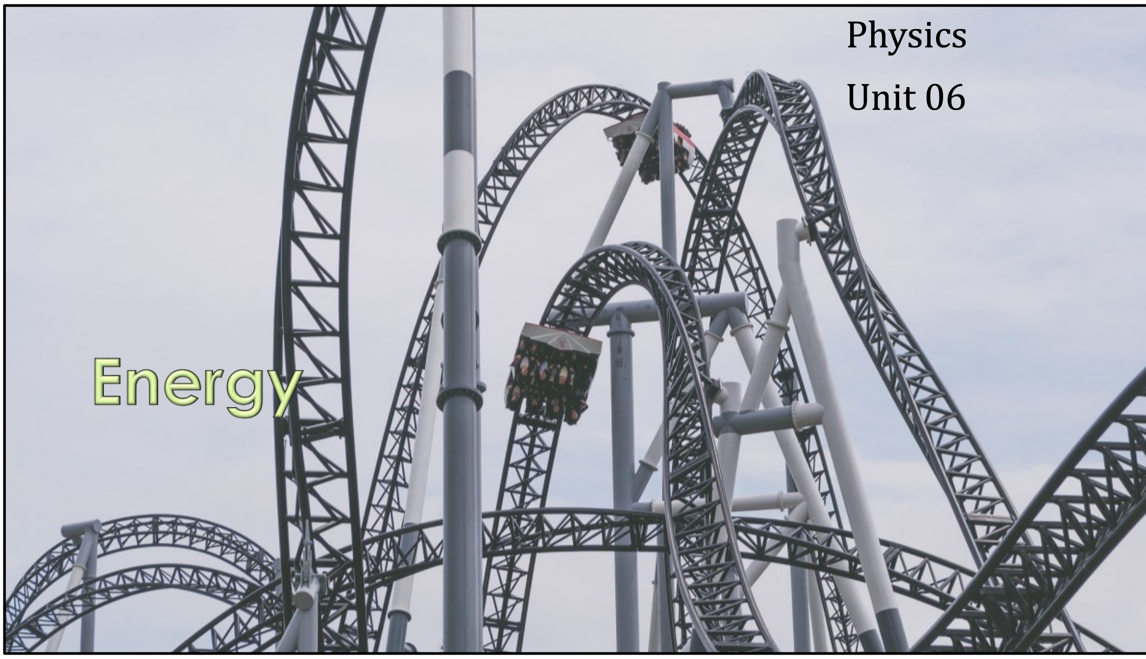
Physics
Unit 06
Energy

Credits

- This Slideshow was developed to accompany the textbook
  - *OpenStax High School Physics*
    - *Available for free at https://openstax.org/details/books/physics*
    - *By Paul Peter Urone and Roger Hinrichs*
    - *2020 edition*
- Some examples and diagrams are taken from the *OpenStax College Physics, Physics,* and *Cutnell & Johnson Physics* 6th ed.

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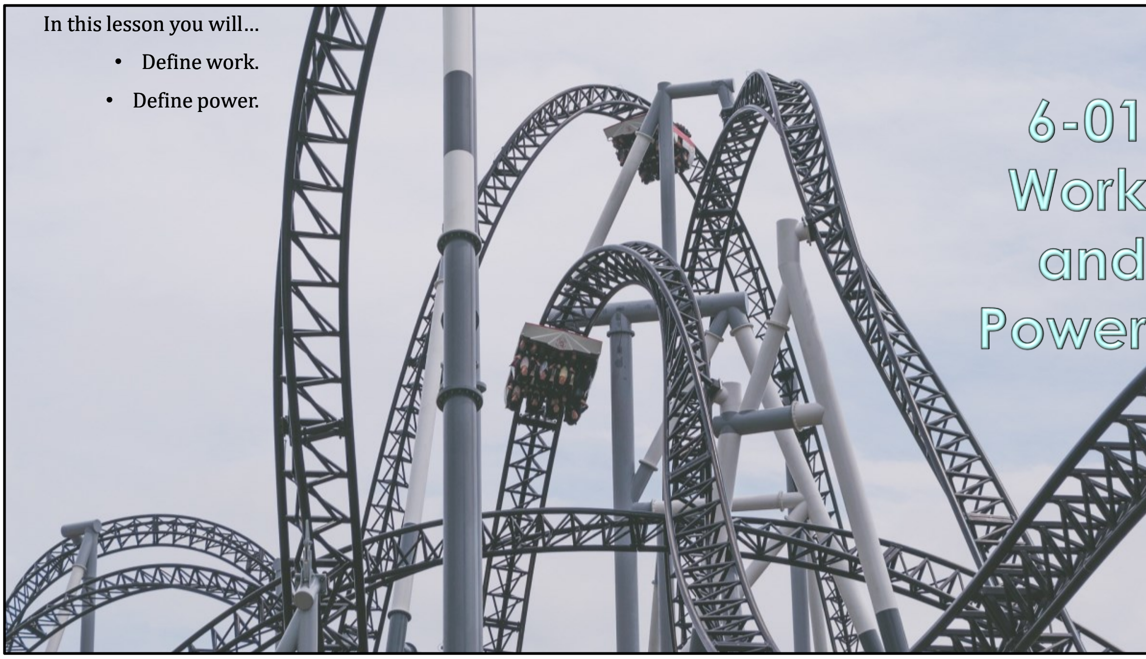


