

**Energy, Work, and Power**  
**Cornerstone Electronics Technology and Robotics Week 10**  
**(4 Hours)**

- Administration:
  - Prayer
  - Turn in quiz
  - Review quizzes
- Electricity and Electronics, **Section 4.1**, Work & Horsepower:
  - Terms & Definitions:
    - **Work:** Work is force applied on an object resulting in the object moving over a distance or displacement. When the force exerted on an object is in the same direction as the displacement of the object, calculating work is a simple matter of multiplication:

$W = F d$ , where:

$W$  = Work in ft-lbs (SI units: newton-meters or joules since  
1 joule = 1 N x 1 meter)

$F$  = Force in lbs (SI units: newton)

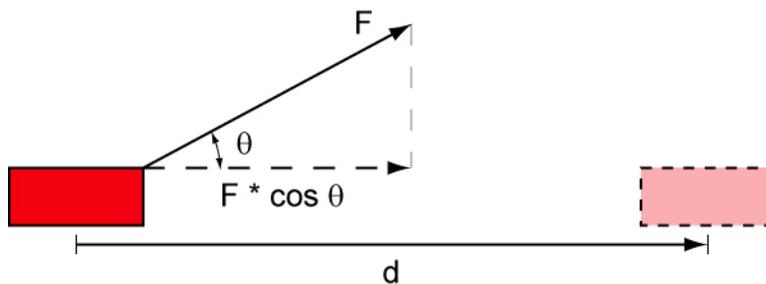
$d$  = distance or displacement in ft (SI units: meters)

- Work is further defined as the product of the magnitude of the displacement times the component of the force parallel to the displacement.

$$W = F_{\text{parallel}} d$$

$$W = F d \cos \theta$$

where  $\theta$  is the angle between the force and the displacement.



See: <http://canu.ucalgary.ca/map/content/position/posivect/simulate/applet.html>

<http://phet.colorado.edu/en/simulation/forces-and-motion>

<http://lectureonline.cl.msu.edu/~mmp/kap5/work/work.htm>

- **Power:** Power is the amount of work done during a period of time. Power is the rate of doing work. For example, a front end loader can move a pile of dirt much faster than someone moving it by hand. The front end loader does the same amount of work as the person but in much less time. The loader exhibits a higher rate of doing the work so it has more power than the person. The formula for mechanical power is:

$$P = W / T, \text{ where:}$$

P = Power in ft-lbs/sec or ft-lbs/min

W = Work in ft-lbs

T = Time in sec. or min.

$$\text{Also, } W = P * T, \text{ and } T = W / P$$

How are P and T related?

- The power equation suggests that a more powerful engine can do the same amount of work in less time, that is, time and power are inversely related.
  - Inverse of a number: The inverse of X is 1/X.
- Horsepower (hp): The term used to describe mechanical power. Horsepower is occasionally used to describe the power delivered by a machine.

$$1 \text{ hp} = 550 \text{ ft-lbs/second.}$$

- Perform Energy Lab 1 – Power Comparison
- Watt (W): The unit of power in electricity. See Watts Law below.
  - 746 watts = 1 horsepower
- Converting watts to horsepower in equations
- Watt's Law:
  - The formula to calculate electrical power.

