Lesson 1

Work and Energy

Energy: the capacity to do work. (see chart p. 324)

Work: a measure of the amount of energy transferred from one object to another.

$$W = Fd$$

Where
W = work done (Joules)
F = force (Newtons)
d = displacement (metres)

According to this formula, work has units,

$$W = N \cdot m = Joule$$
$$1 Joule = 1 N \cdot m$$

Example:
How much work is required when a horizontal force of 5.0 N is applied to a box of books that moves 4.1 m?

Example:
How much work is done if the same force is applied at an angle of 37º to the horizontal?

Objects moved vertically

When objects are moved vertically at a constant speed, the object's weight must be overcome to lift an object to height h. In this case,

$$W = Fd$$
$$W = mgd$$

Example:
How much work is required to lift a 0.50 kg physics book to a height of 6.0 m at a constant speed?

Power

Power is the rate of doing work or transforming energy.

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

Since work is the amount of energy transferred,

$$P = \frac{E}{t}$$

$$units : 1W = 1\frac{J}{s}$$

In electrical appliances, power is usually specified in watts or kilowatts (eg. electric kettle 1500 W, coffee maker 900 W, toaster 850 W)

Example:

What is the power of a cyclist who transforms 2.7×10^4 J of energy in 3.0 minutes?

Example:
What is the power of a motor for a hoist that will lift a 2.0×10^2 kg object through 10.0 m in 10.0 s?

Another commonly used unit of power is horsepower.

$$1 \text{ horsepower} = 746 \text{ W}$$

Example:
How much energy is consumed when an 800.0 W dryer element in an electric dishwasher operates for 5.0 minutes?

Notice that energy and work are both measured in Joules since by definition, work is the transfer of energy.

Lesson 2

Potential and Kinetic Energy

Gravitational Potential Energy (E_g)
The type of energy possessed by an object because of its position with respect to a certain reference level.

$$E_g = mgh$$

The work done to lift an object to a certain height is equal to the object's potential energy at that height.

Example:
A 20.0 kg box of groceries is 0.50 m above a loading platform.
a) Calculate the gravitational potential energy of the box relative to the platform.
b) If the loading platform is 1.2 m above the ground, what is the potential energy of the box relative to the ground?

Kinetic Energy (E_k)

The energy of motion.

$$E_k = \frac{mv^2}{2}$$

Where
E_k = kinetic energy (J)
m = mass (kg)
Note that E_k also has units of Joules since objects can do work while moving.

Example:

What is the kinetic energy of a hammer of mass 3.0 kg while being swung at a speed of 4.0 m/s?

Example:
What is the speed of a 2.0 kg object that has a kinetic energy of 1.0×10^2 J?

Work-Energy Theorem

$$W = \Delta E_k$$

Example:
A car of mass 1.0×10^3 kg accelerates from 1.0 m/s to 4.0 m/s. How much work is done by the engine? If the car travelled 10.0 m, what was the force exerted on the car as a result of the actions of the engine?

Example:
A 50.0 g arrow is pulled back a distance of 80.0 cm in a bow. When the string is released, it exerts an average force of 60.0 N on the arrow. With what speed does the arrow leave the bow?

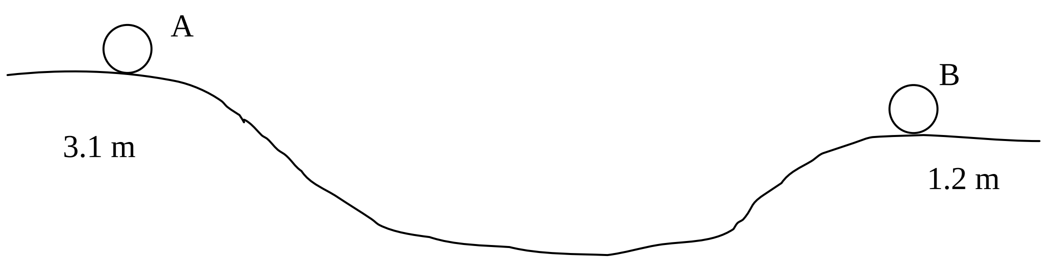
Lesson 3

Conservation of Energy

Energy can change from one form to another, but cannot be lost.

Consider:
- Potential energy is gradually converted to kinetic energy.
- Ideally 100% of the potential energy will be converted to kinetic. In reality, friction is present and some energy will be converted to other forms like heat.
- When friction is ignored, we say that we have a conservative system.

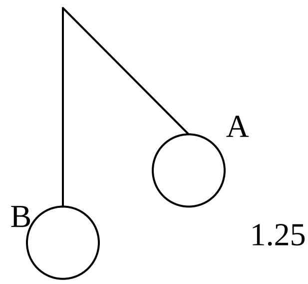
Example:



If the ball shown starts from rest at A, what is its speed at B?

Example:

What speed does the pendulum bob have at the lowest point in its swing?



Extra Examples:

Lesson 4

Elastic Potential Energy and Hooke's Law

A stretched spring can also possess stored energy. This is called elastic potential energy (E_e).

Since a stretched spring can do work as it returns to its original position, it must possess stored energy. The same is true for an elastic band or an arrow pulled back in a bow.