NAD 2022 Standards
ECV1: Energy Conservation

OpenStax High School Physics 9.1
OpenStax College Physics 2e 7.1, 7.7

- Which of the following is NOT work?
  - Pushing a Stalled Car
  - Pulling a Wagon
  - Climbing stairs
  - Falling Down
  - Carrying a Heavy Backpack Down the Hall

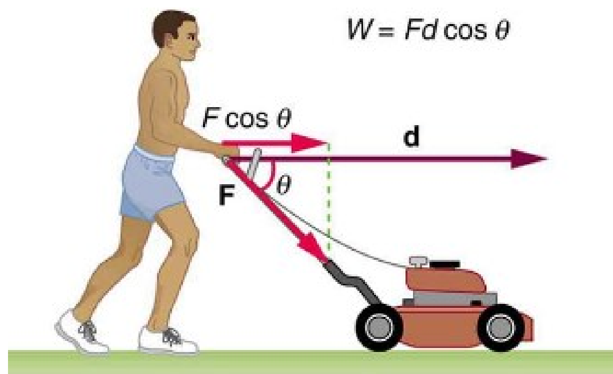
6-01 Work and Power

- Work
  - Depends on the force and the distance the force moves the object.
  - Want the force in the direction of the distance

$$W = \vec{F} \cdot \vec{d}$$

$$W = Fd\cos\theta$$

- Unit: $N \cdot m = J$ (Joule) (Scalar)
- Watch Eureka! 08

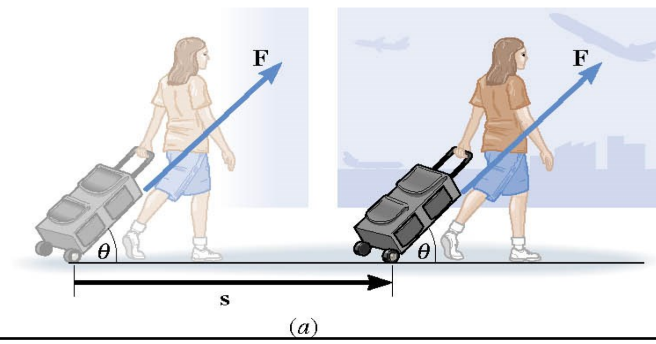


$$J = \frac{kg \cdot m^2}{s^2}$$

6-01 Work and Power

- Marcy pulls a backpack on wheels down the 100-m hall. The 60-N force is applied at an angle of 30° above the horizontal. How much work is done by Marcy?

- W = 5200 J



$$W = Fd\cos\theta$$
$$W = (60\ N)(100\ m)\cos 30° = 5196\ J$$

6-01 Work and Power

- Drew is carrying books (200 N) down the 100-m hall. How much work is Drew doing on the books?

- W = 0 J

- The force is vertical displacement is horizontal.

$$W = Fd\cos\theta$$
$$W = (200\ N)(100\ m)\cos 90° = 0\ J$$

6-01 Work and Power

- You carry some books (200 N) while walking down stairs height 2 m and length 3 m. How much work do you do?

- W = −400 J

F = 200 N (lift up)
d = 2 m (down)

$$W = Fd\cos\theta = (200\ N)(2\ m)\cos 180° = -400\ J$$

6-01 Work and Power

- A suitcase is hanging straight down from your hand as you ride an escalator. Your hand exerts a force on the suitcase, and this force does work. Which one of the following is correct?
- The W is negative when you ride up and positive when you ride down
- The W is positive when you ride up and negative when you ride down
- The W is positive
- The W is negative

6-01 Work and Power

- Two cars with the same mass do the same amount of work to get to 100 km/h.
- Which car is better
    - Takes 8.0 s
    - Takes 6.2 s
- Sometimes the time taken to do the work is important

6-01 Work and Power

- Rate that work is done

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

- Unit: joule/s = **watt (W)**

Unit named after James Watt who invented the steam engine
In the American system, horsepower is often used
One horsepower is moving 550 pounds 1 foot in 1 second

6-01 Work and Power

- Since work changes the amount of energy in an object

- Power is the rate that energy is changing

Power in the human body would be how quickly calories are being burned
Look at the table on page 166 to compare the power with the activity

6-01 Work and Power

- A 1000 kg car accelerates from 0 to 100 km/h in 3.2 s on a level road. Find the average power of the car.

- P = 121000 W
    - 162 horsepower

$v_0 = 0$
v_f = 100 km/h = 27.78 m/s
t = 3.2 s
m = 500 kg

$$P = \frac{W}{t}$$
$$P = \frac{Fd}{t}$$
$$P = \frac{mad}{t}$$
$$v^2 = v_0^2 + 2a(x - x_0)$$
$$v^2 - v_0^2 = 2ad$$
$$\frac{v^2 - v_0^2}{2} = ad$$
$$P = \frac{\frac{m(v^2 - v_0^2)}{2}}{t}$$

$$P = \frac{\frac{(1000\ kg)\left(\left(27.78\frac{m}{s}\right)^2 - 0^2\right)}{2}}{3.2\ s} = 121000\ W$$

6-01 Work and Power

- Electrical Energy
  - Often measured in kWh because $Pt = W$
- If it costs \$0.10 per kWh, how much will it cost to run a 1000 W microwave for 2 minutes?

$$P = 1000\ W = 1\ kW, t = 2\ min = \frac{1}{30} h$$

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

$$1\ kW = \frac{W}{\frac{1}{30}\ h}$$

$$W = \frac{1}{30}\ kWh$$

$$cost = \frac{1}{30} kWh(\$0.10) = \$0.0033$$

6-01 Practice Work

- Power through these problems.