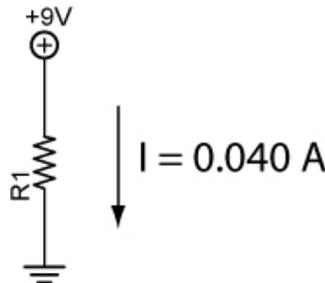
$$P = E \times I, \text{ where:}$$

P = Power (work/time), in watts

E = Volts (work/charge), in volts

I = Amperes (charge/time), in amperes

- Electricity and Electronics, **Section 4.2, Ohm's Law & Watt's Law:**
  - By combining Ohm's law and Watt's law, you can make simple formulas that permit you to solve for current, voltage, resistance, or power if any two of those quantities are known.
  - Solving for several unknowns.
  - Most commonly used forms of the power equation:
    - $P = E \times I$
    - $P = I^2 \times R$
    - $P = V^2 / R$
    - See: <http://www.youtube.com/watch?v=aCOph1lpYc8>
  - Since  $P = V^2 / R$ , what is the minimum resistance value for a ½ watt resistor that you can put across a 9 volt battery and still operate within its power rating?
- Steps in Choosing a Resistor:
  - First, calculate the resistance value required using Ohm's Law  $R = V / I$ .
  - Now calculate the amount of power the resistor dispersed using one of the power equations derived above. Select the power equation based upon the known values that are given.
  - Select a resistor with a wattage rating about twice the calculated value. This safety of 2 allows the resistor to operate at lower temperatures thereby extending the life of the resistor.
  - Example:
    - Choose a resistor in the circuit below that limits the current to about 0.040 A. Calculate both the resistance and wattage values.



- First, apply Ohm's Law:

$$R1 = V / I$$

$$R1 = 9V / 0.040A$$

$$R1 = 225 \text{ ohms}$$

A common resistor value of 220 ohms will work.

- Determine the wattage:

$$P = V * I \text{ (We could have used any of the power equations)}$$

$$P = 9V * 0.040A$$

$$P = 0.36 \text{ watts}$$

Applying a safety factor of 2 makes the power rating 0.72 watts.  
 Choose a resistor with a wattage rating of 1 watt.  
 $R1 = 220 \text{ ohms with a power rating of 1 watt.}$

- Electricity and Electronics, **Section 4.3**, Wattmeter & Watt-Hours:
  - Measuring electrical energy consumption:
    - A wattmeter measures instantaneous power.
    - A watt-hour meter measures the amount of power used in a given time.
 The formula for electrical energy consumption is:

$$\text{Energy (watt-hours)} = \text{Power (watts)} \times \text{Time (hours)}$$

- View GRU house meter operation
- Demonstrate Watts Up? PRO power analyzer and data logger
- See:
  - <http://www.youtube.com/watch?v=OrMUIWcTeQ8&p=BCCF1129FCAE29DF&index=9&feature=BF>

- Electricity and Electronics, **Section 4.4**, Efficiency, Gears, Pulleys, and Power:
  - Efficiency: The comparison of input power to output power. It is defined as:

$$\%E = (\text{Power out}/\text{Power in}) \times 100, \text{ where:}$$

E = Efficiency

Power out = Useful power output from a device

Power in = Power into a device

- Example:
  - Input into a motor is 12 volts dc at 90 amps. The output of the motor under load is 1 hp. What is the efficiency of the motor?  
This example is on page 76 of your text.
- Minimum Efficiencies for National Electrical Manufacturers Association Design B Motors:

Power (hp)	Minimum Nominal Efficiency (%)
1 - 4	78.8
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
>125	92.4

- Gears, Pulleys, & Power:
  - Basics: <http://www.youtube.com/watch?v=odpsm3ybPsA>
  - Gears are used to transfer power. Gears can:
    - Increase/decrease rotational speed with a corresponding decrease/increase in torque.
    - Change the direction of rotation
    - Change the angle of rotation
    - Convert rotational motion to linear motion
    - Change the location of rotation
  - Types: See [http://www.societyofrobots.com/mechanics\\_gears.shtml](http://www.societyofrobots.com/mechanics_gears.shtml)
  - Two parameters or variables associated with gears are rotational speed and torque.
    - Rotational speed is measured in revolutions per minute or rpm.
    - Torque: Torque is the tendency of a force to rotate an object about an axis.

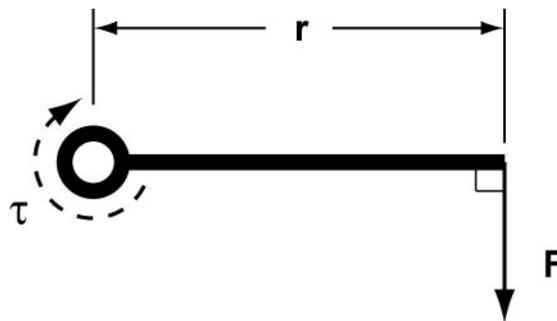
$$\tau = F \times r$$

Where:

$\tau$  = Torque

F = Force perpendicular to the radius

r = Radius



Units of Torque	
International System of Units (SI)	English
newton-meters (N·m)	inch-pounds (in·lb)
	foot-pounds (ft·lb)
	inch-ounces (in·oz)
1 N·m = 0.738 ft·lb	1 in·lb = 0.113 N·m
1 N·m = 0.113 in·lb	1 ft·lb = 1.356 N·m
1 N·m = 141.61 in·oz	1 in·oz = 7.062E-03 N·m

- Torque wrench demonstration

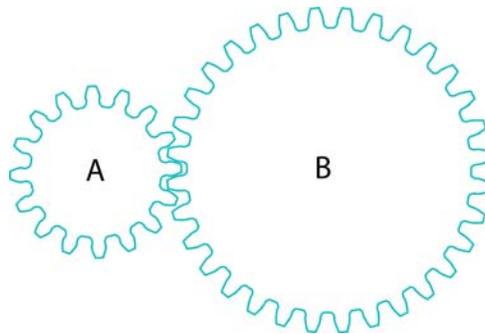
- In robotics, motor torque is more useful than rotational speed. Motors commercially available do not normally have the desirable rotational speed or torque needed for robotics. Gears will convert high rotational velocity (rpm) from a motor to supply a better torque at a lower rotational velocity.
- The basic formula relating torque and rpm for a gear system is:

$$\text{Input Torque} \times \text{Input rpm} = \text{Output Torque} \times \text{Output rpm}$$

See: <http://phet.colorado.edu/en/simulation/torque>

- Gear ratios:

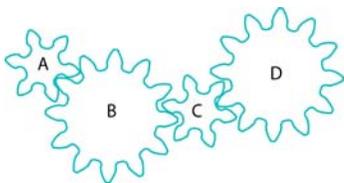
$$\text{Gear ratio} = \text{Number of teeth on Gear B} / \text{Number of teeth on Gear A}$$



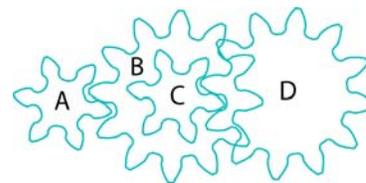
$$\text{Gear ratio} = 32/16$$

$$\text{Gear ratio} = 2:1$$

- The rpm of gear B is  $\frac{1}{2}$  of A.
- The torque from gear B is 2x gear A.
- See: <http://www.rkm.com.au/ANIMATIONS/animation-gear-ratio.html>
- <http://www.osha.gov/SLTC/etools/machineguarding/animations/gears.html>
- 
- Idlers and higher gear ratios:

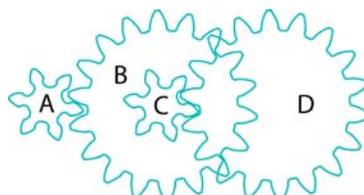


$$\text{Gear Ratio} = 2:1$$



$$\text{Gear Ratio} = 4:1$$

Gear A=6 teeth, B=12 teeth, C=6 teeth, D=12 teeth



$$\text{Gear Ratio} = 9:1$$

Gear A=6 teeth, B=18 teeth, C=6 teeth, D=18 teeth

- Unfortunately, by using gears, you lower your input to output power efficiency. When using two spur gears, typically expect efficiency to be around 90%.
- Bicycle gearing demonstration: see <http://www.mathapprentice.com/Activity/explore.html>
- Efficiency of GH12-1641T-F gearhead motors used in Year 2:

