Name: ______________________

Class: ______________________

Due Date: ______________________

A.3 Work, Energy, and Power

Understandings

- The principle of the conservation of energy.
- Work done by a force is equivalent to a transfer of energy.
- Energy transfers can be represented on a Sankey diagram.
- Work W done on a body by a constant force depends on the component of the force along the line of displacement as given by $W = Fs\ \cos\theta$.
- Work done by the resultant force on a system is equal to the change in the energy of the system.
- Mechanical energy is the sum of kinetic energy, gravitational potential energy, and elastic potential energy.
- In the absence of frictional, resistive forces, the total mechanical energy of a system is conserved.
- If mechanical energy is conserved, work is the amount of energy transformed between different forms of mechanical energy in a system such as
  - the kinetic energy of translational motion as given by $E_\mathrm{k} = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
  - the gravitational potential energy, when close to the surface of the Earth as given by $\Delta E_\mathrm{p} = mg\Delta h$
  - the elastic potential energy as given by $E_\mathrm{H} = \frac{1}{2}k\Delta x^2$
- Power developed P is the rate of work done, or the rate of energy transfer, as given by $P = \frac{\Delta W}{\Delta t} = Fv$
- Efficiency η in terms of energy transfer or power as given by $\eta = \frac{E_\mathrm{output}}{E_\mathrm{input}} = \frac{P_\mathrm{output}}{P_\mathrm{input}}$
- Energy density of the fuel sources.

Equations

$W = Fs\ \cos\theta$

$E_{\mathrm{k}} = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

$\Delta E_{\mathrm{p}} = mg\Delta h$

$E_{\mathrm{H}} = \frac{1}{2}k\Delta x^2$

$P = \frac{\Delta W}{\Delta t} = Fv$

$\eta = \frac{E_{\mathrm{output}}}{E_{\mathrm{input}}} = \frac{P_{\mathrm{output}}}{P_{\mathrm{input}}}$

Equation not given in IB Physics Data Booklet:

$W = \Delta E_{\mathrm{k}} = E_{\mathrm{k,f}} - E_{\mathrm{k,i}}$

The solutions can be found on the YouTube channels Go Physics Go

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Answer the following questions

1. C: What is the meaning of *work*? Equation? Units? Is it a scalar or vector?

2. C: What is the meaning of *energy*? Units? Is it a scalar or vector?

3. C: What is the meaning of *kinetic energy*? Equation? Define each variable.

4. C: What will happen to the kinetic energy of a moving object if its
   a. Mass halves and speed halves?
   b. Mass doubles and speed doubles?
   c. Mass decreases by three (one third) and speed increases by four (quadruples)?

5. C: What is the meaning of *potential energy*?

6. C: What is the meaning of *gravitational potential energy*? What is the equation for *gravitational potential energy* of an object near the surface of a planet? Define each variable. What is the general equation for the *gravitational potential energy* between two objects? Define each variable.

7. C: What is the equation for the *elastic potential energy* of a compressed or stretched spring? Define each variable. What is the meaning and units for the *spring constant k*?

8. C: What is the equation for the *total mechanical energy* of an object?

9. C: True or false: Work is done on an object if the object moves.

10. C: What is the work done on a 3.00 kg rock if it travels 60.0 m with a constant speed of 4.00 m/s in outer space?

11. C: What does the slope of a *force vs. displacement* graph tell us?

12. C: What does the area under a *force vs. displacement* graph tell us?

13.C: What is the meaning of *power P*? Equation? Units? Is it a scalar or vector? Do not confuse power P with pressure P or momentum $\vec{p}$ or density ρ!

14.C: What is the meaning of and the equation for the *law of conservation of energy*?

15.C: State the equation for the work-energy theorem.

16.C: What are some characteristics of a *Sankey diagram*? Sketch a simple *Sankey diagram*.
http://sankeymatic.com/

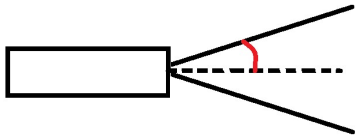
17.C: What is *efficiency*? Equation? Units? Is it a scalar or vector?

Part 2: Answer the following free response questions

1. E: A force of 120. N is applied to the front of a sled at an angle of 28.0° above the horizontal so as to pull the sled a distance of 165 m. How much work was done by the applied force?

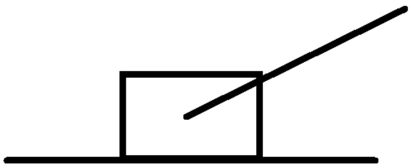
2. E: How much work would be required to lift a 12.0 kg mass up onto a table 1.15 m high?

