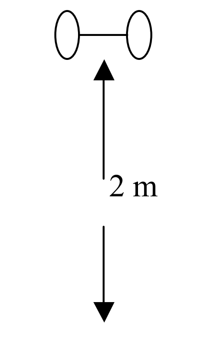
1. (a)



$$W = Fd_{11} = (1\ N)(1\ m) = 1\ Nm = 1\ J$$

   (b) The friction force acting through the 1 m removed the energy as heat.

2. (a) $W = F\ \Delta d_{11} = (mg)\ \Delta h = (2\ kg)(9.8\ m/s/s)(2\ m) = 39.6\ J$



   (b) Into GPE
   (c) GPE = 39.6 J
   (d) ½ KE and ½ GPE
   (e) All KE
   (f) Into heat

3. (a) $GPE = mg\ \Delta h = (1\ kg)(9.8\ m/s/s)(1\ m) = 9.8\ J$
   (b) Since Δh is doubled, GPE is doubled to 19.6 J.
   (c) Since g on the moon is smaller than earth, so is the GPE.

4. (a) If a 1 kg mass is moving at 1 m/s at 1 m above the earth, how much KE is in the mass-earth system?

$$KE = \tfrac{1}{2}\,(1\ kg)(1\ m/s)^2 = 0.5\ J$$

   (b) What is the total energy of the mass-earth system when the 1 kg mass is moving at 1 m/s at 1 m above the earth?

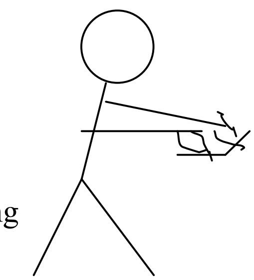
$$E = (1\ kg)(9.8\ m/s/s)(1\ m) + \tfrac{1}{2}(1\ kg)(1\ m/s)^2 = 9.8\ J + 0.5\ J = 10.3\ J$$

   (c) $v^2 = 2 \times 2 = 4$ times greater

Topic 5: Demonstrations/Activities

1. Bend a Wire

   Purpose: To show the conservation of energy conceptually.

   Procedure:

   1. Get a wire coat hanger and two pliers.
   2. Cut the wire into 6” segments.
   3. Use the two pliers to hold the 6” wire near the center at a spacing around ½”.
   4. Bend up and down with each hand until the wire breaks. (Number of bends depends on wire thickness and aggressiveness of the bends—probably about 10 or so.)

   Shows: The work in (force x distance) is transferred into heating the wire (energy) and causes the crystal pattern in the wire to get a fault to cause the breaking to occur.

2. Lead Shot in a Cardboard Tube

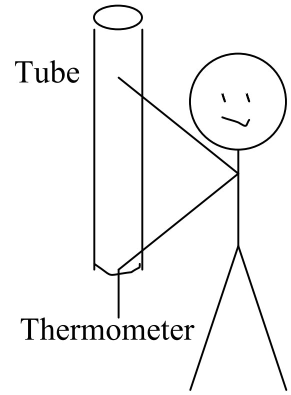
   Purpose: To show the conservation of energy conceptually

   Procedure:

   1. Get 200-400 g of lead shot (scientific supply company, or perhaps at a gun dealer, for loading your own shells) and a 5’ cardboard tube at a carpet store (thick and has a diameter around 4”. Also obtain an accurate mercury/alcohol glass thermometer.
   3. Cut two thick and flat circular cardboard pieces to fit each end of the tube and duct tape at each end of the tube <u>AFTER</u> you cut a hole in the center of one cardboard end plate that just fits the end of the thermometer, <u>AND</u> load the shot.
   4. Insert the thermometer into the hole: upright the tube and thermometer (at bottom).
   5. Record the temperature to start (wait a minute or so). Turn the tube while holding the thermometer over several times (10 to 20); wait a minute or so and record the new temperature.

