Momentum, Energy, Work, & Power

(Chapter 3)

Student Learning Outcomes: Relate momentum to impact force; use the laws of conservation to solve problems; compare and contrast the concepts of energy, work, and power; name examples of simple machines; and contrast renewable and non-renewable energy sources.

1. *What is momentum?*
2. *How does momentum affect the force of impact?*
3. *What is conservation of momentum?*
4. *How are energy and work defined?*
5. *What is mechanical energy?*
6. *How is conservation of mechanical energy used?*
7. *How is power defined?*
8. *What does a machine do?*
9. *What is a renewable energy source?*

What is momentum?

- **Momentum is the combination of mass (inertia) and velocity.**

$$\boxed{p = mv}$$

- The standard units of momentum are:

$$\boxed{\text{kg m/s}}$$

- The greater the momentum, the harder it is to stop an object!

Questions:

1) What is an example of something that could have a large momentum because it has a large mass, if it was moving?

2) What is an example of something that would have a large momentum because it has a large velocity, even though it has a very small mass?

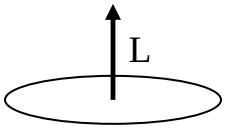
4) Which has the greater momentum? Use standard units.

a) 10,000 lb (4535 kg) 18-wheeler parked at the curb
b) 300 lb (136 kg) football player running 10 mph (4.46 m/s)
c) 150 lb (68 kg) sprinter running 22 mph (9.83 m/s)
d) 1200 kg car moving at 1 m/s

- **Angular momentum is momentum in a circular path.**

$$\mathbf{L = mvr}$$

- The angular momentum vector is perpendicular to the plane of the circular path.



Example: Bicycle

Go To: http://hyperphysics.phy-astr.gsu.edu/hbase/bike.html
http://www.youtube.com/watch?v=8H98BgRzpOM

How does momentum affect the force of impact?

- During an impact, the force of impact depends on how quickly the momentum is changed.

$$\mathbf{Ft = \Delta p}$$

- Force causes acceleration → a change in velocity
- Force times time causes an impulse → a change in momentum
- If you want to decrease the force of impact, you must somehow increase the duration of the impact.

Examples:

- Water barrels at the start of a divided highway
- Carpet vs concrete
- Features of car design

Questions:

1) You (75 kg) are riding in your 2000 kg car at 30 m/s when suddenly a squirrel runs in front of you; you swerve, and hit a tree. If the duration of the impact is ¼ of a second, what is the impact force in Newtons?

2) A 2000 kg car is traveling North with a speed of 30 m/s and another 2000 kg car is traveling South at 30 m/s, and then they hit head-on. If the duration of the impact is ¼ of a second, what is the impact force in Newtons?

What is the law of conservation of momentum?

- The total momentum of a particular system is constant whenever the net external force on the system is zero.

$p_f = p_i$	$m_i v_i = m_f v_f$

- The total amount of momentum does not change; the initial amount equals the final amount. Thus, the variables must change proportionally.

- Momentum is conserved before and after collisions, when forces are balanced.

  - **Elastic collisions**: objects rebound from each other

  - **Inelastic collisions**: objects stick together

Go To: http://www.physicsclassroom.com/mmedia/ (Momentum and Collisions)

- The total angular momentum of a system is constant whenever the net external force on the system is zero.

$L_f = L_i$	$m_i v_i r_i = m_f v_f r_i$

Examples:

- Bicycle
- Ice Skater

Go To: http://www.youtube.com/watch?v=WSg28pzVXjs

Questions: (Always assume momentum is conserved)

1) If the mass of a system is doubled, what must happen to the velocity when momentum is conserved?

2) Two cars of equal mass collide. One is traveling West at 30 m/s, the other is at rest. Then there is an inelastic collision between the two cars. Assuming momentum is conserved, what will be the final velocity of each car?

3) An ice skater spins 5 m/s with outstretched arms. The radius of the circular path that her arms trace out while she spins is 1 meter. When she pulls her arms in, changing the radius of the circular path to 0.33 m, what will be her new velocity?

How are energy and work defined?

- **Energy is the ability to do work.**

- There are many types of energy…
  - Gravitational energy (GPE)
  - Energy of motion (KE)
  - Heat energy (Q)
  - Chemical bond energy
  - Energy of Waves (light and sound)
  - Electrical energy
  - Nuclear energy
  - Energy of mass ($E = mc^2$)

- More than one type of energy can be present at a time.

- Energy can change form or become work.

- **Work is the use of energy to move an object a distance.**

- The amount of work done on an object depends on the force applied and the amount of distance an object is moved; it does not depend on the direction the object was moved.

$$\mathbf{W = Fd}$$

- The standard unit for all types of energy and for work is the **Joule**.

$$\text{Joule} = \text{N m}$$

Questions:

1) How much work would be done on a 150 lb (667 N) barbell?

a) When it is lifted 2 ft (0.61 m)?
b) While it is held overhead?
c) When it is lowered 2 ft (0.61 m)?