- Read
  - OpenStax College Physics 2e 7.2-7.4
  - OR
  - OpenStax High School Physics 9.2

NAD 2022 Standards
ECV1: Energy Conservation

OpenStax High School Physics 9.2
OpenStax College Physics 2e 7.2-7.4

6-02 Types of Energy

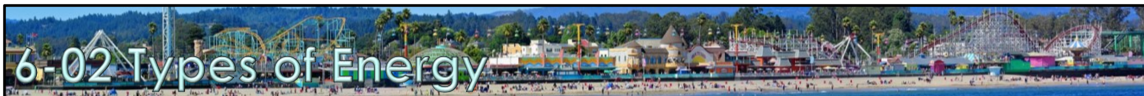
- Energy is the ability to do work
- Kinetic Energy - Energy due to motion
  - If something in motion hits an object, it will move it some distance
- $KE = \frac{1}{2}mv^2$
  - Scalar
  - Unit is joule (J)
  - Watch Eureka! 09

6-02 Types of Energy

* Rotational Kinetic Energy

$$KE = \frac{1}{2} I\omega^2$$

* Refer back to previous notes to find the formulas for the moment of inertia, *I*.



6-02 Types of Energy

- Potential energy
  - Energy due to position
- $W = Fd$
- Gravity
- $W_{gravity} = mgh$

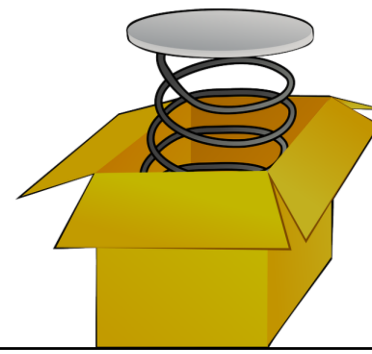
$$PE = mgh$$

- Since the force of gravity is down
  - We only worry about the vertical distance
- Potential Energy is not absolute
  - It is a difference
- The path the object takes doesn't matter, just the vertical distance
- h is measured from any chosen point. Just be consistent

6-02 Types of Energy

- Spring Potential Energy
  - $W = Fd$
  - $F = kx$ and $d = x$, but it requires calculus to properly calculate the work because the size of the force changes with the distance.

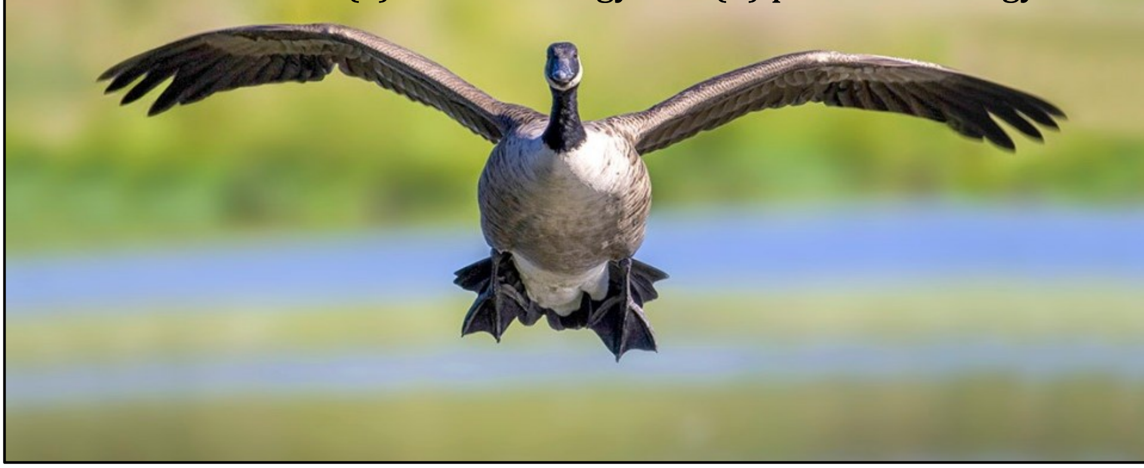
$$PE_S = \frac{1}{2}kx^2$$



$$W = Fd$$
$$PE_S = (average\ from\ 0\ to\ kx\ by\ Hooke's\ Law)x$$
$$PE_S = \frac{1}{2}kx \cdot x$$
$$PE_S = \frac{1}{2}kx^2$$

6-02 Types of Energy

- A 5.2-kg Canada goose is flying towards you at 18 m/s and a height of 3 m. What is its (a) kinetic energy and (b) potential energy?



a. $KE = \frac{1}{2}mv^2$

$$KE = \frac{1}{2}(5.2\ kg)\left(18\frac{m}{s}\right)^2 = 840\ J$$

b. $PE = mgh$

$$PE = (5.2\ kg)\left(9.8\frac{m}{s^2}\right)(3\ m) = 150\ J$$

6-02 Types of Energy

- Let's say a coil suspension spring on a car is compressed 9.0 cm after it is installed in a car. If it has a spring constant of 33000 N/m, what is the potential energy stored in the spring?

$$PE_S = \frac{1}{2}kx^2$$

$$PE_S = \frac{1}{2}\left(33000\frac{N}{m}\right)(0.09m)^2$$

$$PE_S = 130\,J$$

6-02 Practice Work

- Increase your potential while practicing with these problems.