   Shows: Conversion of GPE into HEAT. Each time the shot falls through the length of the tube, the loss in energy (GPE) upon impact is converted into heat. The larger the number of shot drops, the larger the change in temperature. The cardboard is a good insulator and retains the heat well. If you wanted to do this mathematically, it works if your thermometer is graduated by ½ degree.

Or, Δ m g Δ h = c m Δ T



m = mass (kg) of lead shot
g = acceleration due to gravity 9.80 m/s^2
Δ h = falling distance of shot (m)

c = specific heat of lead = 128 J/kg K
m = mass of lead shot
Δ T = change in temperature of shot (Tf – Ti) in K, Kelvin

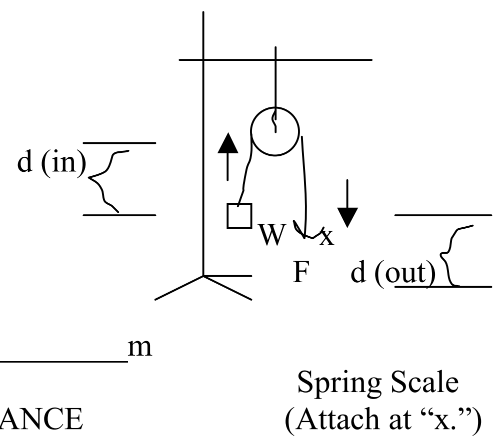
3. Pulley and Lever

Purpose: This demonstration/activity shows energy being conserved (if one recalls that friction plays a part in removing energy).

Procedure:

1. Set up a ring stand with a cross bar.
2. Hang a string from the cross bar and attach a single pulley.
3. Attach a weight (around 1 kg) to a string that goes over the pulley.
4. Measure the weight in Newtons and record.
5. Pull the weight upward and measure how far you lift the weight.
6. Use a spring scale to lift the weight and record the force needed to lift the weight and the distance you moved the force in lifting the weight.

Table:



Weight = _________________________N

Distance weight was lifted = __________m

Input force to lift weight = ____________N

Distance force moved to lift the weight = _______________m

INPUT WORK = INPUT FORCE x INPUT DISTANCE

W (in) = __________________N x ___________________m

= __________________________N m (Joules)

OUTPUT WORK = OUTPUT FORCE x OUTPUT DISTANCE

W (out) = ______________________N x _______________________m

= _________________________N m (Joules)

Compare: Input work to output work. ____

____

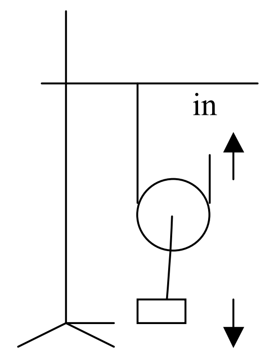
What should happen? ____

____

If the outcome didn't match predicted idea, why not? ________________________________

____

PULLEY (Setup #2)



Repeat the above using this setup and answer the same questions.

W (in) =

W (out) =

Compare W (in) to W (out). ____

____

What should happen? ____

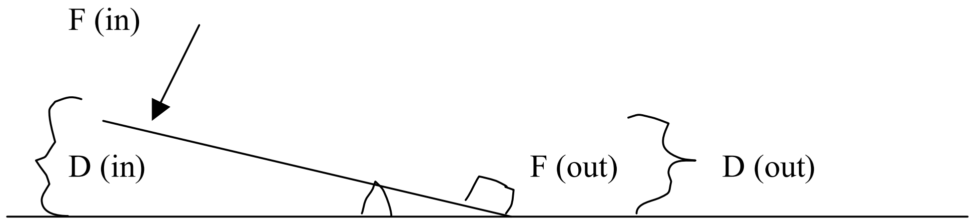
____

If the outcome doesn't match predicted idea, why not? _______________________________

____

LEVER:

Repeat using this setup with a lever.



Compare WORK IN TO WORK OUT and explain.

____

____

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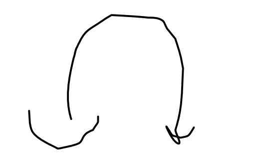
4. Jumping Disk
   (Cut a tennis ball in half, or, buy jumping disks from Edmond Scientific or other supplier.)