3. E: A barge is being pulled along a canal by two cables being pulled as shown below. The tension in each cable is 1.40×10^4 N and each cable is being pulled at an angle of 18.0° relative to the direction of motion. How much work will be done in pulling this barge a distance of 3.00 km?



4. E: Job pulls a massless rope at an angle of 40.0° from the horizontal which is attached to a block of mass $m = 60.0$ kg on a rough horizontal surface with a coefficient of friction of $\mu = 0.200$ with a constant speed of 2.00 m/s for 300. m.

   a. Draw a free body diagram.



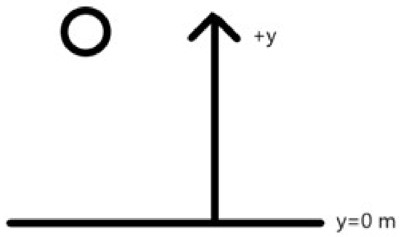
   b. Use Newton's second law of motion to find F_{pull}.

c. How much work was done by Job?

d. What is the average power performed by Job?

5. E: A 10.0 kg object initially at rest is 12.0 m above the surface of the Earth. It is released. There is no air friction.

a. Draw a figure.



b. What is the initial kinetic energy of the object?

c. What is the initial gravitational potential energy of the object?

d. What is the initial total energy of the object?

e. What is the kinetic energy of the object when it is halfway to the surface?

f. What is the gravitational potential energy of the object when it is halfway to the surface?

g. What is the total energy of the object when it is halfway to the surface?

h. What is the final gravitational potential energy of the object just before it reaches the surface?

i. What is the final kinetic energy of the object just before it reaches the surface?

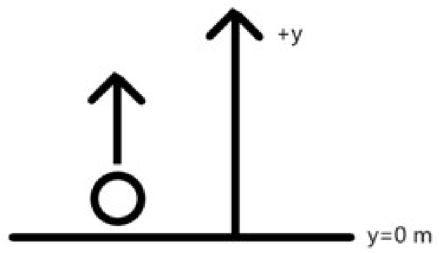
j. What is the total energy of the object just before it reaches the surface?

k. What is the final speed of the object just before it reaches the ground? From part d the total energy of the object is 1,177.2 J.

l. Draw a *gravitational potential energy vs. height* graph, a *kinetic energy vs. height* graph, and a *total energy vs. height* graph.

6. E: Jethro throws a 5.00 kg object from the surface of the Earth vertically upwards with an initial speed of 8.00 m/s. There is no air friction.

   a. Draw a figure.



   b. What is the initial gravitational potential energy of the object?

   c. What is the initial kinetic energy of the object?

   d. What is the initial total energy of the object?

   e. What is the maximum height the object will travel?

   f. How long will it take for the object to reach its maximum height?

   g. What is the gravitational potential energy of the object when it is halfway to its maximum height?

   h. What is the kinetic energy of the object when it is halfway to its maximum height?

i. What is the total energy of the object when it is halfway to its maximum height?

j. What is the gravitational potential energy of the object when it reaches its maximum height?

k. What is the kinetic energy of the object when it reaches its maximum height?

l. What is the total energy of the object when it reaches its maximum height?

m. What is the speed of the object when it reaches its maximum height?

n. Draw a *gravitational potential energy vs. height* graph, a *kinetic energy vs. height* graph, and a *total energy vs. height* graph.

7. E: A 8.00 kg object is falling vertically freely with a speed of 40.0 m/s at an elevation of h_1. What will be the speed of the object after it has fallen a distance of 70.0 m? Round your answer to two decimal places.

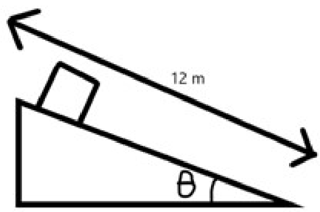
8. E: A 8.00 kg object is falling down with a speed of 40.0 m/s at an elevation of 300. m. After the object has fallen a distance of 90.0 m its speed is now 45.0 m/s.

   a. What is the magnitude of energy lost from air friction? Round your answer to two decimal places.

   b. What is the magnitude of the force of air friction during this 90.0 m? Round your answer to two decimal places.

9. E: A 7.00 kg object is placed on top of a 12.0 m long smooth incline which is 30.0° above the horizontal. It is released and slides down.

   a. Draw a figure.



   b. What is the initial height of the object?

   c. What is the initial gravitational potential energy of the object?

d. What is the initial kinetic energy of the object?

e. What is the initial total energy of the object?

f. What is the final speed of the object when it reaches the bottom of the incline?

g. What is the final kinetic energy of the object?