- Read
  - OpenStax College Physics 2e 7.4
  - OR
  - OpenStax High School Physics 9.2

NAD 2022 Standards
ECV1: Energy Conservation

OpenStax High School Physics 9.2
OpenStax College Physics 2e 7.4

6-03 Mechanical Energy Conservation

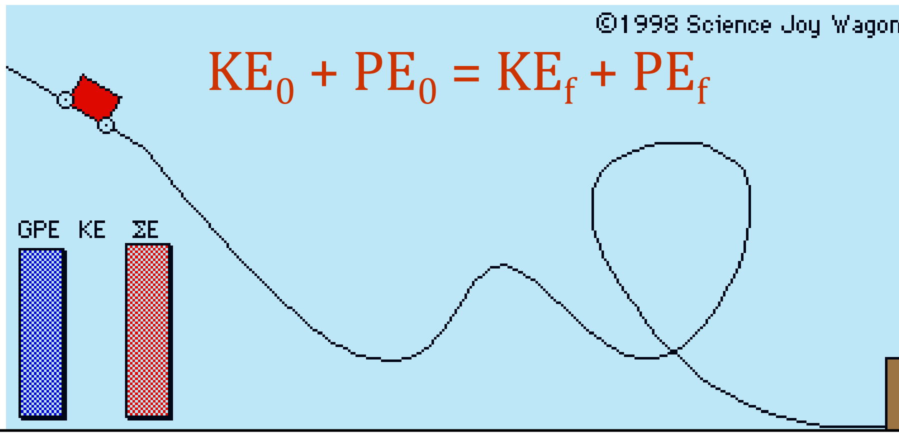
- Potential energy can be converted into Kinetic energy and back
- Think of an object thrown up
- Bottom → 0 PE, high KE
- Top → high PE, 0 KE

- $\Delta KE = -\Delta PE$
- $KE_f - KE_0 = -(PE_f - PE_0)$
- Rearrange
- Conservation of Mechanical Energy

$$KE_f + PE_f = KE_0 + PE_0$$

6-03 Mechanical Energy Conservation

- If there is only kinetic and potential energy
- Total mechanical energy is constant



$$KE_0 + PE_0 = KE_f + PE_f$$

6-03 Mechanical Energy Conservation

- A toy gun uses a spring to shoot plastic balls ($m = 50\ g$). The spring is compressed by 3.0 cm. Let $k = 2.22 \times 10^5\ N/m$.
- (a) Of course, you have to do some work on the gun to arm it. How much work do you have to do?
- (b) Suppose you fire the gun horizontally. How fast does the ball leave the gun?
- (c) Now suppose you fire the gun straight upward. How high does the ball go?

$$a)\ W = Fd$$
$$W = \frac{1}{2}kx^2$$
$$W = \frac{1}{2}\left(2.22 \times 10^5 \frac{N}{m}\right)(0.03\ m)^2 = 99.9\ J$$

$$b)\ KE_f + PE_f = KE_0 + PE_0$$
$$\frac{1}{2}mv_f^2 + \frac{1}{2}kx_f^2 = \frac{1}{2}mv_0^2 + \frac{1}{2}kx_0^2$$
$$\frac{1}{2}(0.050\ kg)v_f^2 + 0 = 0 + \frac{1}{2}\left(2.22 \times 10^5 \frac{N}{m}\right)(0.03\ m)^2$$
$$0.025\ kg\ v_f^2 = 99.9\ J$$
$$v_f^2 = 3996 \frac{m^2}{s^2}$$
$$v_f = 63.2 \frac{m}{s}$$
$$c)\ KE_f + PE_{Gf} + PE_{Sf} = KE_0 + PE_{G0} + PE_{S0}$$

At end of barrel

$$\frac{1}{2}mv_f^2 + mgh_f + 0 = 0 + 0 + \frac{1}{2}kx_0^2$$

$$\frac{1}{2}(0.050\ kg)v_f^2 + (0.050\ kg)\left(9.80\frac{m}{s^2}\right)(0.03\ m) = \frac{1}{2}\left(2.22 \times 10^5\frac{N}{m}\right)(0.03\ m)^2$$

$$0.025\ kg\ v_f^2 + 0.0147\ J = 99.9\ J$$

$$0.025\ kg\ v_f^2 = 99.8853\ J$$

$$v_f^2 = 3995.412\frac{m^2}{s^2}$$

$$v_f = 63.2\frac{m}{s}$$

At top of path

$$KE_f + PE_{Gf} = KE_0 + PE_{G0}$$

$$\frac{1}{2}mv_f^2 + mgh_f = \frac{1}{2}mv_0^2 + mgh_0$$

$$0 + (0.050\ kg)\left(9.80\frac{m}{s^2}\right)h_f = \frac{1}{2}(0.050\ kg)\left(63.2\frac{m}{s}\right)^2 + 0$$