Purpose: To recognize how energy flows using the conservation of energy.



Inside out ball

Procedure:

1. Invert the tennis ball and place it on the table (or use the commercial disks).
2. Wait for the jumping into the air to occur. The ball inverts and pops upward.

Explain the energy flow: ____

____

____

____

Topic 5: Demonstrations/Activities Answer Sheet

1. Bend a Wire – Given in demo

2. Lead shot in a Cardboard Tube – Given in the demo

   (Additional: With a 1.5 m-long tube and 400 g of shot and dropping about 10 times, the gain in temperature is about 2 degrees Celsius; you must wait after the dropping of the shot for the temperature to peek.)

3. Pulley and Lever

   <u>Pulley Sample Data</u>
   Weight = 9.8 N
   Distance up = 0.3 m
   Force in = 9.9 N
   Distance down = 0.3 m

   W (in) = 2.97 Nm = 2.97 J
   W (out) = 2.94 J
   Compare W (in) to W (out) – The input work and output work are nearly the same (conservation of energy), but friction acts for 0.3 m and removes a small amount of energy (F x D), thus a slightly greater input work. If the pulley has little friction, the values will be very close.

   <u>Pulley #2</u>
   Sample Data:
   Weight = 9.8 N
   Distance output = 0.3 m
   Force in = 5.0 N
   Distance input = 0.6 m

   W (in) = 3.0 J
   W (out) = 2.94 J
   Compare W (in) to W (out) – The input work and output work are nearly the same (conservation of energy), but friction acts for 0.6 m and removes a small amount of energy (F x D), thus a slightly greater input work. If the pulley has little friction, the values will be very close.

   <u>Lever</u>
   The same result occurs for the lever as the pulley, but even better since friction is very small compared to the pulley.

4. Jumping Disk

   This demo can nicely show, conceptually (or quantitatively), the transfer of energy. The sequence is putting energy into the ball with your effort (F x D)—work. Now the ball has stored spring potential energy; when the stored energy is released in the pop, the energy goes to kinetic. Then at the top of the jump, the energy becomes gravitational potential energy. As the disk falls, the energy returns to kinetic and, after the hit, the energy dissipates into heat.

   Work → SPE → KE → GPE → KE → Heat

5. Energy Transfer Demo #1

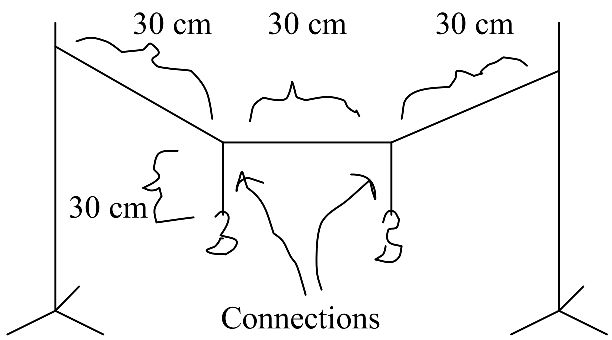
   The conceptual discussion is on the discussion of the demo.

6. Energy Transfer Demo #2

   The conceptual discussion is on the discussion of the demo.

Topic 5: Energy Transfer Demo #1

Setup
Connect two equal mass objects (I use two 200 g hooked masses or, for more interest, two oranges, apples, shoes, etc.) from two strings about 30 cm long. Attach these weights at 30 cm from each pole with 30 cm spacing between the connections.



Procedure
Pull one weight back in a 20-cm-long arc and release when the masses are near rest. Observe for a minute or two.

Outcome
If the support poles are made secure (weights on the tripod, hold them, etc.), it will take several minutes for the energy to dissipate. What is seen is a transfer of energy between the weights where one weight stops and the other swings as did the first.