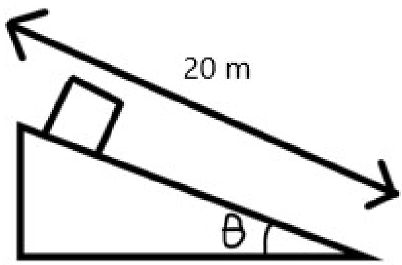
h. What is the final gravitational potential energy of the object?

i. What is the acceleration of the object?

j. How long does it take for the object to reach the bottom of the incline?

10.E: A 4.00 kg block is placed on top of a 20.0 m long rough incline which is 30.0° above the horizontal. The coefficient of friction between the block and the incline is $\mu = 0.300$. The block is released and slides down.

a. Draw a figure.



b. What is the initial height of the object?

c. What is the initial gravitational potential energy of the object?

d. What is the initial kinetic energy of the object?

e. What is the initial total energy of the object?

f. What is the normal force acting on the block?

g. What is the force of friction acting on the block?

h. What is the final speed of the object when it reaches the bottom of the incline?

i. What is the acceleration of the object?

j. What is the final kinetic energy of the object?

k. What is the final gravitational potential energy of the object?

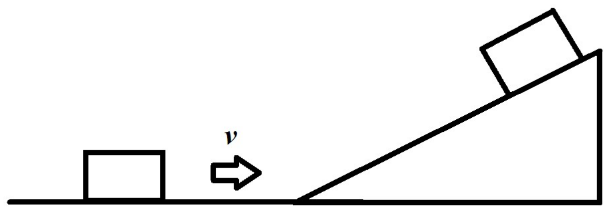
l. What is the final total energy of the object?

m. How long will it take for the object to reach the bottom of the incline?

n. How much energy was lost by the block?

11.E: A 6.00 kg block is moving to the right with a constant speed of 22.0 m/s on a horizontal frictionless surface. The block then goes up a 30.0° incline which has a coefficient of friction of 0.800.

a. Draw a figure.



b. How many meters up the incline and how high does the block move?

12.E: A force of 35.0 N is applied to a spring and as a result the spring stretches a distance of 12.0 cm.

a. What is the spring constant k for this spring?

b. How much energy will be stored in this spring?

13.E: A spring, which has a spring constant k, is hung from the ceiling. A mass of 3.00 kg is added to the end of the spring and is then slowly lowered until equilibrium is reached. At this point the bottom of the mass has been lowered a distance of 52.0 cm.

a. What is the magnitude of the force being exerted by the spring when the system reaches equilibrium?

b. What is the spring constant of this spring?

c. How much energy is stored in the spring when equilibrium is reached?

14.E: A mass of 5.00 kg is dropped from a height of 2.20 m above a vertical spring sitting on a horizontal surface. Upon colliding with the spring the mass compresses the spring 30.0 cm before it momentarily comes to a halt. Assume $h = 0.00$ m at the lowest point.

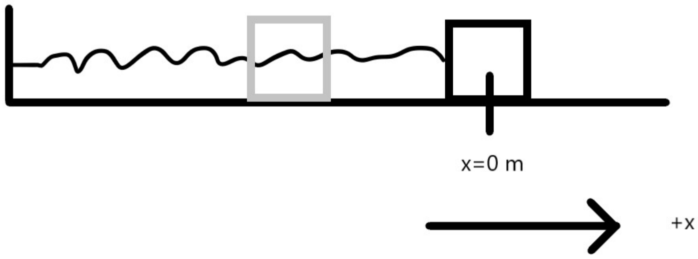
a. How much gravitational potential energy was contained in the 5.0 kg mass before it was dropped?

b. How much energy will be stored in the spring when the mass comes briefly to a halt?

c. What is the spring constant of this spring?

15.E: A horizontal spring with a spring constant $k = 3.00 \times 10^4 \ \frac{\mathrm{N}}{\mathrm{m}}$ is compressed 6.00 cm by an 800. gram block which is resting on a frictionless surface. The block is then released from rest.

a. Draw a figure.



b. What is the initial potential energy of the spring?

c. What is the kinetic energy of the block after it leaves the spring?

d. What is the final speed of the block after it leaves the spring?

e. After some distance the block moves through a rough surface with a coefficient of friction $\mu = 0.0500$. What is the total distance the block travels along the rough surface?

16.E: A mass of 2.20 kg is placed on a stiff vertical spring, which has a spring constant of 950. N/m. The object is then pressed against the spring until it has been compressed a distance of 77.0 cm. The mass is then released and is allowed to be thrown up into the air.

a. What will be the elastic potential energy stored in the spring just before the mass is released?

b. What will be the gravitational energy of this mass when it reaches the highest point?

c. How high in the air will the mass be thrown?

d. What will be the velocity of the mass just as it leaves the end of the spring?

17.E: A vertical spring is hung from one end. A mass of 5.00 kg is hung from the end of the spring. As a result of the addition of this mass the spring is stretched a distance of 125 cm.

a. What is the spring constant for this spring?

b. How much would this spring be stretched if the mass is 15.0 kg?