$$\left(0.49\ kg \cdot \frac{m}{s^2}\right)h_f = 99.9\ J$$

$$h_f = 204\ m$$

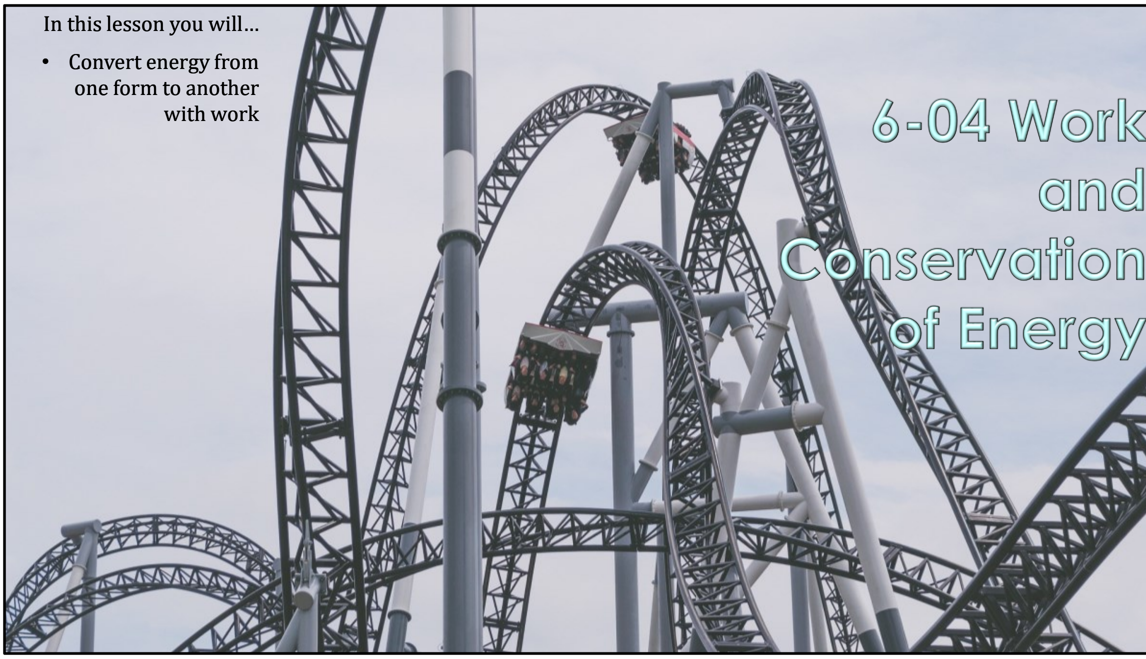
6-03 Mechanical Energy Conservation

- A 1500-kg car is driven off a 50-m cliff during a movie stunt. If it was going 20 m/s as it went off the cliff, how fast is it going as it hits the ground?

$$PE_0 + KE_0 = PE_f + KE_f$$
$$mgh_0 + \frac{1}{2}mv_0^2 = mgh_f + \frac{1}{2}mv_f^2$$
$$(1500\ kg)\left(9.8\frac{m}{s^2}\right)(50\ m) + \frac{1}{2}(1500\ kg)\left(20\frac{m}{s}\right)^2 = 0 + \frac{1}{2}(1500\ kg)v_f^2$$
$$v_f = 37.1\ m/s$$

6-03 Practice Work

- Don't try to conserve energy. Actually do the work.
- Read
  - OpenStax College Physics 2e 7.5-7.6
  - OR
  - OpenStax High School Physics 9.2



NAD 2022 Standards
ECV1: Energy Conservation

OpenStax High School Physics 9.2
OpenStax College Physics 2e 7.5-7.6

6-04 Work and Conservation of Energy

- We can write Work done by net external force as
  - $W_{net} = \Delta KE + \Delta PE$
  - $KE_0 + PE_0 + W_{net} = KE_f + PE_f$
  - $E_0 + W_{net} = E_f$

6-04 Work and Conservation of Energy

- Law of Conservation of Energy
  - The total energy is constant in any process. It may change form or be transferred from one system to another, but the total remains the same

- Energy is transformed from one form to another
  - Box sliding down incline
    - PE transformed to KE
    - KE transformed to Heat and Sound
  - Engine
    - Chemical to KE and Heat

- A rocket starts on the ground at rest. Its final speed is 500 m/s and height is 5000 m. If the mass of the rocket stays approximately 200 kg. Find the work done by the rocket engine.

- $W = 3.48 \text{ x } 10^7$ J

$$E_0 + W_{nc} = E_f$$

$$\frac{1}{2}mv_0^2 + mgh_0 + W_{nc} = \frac{1}{2}mv_f^2 + mgh_f$$

$$\frac{1}{2}(200\ kg)(0)^2 + (200\ kg)\left(9.8\frac{m}{s^2}\right)(0) + W_{nc}$$

$$= \frac{1}{2}(200\ kg)\left(500\frac{m}{s}\right)^2 + (200\ kg)\left(9.8\frac{m}{s^2}\right)(5000\ m)$$

$$W_{nc} = 2.50 \times 10^7\ J + 9.80 \times 10^6\ J$$

$$W_{nc} = 3.48 \times 10^7\ J$$

6-04 Work and Conservation of Energy

- A 1500-kg car's brakes failed and it coasts down a hill from rest. The hill is 10 m high and the car has a speed of 12 m/s at the bottom of the hill. How much work did friction do on the car?