Specifically, you do work pulling a weight back (W = F x D), which is transferred into GPE of the earth-weight system. When released, GPE is transferred into KE of the falling weight. The moving weight moves the connection back and forth to do work on the string. This energy is moved through the string to the other connection and in turn transferred to the weight below. This second weight moves with KE and the first weight stops as it has lost its starting energy. The energy flips back and forth until the moving poles and air drain the energy from this system.

Discuss the heat loss and how could you increase the time of swinging (reduces energy loss rate, start with more starting energy, change length of strings holding the weights, etc.). Students could pair off and see who could do the best as a competition activity.

This classic started a national TV show in the fall of 1966 about the upcoming ENERGY CRISIS. (Here we are! Time for some young minds to get serious, unlike our past generations!)

In General:
Work on Mass 1 → Gravitational Potential Energy Gain on Mass 1 →
Kinetic Energy Gain on Mass 1 → Work on Connection to Mass 1 →
Kinetic Energy Gain on Mass 2 → Gravitational Energy Gain on Mass 2

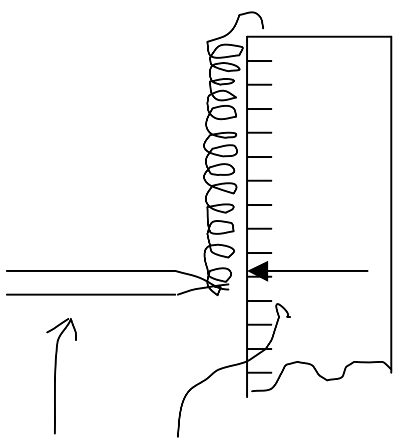
Topic 5: Energy Transfer Demo #2

Spring Energy:

Theory: This demo/activity works very much as theory suggests assuming good user skill. I like this one done quantitatively since it works well (notice I didn't say perfectly). Again, this demo/activity shows the transfer of energy from spring potential into kinetic into gravitational potential energy.

Procedure:

1. Obtain a spring (or set of springs) that is about 15 cm long and can be stretched about 15 cm without much difficulty (not too strong)—say 5 N at 15 cm stretch.
2. Bend the end of the spring, as shown, so it can be placed on the top of a meter stick (sketch). These spring values are just made up so you must experiment to find what works for you.



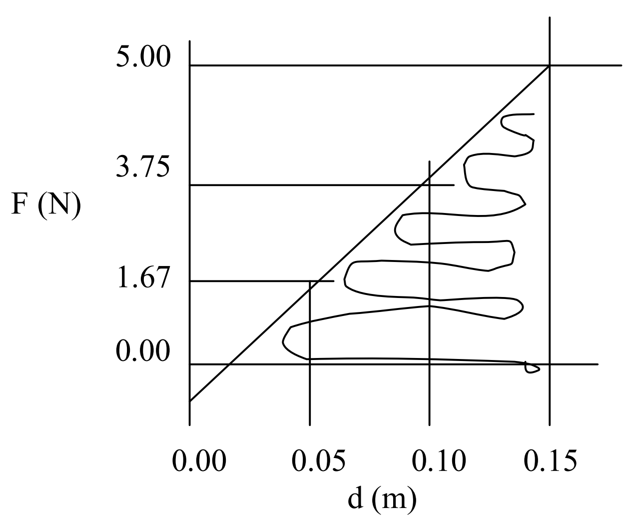
Pencil Starting Point
(for the important release)

Take Data:

1. Pull the spring from its starting point down in steps with a <u>spring scale</u> and record the stretch and force needed to obtain about 4 data points.
2. Plot a force vs. stretch graph using Newtons and meters.
3. Calculate the area under the curve that represents the stored energy in the spring.
4. Pull down on the spring to the largest distance in collecting your data. Release by using the tip of a sharp pencil by letting the spring gently slip off the pencil.
5. Measure the mass of the spring and the height to which it flies.

Sample Data:
Mass = 20 g = 0.02 kg
Height = 191 cm

Force (N)	Stretch (m)
0	0
1.67	0.05
3.75	0.10
5.00	0.15



Calculations:
Calculate the area under the curve.

