Lecture 3:
Electrical Power and Energy

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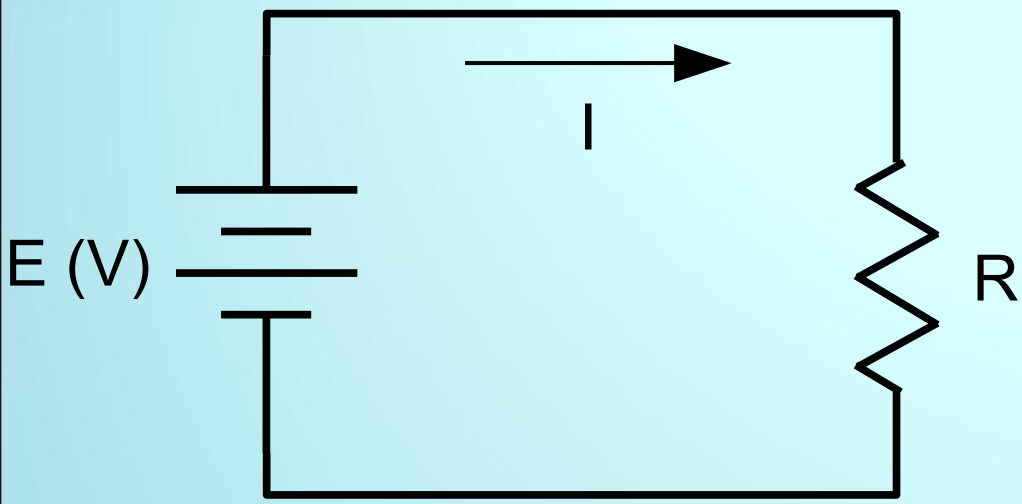
Recall from Lecture 2



E → Voltage

Similar to water pressure

Unit: Volts (V)

I → Current

Similar to water flow

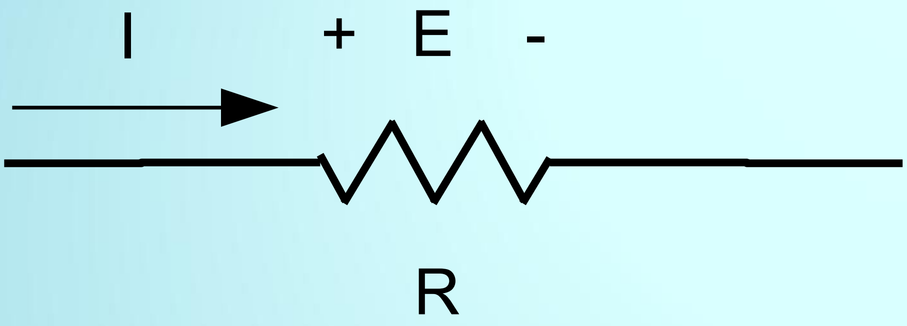
Unit: Amperes (A)

R → Resistance

Similar to water pipe friction

Unit: Ohms (Ω)

Recall from Lecture 2



Ohm's Law:

$$E = I\,R$$

$$I = \frac{E}{R}$$

$$R = \frac{E}{I}$$

Defines the relationship between electric circuit current, component resistance, and the voltage drop across the component

Work

- Book definition: Overcoming resistance through a distance
- Mechanical:
  - If force not constant in space: $W = \int F(D)\,dD$
  - If force constant: $W = FD$
- Units of measure:
  - SI: Joule (J) → 1 N·m, 1 W·s
  - Common in US: ft-lb_f
  - 1 J = 0.7376 foot-pounds (ft-lb_f)

Power

- Book definition: Measurement of the rate of doing work.
- If work performed is not constant with time: $P = \frac{dW}{dT}$
- If work performed is constant: $P = W / T$
- Units of measure:
  - SI: Watts (W)
  - Common in US: hp (horsepower)
  - 1 hp = 746 W