Springs can have different amounts of stiffness, as indicated by the spring constant k.

Hooke's Law:
The restoring force of a spring is given by,

$$F = kx$$

Where,
F = applied force (N)
k = spring constant (N/m)
x = amount stretched from the rest position (m)

Example:
The spring constant for a tire gauge is 3.0×10^2 N/m. When the tire gauge is pushed onto the valve stem of the tire the bar indicator extends 1.9 cm. What force does the air in the tire apply to the spring?

Example:
What is the spring constant for a mass of 2.0 kg hanging on a spring stretched 4.0 cm from its rest position?

Note: When a spring is stretched, we generally use positive values for F and x; we use negative values when a spring is compressed (squeezed).

If too much force is applied to a spring, it may become permanently deformed or may even break. Use of excessive force destroys the elasticity of the spring.

Energy in a Spring

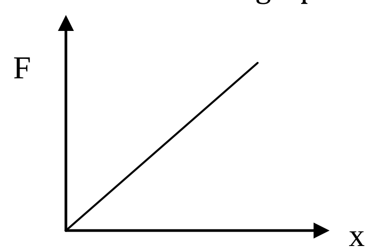
The energy stored in a spring (elastic potential energy) has the ability to do work.

$$E_e = \frac{kx^2}{2}$$

Where,
E_e = elastic potential energy (J)
k = spring constant (N/m)
x = amount of stretch or compression (m)

We can look at the work required as the area under a graph of force vs. stretch.

$$Area = \frac{1}{2}bh$$



$$Area = \frac{1}{2}Fx$$

$$but\ F = kx$$

$$So,$$

$$Area = \frac{1}{2}kx \cdot x$$

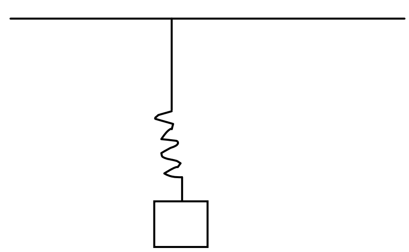
$$Area = \frac{kx^2}{2} = work$$

Example:
A spring with a force constant of 240 N/m has a 0.80 kg mass suspended from it. What is the extension of the spring and how much elastic potential energy does it have once the mass is suspended?

Example:
How much work must be done to compress a spring 4.0 cm if the spring constant is 55 N/m?

Example:
A toy gun has its spring compressed 3.0 cm by a 50.0 g projectile. The spring constant is 4.0×10^2 N/m. Calculate the velocity of the projectile if it is launched horizontally.

Simple Harmonic Motion
Consider a mass hanging from a spring as shown.



The mass has an equilibrium position where it is not moving. If the spring is stretched the spring will oscillate back and forth past the equilibrium point until equilibrium is achieved. Ideally the mass should move an equal distance above and below the equilibrium point. This does not actually happen due to damping and friction.

Motion that obeys Hooke's Law is called simple harmonic motion (SHM). The total energy of a mass-spring system is given by:

$$E_T = \frac{mv^2}{2} + \frac{kx^2}{2}$$

*Note that at maximum compression, the kinetic energy is 0 because the system is motionless. As the mass passes the equilibrium point, there is no potential energy since x=0.

Example:
Given a mass-spring system with a bob of mass 0.485 kg, a spring constant of 33 N/m and an initial displacement of 0.23 m determine,

a) the kinetic energy of the bob as it passes the equilibrium point.
b) the bob's speed as it passes the equilibrium point?

To calculate the acceleration of a mass on a spring, note that ,

$$F_{net} = F_{spring}$$

$$ma = kx$$

$$a = \frac{kx}{m}$$

Example:
A 2.0 kg mass on a spring is extended 0.30 m from the equilibrium position and released. The spring constant is 65 N/m.
a) What is the initial elastic potential energy of the spring?
b) What maximum speed does the mass reach?
c) At 0.20 m displacement, what is the speed of the mass?
d) What is the maximum acceleration?
e) What is the acceleration when the displacement is 0.20 m?

Example:
A spring stretches 0.150 m when a 0.300 kg mass is hung from it. The spring is then stretched an additional 0.100 m from this equilibrium point an released. Determine:
a) the spring constant
b) the maximum velocity.
c) the velocity when the mass is 0.050 m from equilibrium.
d) the maximum acceleration of the mass

The period of simple harmonic motion (time for one complete cycle) is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Lesson 5

Percent Efficiency

Recall labs done of work-energy theorem and conservation of energy. Friction was a big source of error in these labs that resulted in less than 100% energy transfer.

We compute a percent efficiency to determine how complete an energy transfer is.

$$Efficiency = \frac{useful\ output\ energy}{total\ input\ energy} x100\%$$

Example:
What is the efficiency of a crane that uses 5.10×10^5 J of energy to lift 1.0×10^3 kg a vertical height of 32.0 m?

Example:
A worker uses a pulley system to raise a 24.0 kg carton 16.5 m. A force of 129 N is exerted and the rope is pulled 33.0 m. What is the efficiency of the system?

Example:
A boy exerts a force of 225 N on a lever to raise a 1250 N rock a distance of 13 cm. If the efficiency of the lever is 88.7%, how far did the boy move his end of the lever?