2) What is the work done to lift a 15 kg child up one meter?

What is mechanical energy?

- Mechanical energy is the energy an object has that is in motion or may become in motion.

- **Gravitational potential energy is the energy an object has that may fall or move from a height.**

$$\mathbf{GPE = mgh}$$

- **Kinetic energy is the energy an object has when it is in motion.**

$$\mathbf{KE = (½)\, mv^2}$$

- An object can have both GPE and KE at the same time!

Go To: http://www.physicsclassroom.com/mmedia/energy/se.cfm
http://www.physicsclassroom.com/mmedia/energy/ce.cfm

Questions:

1) A 60 kg person stands on top of a 4 m tall ladder. What is the gravitational potential energy of the person?

2) Which has more kinetic energy? Which had more momentum? Which has the greatest inertia?

a) A 10,000 lb (4535 kg) 18-wheeler parked at the curb
b) A 300 lb (136 kg) football player running 10 mph (4.47 m/s)
c) A 150 lb (68 kg) sprinter running 22 mph (9.83 m/s)
d) A 1200 kg car moving at 1 m/s

3) How much work can the football player do on an opposing player?

How is conservation of mechanical energy used?

- ❖ Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy in the universe is conserved.

- ❖ Mechanical energy is conserved when no energy is lost or gained by the system.

For Systems on a Hill

$$\mathbf{GPE_{top} = KE_{bottom}}$$

- ❖ Mechanical energy may also be transformed into work.

Energy = Work

Go To: http://www.youtube.com/watch?v=mhIOylZMg6Q

Questions: (Always assume energy is conserved)

1) A 10 kg steel ball is dropped 12 meters from the roof of a building onto a concrete sidewalk.

a) What is the initial energy?
b) What is the KE the instant before impact?
c) What happens to this KE?

2) The 68 kg skier begins at the top of a hill with 20,000 J of energy.

a) How much gravitational potential energy does the skier have a quarter of the way down the mountain?

b) How much kinetic energy does the skier have 75% of the way down?

c) When are GPE and KE equal?

d) If the skier runs into someone at the bottom of the hill, how much work could they do on that person?

e) If the skier is traveling 24 m/s at the bottom of the hill, what is the height of the hill she traveled down?

What is Power?

- **Power is the rate at which work is done, or the rate at which energy is used.**

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

- The standard unit of power is the **Watt**.

$$\text{Watts} = \frac{\text{Joules}}{\text{sec}}$$

(1 hp = 745.7 W)

Examples: 350 hp engine vs. 250 hp engine
200-Watt vs. 60-Watt light bulb

Questions:

1) How much power is needed to lift a 150 lb (667 N) barbell 2 ft (0.61 m), in 0.25 seconds? How many horsepower is this?

2) What is the energy used by a 60 Watt light bulb in 2 hours?

3) What exactly is a kWh?

What does a machine do?

- **Machines transform energy into work.**

- The most basic machine is the **lever**.

Go To: http://www.youtube.com/watch?v=W7SvmZgfRj4

- When force is applied perpendicular to a lever arm, the force acts "through" the lever arm. This is called **torque**.

$$\tau = Fd$$

- The standard unit of torque is the **Joule**.

- The placement of the fulcrum, determines the amount of force that can be applied at the other end of the lever.

Questions:

1) If a 667 N person sits 3 meters from the pivot, where would a 533 N person need to sit to balance a seesaw?

2) A wrench measures 12 inches on the long side and 2 inches on the short side. If a person applies 300 N to the long side of the wrench, how many Newtons are exerted on the other end of the wrench?

- Another basic machine is the **pulley**; the more pulleys in the system, the more work the pulley does for you.

What is a renewable energy source?

- Renewable energy sources can be replenished in a short period of time.
- **Biomass** is organic material made from plants and animals; it comes from trees, grasses, manure, and some garbage. **(heat, steam, electricity, fuels)**
- **Hydropower** is the use of water to generate electricity. The flow of water is used to turn blades in a turbine, spin a generator. **(electricity)**
- **Geothermal** energy is heat from within the Earth. Radioactive decay heats ground water producing steam and hot water. **(heat, electricity)**
- **Wind** energy is used primarily to generate electricity. Windmills convert energy from the flow of air to mechanical energy. **(work, electricity)**
- **Solar** energy is radiation from the Sun. Solar cells convert radiation to electricity. **(electricity)**

Go To: http://www.youtube.com/watch?v=eXejxcW-XGo
http://www.youtube.com/watch?v=x2zjdtxrisc