- $W_f = -39000$ J

$$E_0 + W_{nc} = E_f$$
$$\frac{1}{2}mv_0^2 + mgh_0 + W_{nc} = \frac{1}{2}mv_f^2 + mgh_f$$
$$0 + (1500\ kg)\left(9.8\frac{m}{s^2}\right)(10\ m) + W_{nc} = \frac{1}{2}(1500\ kg)\left(12\frac{m}{s}\right)^2 + 0$$
$$W_{nc} = -39000\ J$$

6-04 Work and Conservation of Energy

- Captain Proton's rocket pack provides 800,000 J of work to propel him from resting on his ship which is near the earth to 50 m above it. Captain Proton's mass is 90 kg. What is his final velocity?

- v = 130 m/s

$$E_0 + W_{nc} = E_f$$
$$\frac{1}{2}mv_0^2 + mgh_0 + W_{nc} = \frac{1}{2}mv_f^2 + mgh_f$$
$$0 + 0 + 800000\ J = \frac{1}{2}(90\ kg)v_f^2 + (90\ kg)\left(9.8\frac{m}{s^2}\right)(50\ m)$$
$$129.6\frac{m}{s} = v_f$$

6-04 Practice Work

- How much work do you do while you convert energy into solutions.

- Read
  - OpenStax College Physics 2e 9.5
  - OR
  - OpenStax High School Physics 9.3

NAD 2022 Standards
ECV1: Energy Conservation

OpenStax High School Physics 9.3
OpenStax College Physics 2e 9.5

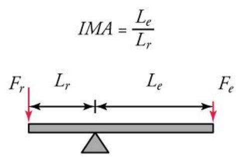
6-05 Simple Machines

- Simple Machines
  - Make work easier
  - Do not change the amount of work done
  - Do change the force required to do work
    - $W = Fd$
  - If work stays constant
    - $F_1 d_1 = F_2 d_2$
  - Less force means move over more distance

6-05 Simple Machines

- Mechanical Advantage
  - The ratio of how much the simple machine multiplies the effort force (F_e) into the resistance force (F_r) required force to do work
    - $MA = \frac{F_r}{F_e}$
  - Because $F_e d_e = F_r d_r$
  - Ideal Mechanical Advantage
    - $IMA = \frac{F_r}{F_e} = \frac{d_e}{d_r}$

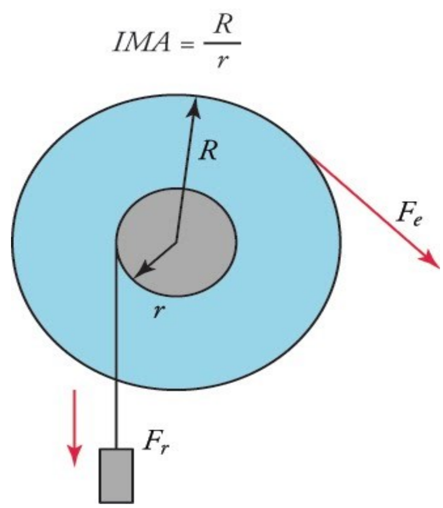
- Lever



- The rotation point is called the fulcrum

6-05 Simple Machines

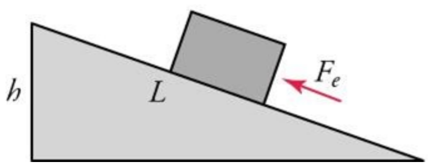
- Wheel and Axle
  - Actually a lever where effort arm can rotate completely around the fulcrum
- d_e is the radius of the wheel R
- d_r is the radius of the axle r



Inclined Plane

- Sloped surface such as a ramp
- d_e = Length
- d_r = height

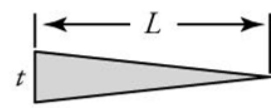
$$IMA = \frac{L}{h}$$



Wedge

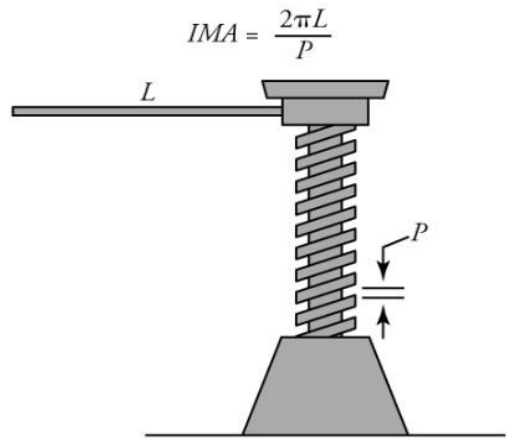
- Two inclined planes put together
- d_e = Length
- d_r = thickness

$$IMA = \frac{L}{t}$$

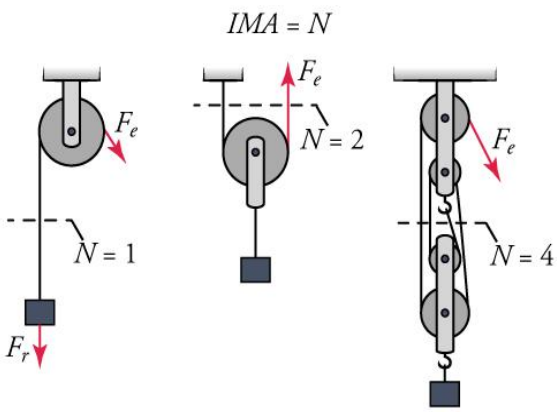


6-05 Simple Machines

- Screw
  - Inclined plane wrapped around a wheel and axle
  - Lever attached to circular inclined plane
  - d_e = circumference of screwdriver ($2\pi L$)
  - d_r = distance between treads (pitch, p)