The 5.00 kg mass is then lifted up until the spring is unstretched. The mass is then released and is allowed to fall until at some lower point it stops. Assume that at this point $h = 0$ m.

c. How far will the mass have fallen when it stops at the lowest point?

d. What will be the gravitational potential energy stored in this system when the mass is at the lowest point?

e. What will be the kinetic energy of this system when the mass reaches the lowest point?

f. What will be the elastic potential energy stored in the spring when the mass is at the lowest point?

g. What will be the elastic potential energy stored in the system when the mass is at the highest point?

h. What will be the kinetic energy of this system when the mass is at the highest point?

i. What will be the gravitational potential energy of this system when the mass is at the highest point?

j. What will be the total energy of this system at the highest point?

k. What will be the total energy of this system at the lowest point?

l. What will be the total energy of this system when the mass is 65.0 cm below the highest point?

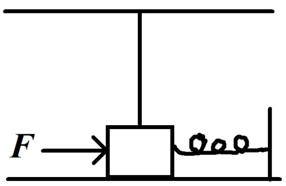
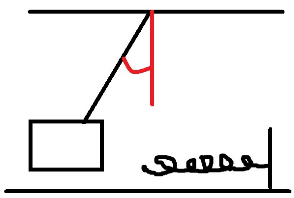
m. What will be the gravitational energy of this system when the mass is 65.0 cm below the highest point?

n. What will be the elastic potential energy of this system when the mass is 65.0 cm below the highest point?

o. What will be the kinetic energy of this system when the mass is 65.0 cm below the highest point?

p. What will be the velocity of the mass when it is 65.0 cm below the highest point?

18.E: A mass of 4.40 kg is attached at the end of a string, which is 2.60 m long, is pressed against a horizontal spring with $k = 5.60 \times 10^2\ \frac{\text{N}}{\text{m}}$ as shown below. The other end of the string is attached to the ceiling. The spring is compressed by 12.0 cm by the applied force. The mass is then released and is allowed to swing outward until at some point it stops.

Before	After
	

a. What will be the total energy of this system just before the mass is released?

b. How much force is needed to press this mass against the spring?

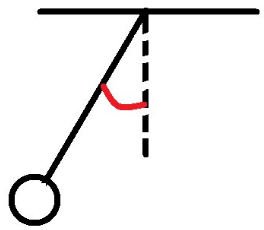
c. What will be the velocity of the mass just as it leaves the spring?

d. What will be the total energy of the mass when it reaches the highest point?

e. How high, in cm, will the mass be when it stops at the highest point?

f. What will be the angle α between the string and the vertical line as shown in the diagram when the mass reaches the highest point?

19.E: A child, which has a mass of 23.0 kg, is sitting on a swing. The ropes of the swing are 5.20 m long and the child is pulled back until the angle between the ropes of the swing and the vertical is 35.0° as shown below. The child is released and is allowed to swing back and forth.



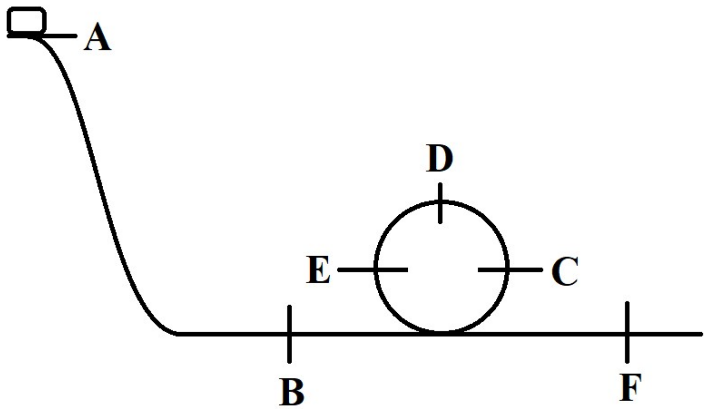
a. What is the gravitational potential energy, relative to the lowest point reached by the swing as it swings back and forth, of the child at the moment the child is released?

b. What will be the total kinetic energy of the child at the lowest point of the swing?

c. What will be the child's velocity at the bottom of the swing?

d. What will be the tension in the ropes of the swing when the child swings through the lowest point?

20.E: A 425. kg roller coaster begins from rest at a height $h_1 = 140.\text{ m}$ above the surface of the Earth. The roller coaster makes a circular loop with a radius of $r = 24.0\text{ m}$.



a. Determine the total energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

b. Determine the gravitational potential energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

c. Determine the kinetic energy of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.

d. Determine the speed of the roller coaster at points A, B, C, D, E, and F. Write neatly, show all your work, and place a box around all six of your answers.