

Chapter 3: Momentum & Energy

- Momentum
- Energy
- Work
- Potential Energy
- Kinetic Energy
- Machines

3.1. Momentum

- The older concept of impedo
- The modern concept of momentum
- Momentum = mass x velocity
- $p = mv$

3.2. Impulse

- An impulse is a change in momentum
- An impulse is caused by a force acting for a period of time
- Impulse = Force x Time

3.3. Impulse-Momentum

- Impulse = Change in Momentum
- $\Delta p = \Delta mv = Ft$
- A force also produces an acceleration
- So when a force is applied for a time t , the result is a change in velocity, $v = at$, and a change in momentum, $p = \Delta mv$

Case 1: Increasing Momentum

- When a force is applied to a motionless object, its momentum is increased
- The momentum increase can be made larger by allowing the force to act for a longer time

- Rapid changes in momentum are usually due to collisions
- Collisions occur very quickly

Case 2: Decreasing Momentum over a Long Time

- Momentum is decreased when a force acts in the opposite direction from the velocity
- There are two ways to stop an object:
 - Large force for short time
 - Small force for long time
- To avoid damage the second method is better as it requires less force

Case 3: Decreasing Momentum over a Short Time

- Shorter time means more force in a collision

Bouncing

- When a ball rebounds from a wall, the momentum change is increased
- So bouncing back produces more force than just stopping

3.4. Conservation of Momentum

- If a cannon is fired, the cannonball goes one way and the cannon recoils in the opposite direction
- Both cannon and cannonball are moving after the cannon is fired
- So they both have momentum

The Law of Conservation of Momentum

- In the absence of an external force, the momentum of a system remains unchanged
- So momentum is conserved unless an external force is applied
- Purely internal forces don't change the momentum of a system since these forces come in equal but opposite pairs

Collisions

- The law of conservation of momentum is best shown in a collision
- If two balls collide, the total combined momentum of the balls after the collision must equal that from before the collision
- Net momentum before collision =
Net momentum after collision

3.5. Energy

- Energy is a concept that was developed in the 19th century
- The idea of energy comes from Newton's Laws
- Problems can be solved using energy more easily than using Newton's Laws directly
- Energy has many forms

Work

- Work is the transfer of energy
- One kind of mechanical energy transfer is the work done by a force
- Work = Force x Distance
- $W = Fd$
- Thus mechanical work is done when a force moves an object through a distance

- A force alone does no work
- Pushing against a wall does no work unless the wall is moved in the direction of the force
- No movement, No work
- The unit of work (and energy) is the Joule
- 1 Joule = 1 N x 1 m

3.6. Power

- Power is the rate at which work is done
- $\text{Power} = \text{Work} / \text{Time}$
- The unit of power is the Watt
- $1 \text{ Watt} = 1 \text{ Joule} / 1 \text{ second}$
- The power company uses kW or kilowatts for power
- $\text{Energy} = \text{Power} \times \text{Time}$
- $1 \text{ KWH} = 1 \text{ kilowatt} \times 1 \text{ hour}$

3.7. Potential Energy

- Stored energy is called potential energy
- Energy can be stored in coiled springs, in electrical batteries, in burnable fuels, and in many other ways
- Mechanical potential energy is generally stored in springs and in the earth's gravitational field
- Gravitational potential energy is the easiest to understand

Gravitational Potential Energy

- When a force raises a mass in the earth's gravitational field, it does work
- The work is the product of the weight of the mass, mg , and the height change, h
- So the work done is $W = mgh$
- Where does that work go?
- It is stored as gravitational potential energy: $PE = mgh$
- The gravitational potential energy, mgh , is stored
- The stored energy can be recovered by letting the mass fall back to the ground
- This is the way that hydroelectric power is generated
- The water behind a dam at height h drops through an electric turbine and converts the mgh to electrical energy

3.8. Kinetic Energy

- When a force acts on a mass and accelerates it, the force also does work
- The energy transferred is stored in the mass as Kinetic Energy (KE)
- The formula for kinetic energy is:
- $KE = mv^2/2$
- Kinetic Energy (KE) is energy of motion
- Potential Energy (PE) is energy of position

Work-Energy Theorem

- Mechanical energy is lost only when frictional forces are present
- Kinetic energy can be used to do work
- $W = \Delta KE$, work done equals the change in kinetic energy
- This is the work-energy theorem

Energy vs. Momentum

- What is the difference between energy and momentum?
- Energy is a scalar; momentum is a vector
- Momentum depends on velocity
- Kinetic energy depends on the square of the velocity
- Momentum has only one form
- Energy has many forms

3.9. Conservation of Energy

- When energy is transformed from one form to another, the total amount of energy is conserved
- Energy is never lost though it may change form
- This also means that the energy of a system is constant unless energy is added or subtracted by an external force

The Pendulum

- A pendulum is a mass supported by a string
- A pendulum is a good example of conservation of mechanical energy

- A pendulum has all its energy in the form of KE when the mass is at the lowest point
- All the energy is in the form of PE when the mass is at its highest point
- The total energy of a pendulum is the sum of the kinetic and potential energies
- $E = KE + PE$
- As the mass swings up, KE falls and PE rises
- As the mass swings down, KE rises and PE falls
- But the total E is always a constant

3.10. Machines

- A machine is a device for multiplying forces or changing the direction of forces
- A lever is a simple machine
- A wedge is a simple machine
- Machines usually trade off force for distance
- More force means less distance

Efficiency

- Efficiency in a machine is defined as the ratio of work done to energy used
- $\text{Efficiency} = \text{Work Done} / \text{Energy Used}$
- An electric heater converts almost 100% of the energy used into heat
- Most machines are less efficient
- Wasted energy that doesn't go into useful work usually appears as heat

3.11. Sources of Energy

- All energy ultimately comes from the sun (or another star)
- All burnable substances were originally made using energy from

sunlight

- Hydroelectric power comes from water evaporated by sunlight
- Wind power is due to the uneven heating of air due to sunlight

- Nuclear power plants “burn” radioactive fuel that was originally were created in other stars
- Geothermal power comes from the hot interior of the earth which is due to the natural radioactive decay of elements deep within the earth
- So all power is ultimately solar power