6-05 Simple Machines



- Pulley
  - Rope wrapped around a wheel and axle
    - Which was a lever
  - d_e = distance the rope is pulled
  - d_r = distance the weight is lifted
  - When a 2nd rope supports the weight, then the distance it travels is halved
  - MA = number of ropes supporting the weight

- Find the ideal mechanical advantage of a ramp of length 10 m and height 3 m.
- Find the ideal mechanical advantage of a 3 m lever whose fulcrum is 50 cm from one end with the load.

$$IMA = \frac{L}{h}$$
$$IMA = \frac{10\ m}{3\ m} = 3.33$$

$$IMA = \frac{L_e}{L_r}$$
$$IMA = \frac{2.5\ m}{0.5\ m} = 5$$

- What is the ideal mechanical advantage of a pulley that is supporting the load by 4 ropes?
- How much rope needs to be pulled to lift the load 2 m?
- If the load's mass is 120 kg, how much force is required to lift the load?

$$IMA = N = 4$$

$$IMA = \frac{d_e}{d_r}$$
$$4 = \frac{d_e}{2\ m}$$
$$8\ m = d_e$$

$$IMA = \frac{F_r}{F_e}$$
$$4 = \frac{120\ kg \cdot 9.8 \frac{m}{s^2}}{F_e}$$
$$4F_e = 1176\ N$$
$$F_e = 294\ N$$

6-05 Simple Machines

- Efficiency
  - Useful energy output is always less than energy or work input
    - Some energy lost to friction, heat, etc.

$$Efficiency\ (Eff) = \frac{\text{useful energy or work output}}{\text{total energy or work input}} \times 100\%$$

$$= \frac{W_{out}}{W_{in}} \times 100\%$$

- The actual efficiency of a screw is 94%. The screwdriver handle has a radius of 1.25 cm, and the screw has a pitch of 1 mm and radius of 1.2 mm. If it takes 9 N of force on the screwdriver to screw it in, what is the frictional force resisting the screw?

$$IMA = \frac{2\pi L}{P} = \frac{2\pi(1.25\ cm)}{0.1\ cm} = 25\pi$$

Ideal resistive force

$$IMA = \frac{F_r}{F_e}$$
$$25\pi = \frac{F_r}{9\ N}$$
$$F_r = 225\pi\ N$$

Effort distance for 1 rotation

$$C = 2\pi r = 2\pi(0.0125\ m) = 0.025\pi\ m$$

Resistance distance for 1 rotation (pitch)

$$d_r = 0.001\ m$$

Find actual resistance distance

$$efficiency = \frac{W_o}{W_i} \times 100\%$$
$$94\% = \frac{F_r(0.001\ \ m)}{(9\ N)(0.025\ \pi\ m)} \times 100\%$$