Area equals that of a triangle: A = ½ x b x h = ½ x (0.15 m) x (5.00 N) = 0.375 Nm = 0.375 J
This is the spring's stored energy (SPE).

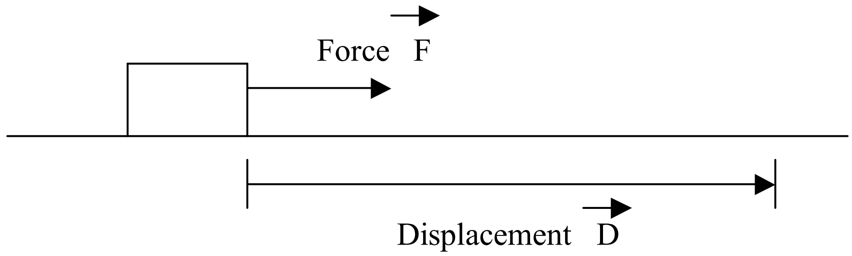
The Gravitational Potential Energy gained is:
GPE = mgh = (0.02 kg) x (9.8m/s^2) x (1.91 m) = 0.375 J

You can predict the height and it works well if the RELEASE of the spring is clean!
SPE $\longrightarrow$ GPE

Topic 5: Joke – Work and Energy

(a) Recall: Work = force x displacement

Pictured:



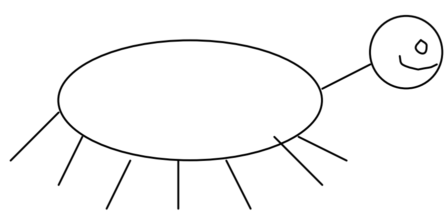
By definition, let $\vec{F}$ = 1 N and let $\vec{D}$ = 1 m

So, W = $\vec{F}\,\vec{D}$ = (1 N)(1 m) = 1 Joule = 1 J (used in the MKS and SI system of measurement)

(b) Smaller metric units are often used in chemistry (the CGS system).
Force is in dynes and distance is in centimeters, or 1 dyne and 1 cm.
100,000 dynes = 1 N and 100 cm = 1 m

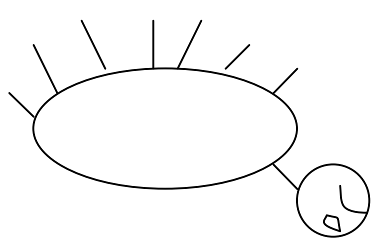
W = (1 dyne)(1 cm) = 1 erg (or, 1 J = 10,000,000 ergs)

(c) Ask: What is this?



Answer: Centipede

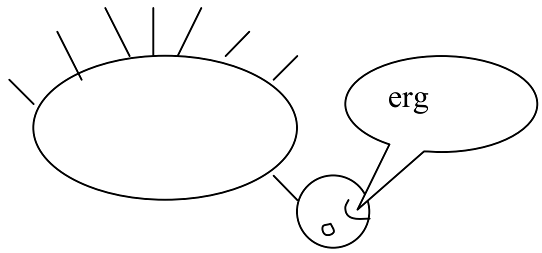
(d) Ask: What is this?