Power In:

$$P_{IN} \text{ (watts)} = E \text{ (V)} \times I \text{ (A)}$$

$$P_{IN} \text{ (watts)} = 12 \text{ V} \times .25 \text{ A}$$

$$P_{IN} \text{ (watts)} = 3.00 \text{ watts}$$

Power Out:

$$P_{OUT} \text{ (watts)} = (\text{Torque (N-m)} \times 2\pi \times \text{Rotational Speed (rpm)}) / 60$$

$$P_{OUT} \text{ (watts)} = (1000 \text{ gm-cm} \times 9.81 \times 10^{-5} \text{ N-m / gm-cm} \times 2\pi \times 71 \text{ rpm}) / 60$$

$$P_{OUT} \text{ (watts)} = 0.73 \text{ watts}$$

Efficiency:

$$\%E = (\text{Power}_{OUT} / \text{Power}_{IN}) \times 100$$

$$\%E = 0.73 \text{ watts} / 3.00 \text{ watts} \times 100$$

$$\%E = 24\%$$

- Perform Energy Lab 2 – Function of Gears
- Perform Energy Lab 3 – Timed Course Challenge
- Related web sites:
  - <http://www.societyofrobots.com/downloads/gearology.pdf>

**Electronics Technology and Robotics I Week 10**  
**Energy Lab 1 – Power Comparison**

- **Purpose:** The purpose of this lab is to acquaint the student with the principles of work and power through competition.
- **Apparatus and Materials:**
  - 1 – 40 Pound Weight
  - 1 – Stop Watch
  - 1 – Tape Measure
- **Procedure:**
  - Measure the distance the students and instructor lift the 40 pound weight.
  - Count the number of lifts each makes in 1 minute.
  - Calculate the power in ft-lbs/min
  - Convert ft-lbs/min to ft-lbs/sec
  - Convert ft-lbs/sec to hp
- **Results:**

<b>Power Comparison</b>			
	Student 1	Student 2	Instructor
Force (lbs)	40 lbs	40 lbs	40 lbs
Distance/Lift (ft)	ft	ft	ft
Lifts/min			
Work (ft-lbs)			
Power (ft-lbs/min)			
Power (ft-lbs/sec)			
Power (hp)			

- **Conclusions:**

**Electronics Technology and Robotics I Week 10**  
**Energy Lab 2 – Functions of Gears**

- **Purpose:** The purpose of this lab is to acquaint the student with the 5 ways gears can transfer power.
- **Apparatus and Materials:**
  - An assortment of Lego gears, shafts, connectors, and other parts
- **Procedure:**
  - Each student must make a working model illustrating each of the gear functions:
    - Increase/decrease rotational speed with a corresponding decrease/increase in torque.
    - Change the direction of rotation
    - Change the angle of rotation
    - Convert rotational motion to linear motion
    - Change the location of rotation
  - Have the instructor check off each completed task.
  - Build a combination of gears with a 25:1 gear ratio.
- **Results:**

<b>Task</b>	<b>Completed</b>
Increase/decrease rotational speed	
Change the direction of rotation	
Change the angle of rotation	
Convert rotational motion to linear motion	
Change the location of rotation	

## Electronics Technology and Robotics I Week 10

### Energy Lab 3 – Timed Course Challenge

- **Purpose:** The purpose of this lab is for the student to apply their knowledge of gears and gear ratios to a practical challenge.
- **Apparatus and Materials:**
  - An assortment of Lego gears, shafts, connectors, wheels, and other Lego parts
  - 1 – 176 RPM Gearhead Motor from Jameco #162191 (See: [http://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?langId=-1&productId=162191&catalogId=10001&freeText=162191&app.products.maxperpage=15&storeId=10001&search\\_type=jamecoall&ddkey=http:StoreCatalogDrillDownView](http://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?langId=-1&productId=162191&catalogId=10001&freeText=162191&app.products.maxperpage=15&storeId=10001&search_type=jamecoall&ddkey=http:StoreCatalogDrillDownView))
  - 2 – Couplers
  - 1 – 9V Battery
- **Procedure:**
  - Build a Lego car equipped with the two gearhead motors supplied such that the car travels 3 meters in 20.9 seconds. The team with the time closest to 20.9 seconds wins.
- **Rules:**
  - The teams must only use the wheels furnished.
  - No tape may be used on the car.
  - The motors must be powered by the 9 volt battery.
  - Only one car may be on the course at a time.
  - The team may have as many trials as time permits.
  - If more than one team is able to traverse the course in 20.9 seconds, the first team to achieve that time wins.
  - After the challenge, all Lego parts must be disassembled and returned to their proper bins.
  - No team member may view any other competitive car until the other competitive car is on the 3 meter course.