$$0.94 = F_r\left(0.00141\,\frac{}{N}\right)$$

$$664\ N = F_r$$

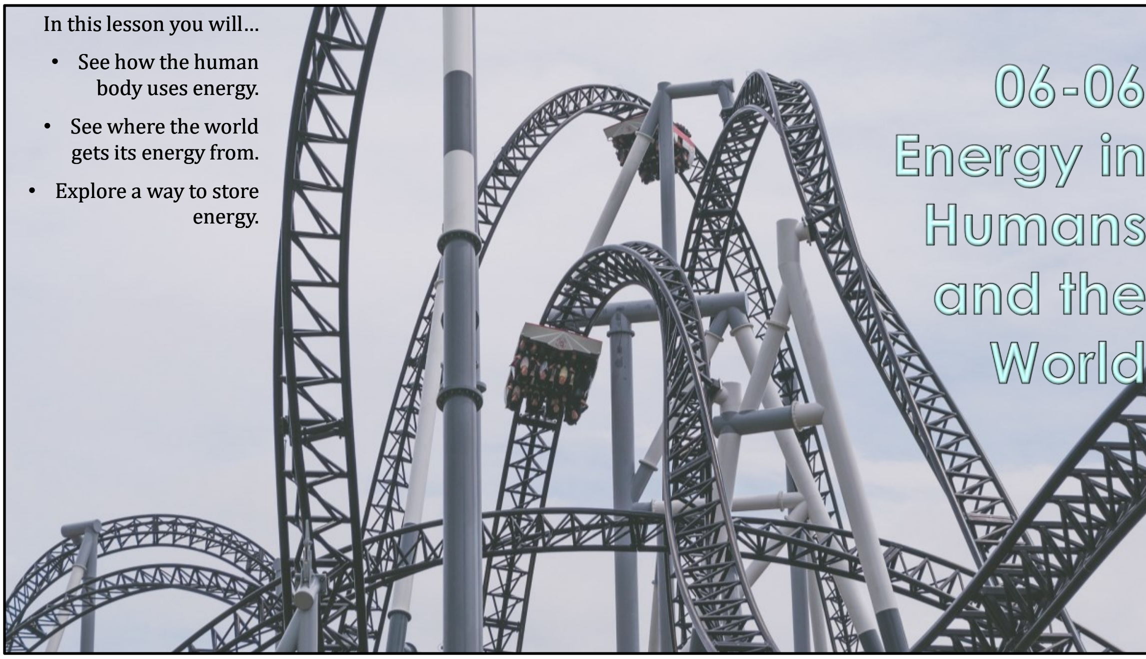
Friction force = ideal F_r − actual F_r

$$F_f = 225\pi\ N - 664\ N = 42.4\ N$$

6-05 Practice Work

- What simple machines do you use to do homework? (Your pencil is a lever…)

- Read
  - OpenStax College Physics 2e 7.8-7.9
  - OR
  - Not in OpenStax High School Physics

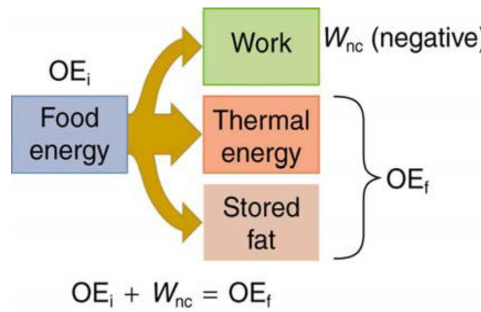


NAD 2022 Standards
ECV1: Energy Conservation

Not in OpenStax High School Physics
OpenStax College Physics 2e 7.8-7.9

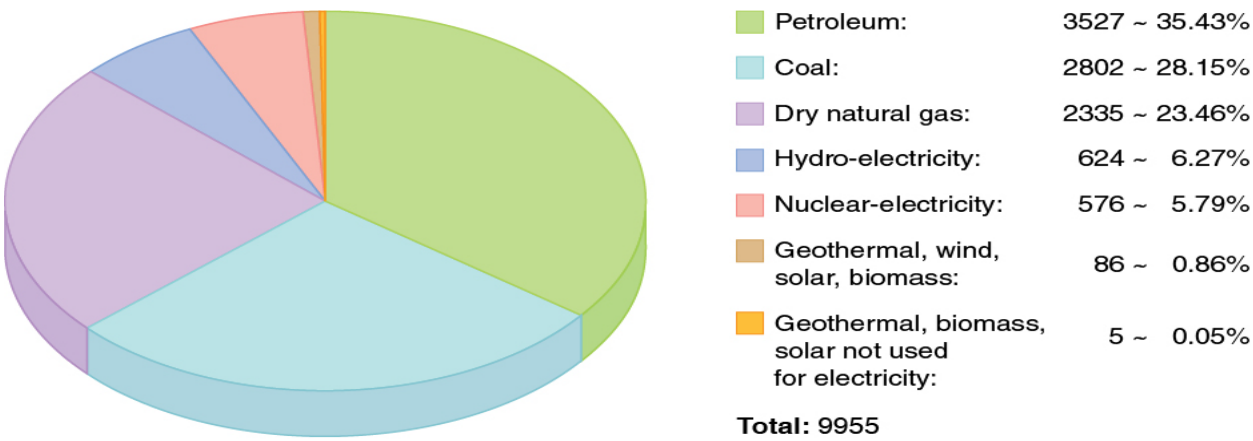
06-06 Energy in Humans and the World

- Human bodies (all living bodies) convert energy
- Rate of food energy use is metabolic rate
- Basal metabolic rate (BMR)
  - Total energy conversion at rest
  - Highest: liver and spleen
  - See table 7.4
- Table 7.5 shows energy consumed for various activities



06-06 Energy in Humans and the World

- Energy is required to do work
- World wide, the most common source of energy is oil



From 2008 units are billions of kWh

06-06 Energy in Humans and the World

- USA has 4.5% of world population, but uses 24% of world's oil
- World energy consumption continues to increase quickly
  - Growing economies in China and India
  - Fossil Fuels are very polluting
  - Many countries trying to develop renewable energy like wind and solar
- Generally, higher energy use per capita = better standard of living

06-06 Energy in Humans and the

Ludington Pumped Storage Power Plant

- It consists of a reservoir 110 feet (34 m) deep, 2.5 miles (4.0 km) long, and one mile (1.6 km) wide which holds 27 billion US gallons (100 Gl) of water. The 1.3-square-mile (3.4 km2) reservoir is located on the banks of Lake Michigan.
- The power plant consists of six reversible turbines that can each generate 312 megawatts of electricity for a total output of 1,872 megawatts.
- At night, during low demand for electricity, the turbines run in reverse to pump water 363 feet (111 m) uphill from Lake Michigan into the reservoir.
- During periods of peak demand water is released to generate power. Electrical generation can begin within two minutes with peak electric output of 1872 MW achieved in under 30 minutes. Maximum water flow is over 33 million US gallons (120,000 m^3) per minute.
- This process was designed to level the load of nearby nuclear power plants on the grid. It also replaces the need to build natural gas peak power plants used only during high demand.

- Energy is what makes the world go 'round.