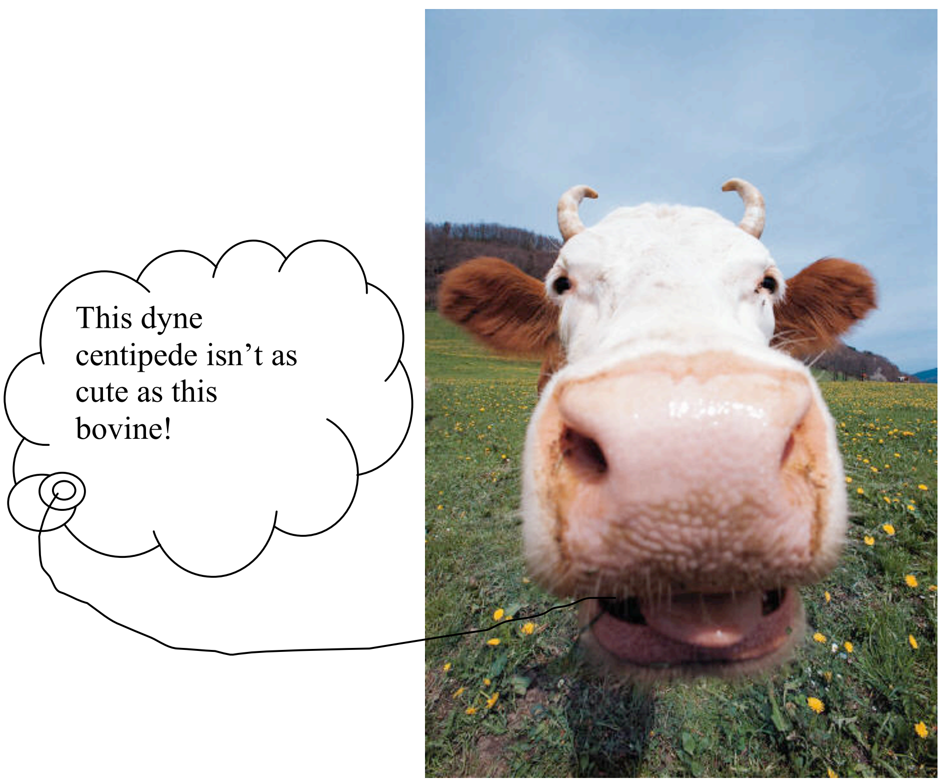


Answer: dyne centipede (centimeter) (Most will say a dead centipede.)

(e) Ask: What does the dyne centipede say as he/she is dyne?

(f) Answer: erg





The Household Match

The earliest version of a simple household match used to start fires was invented in the year 577 A.D. by poor court attendants during a military engagement in the Chinese kingdom of the Northern Qi. Pressed for time during the siege, they must have been so short of tinder that without the "match" lighting fires would have been difficult.

Early matches were made of sulphur. A description is found in a book called *Records of the Unworldly and the Strange*. Tao Gu wrote this account around 950 A.D.

If there occurs an emergency at night, it may take some time to make a light to light a lamp. An ingenious man devised the system of impregnating little sticks of pinewood with sulphur and storing them ready for use. At the slightest they burst into flame. One gets a little flame like an ear of corn.

This wondrous invention at first was called a "light-bringing slave," but later when the match became a trade item, its name was changed to "fire inch-stick."

There is no account of the match in Europe before 1530. It could easily have been brought to the West from China at around the time of Marco Polo. It was at this time that the records show that matches were being sold in Hangzhou in about the year 1270.

Joule – Jewel – Jowl

James Prescott Joule was born on Christmas Eve, 1818, into a wealthy English brewing family. Initially he was home-schooled until at the age of sixteen the eminent scientist John Dalton became his teacher. Apart from this, he had no formal education and was largely self-taught in science. Later in life he had difficulty keeping up with the new science of thermal energy (thermodynamics) because of his lack of mathematics.

The income from the brewery (Joule's Stone Ales) allowed him to indulge his scientific curiosity. Some of his experiments were done in the laboratory at the brewery. He is famous for his mechanical equivalent of heat energy, Joules Law. Joule had trouble getting his results accepted because he was considered to be a brewer and not a scientist. Also, his lack of a university education didn't help. His papers were rejected by the scientific journals, so Joule resorted to publishing his findings in the Manchester newspapers. When Michael Faraday and Lord Kelvin took an interest in his work, he was finally recognized in scientific circles.

One famous story of his devotion to science relates to his honeymoon. When he and his wife visited a waterfall, he took out a thermometer to record the temperature difference between the top and bottom of the falls.

And how do you pronounce Joule anyway? Does it rhyme with jewels, with bowls or with scowls? The Joule Brewery used to take advantage of the confusion and created a company slogan: "Whatever you call it, it's good!"