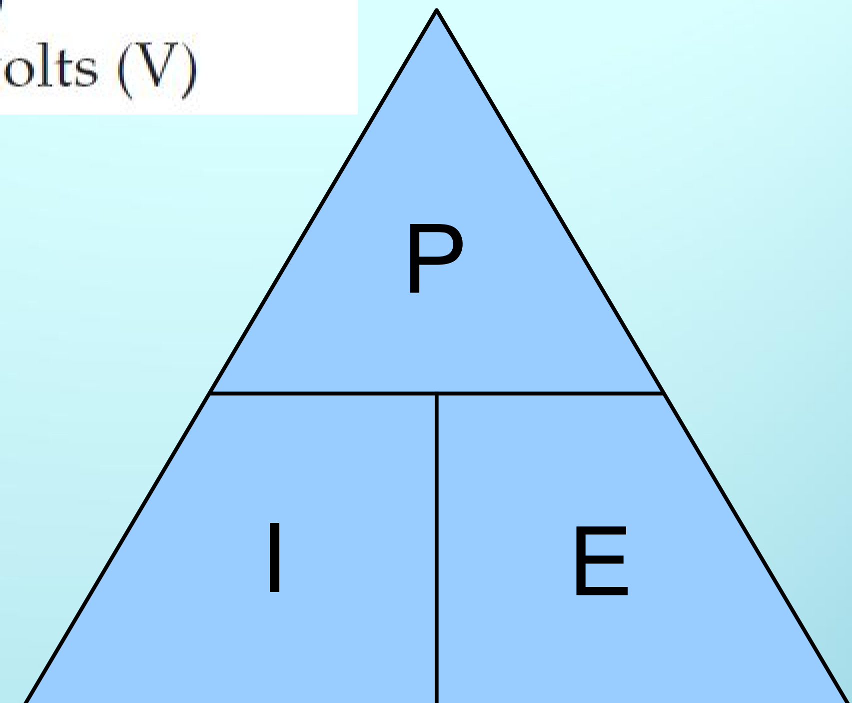
$$hp = \frac{\text{ft 1b/min}}{33{,}000} \qquad \text{(Eq. 3.1)}$$

Power (cont'd)

Electrical Power:

$$P = IE \left(I = \frac{P}{E} \text{ or } E = \frac{P}{I} \right) \qquad \text{(Eq. 3.2)}$$

where P = power, in watts (W)
I = current, in amperes (A)
E = electrical pressure, in volts (V)



Power (cont'd)

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Electrical Power:

PIRE wheel

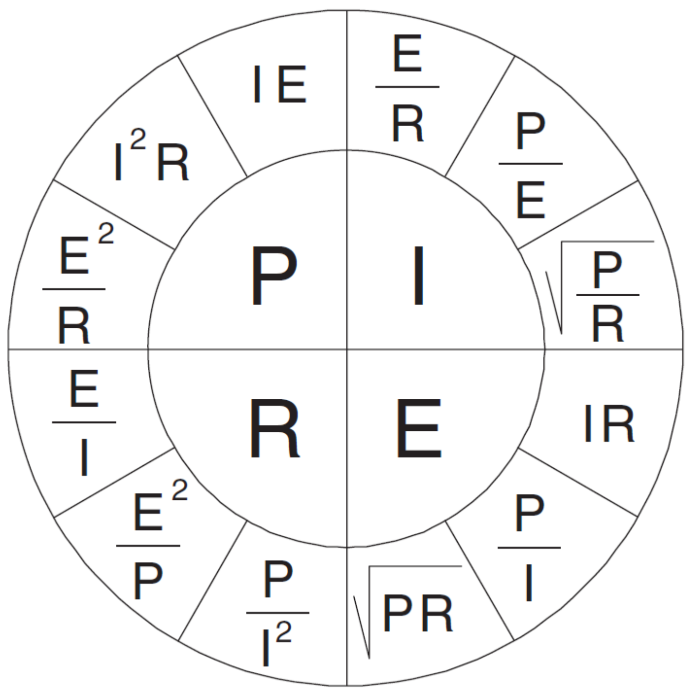

FIGURE 3–2 PIRE wheel.

All you REALLY need to remember:

- $E = I\,R$
- $P = I\,E$
- algebra

Power (cont'd)

Proof 1: Show that $P = I^2 R$

Proof 2: Show $I = \sqrt{\frac{P}{R}}$

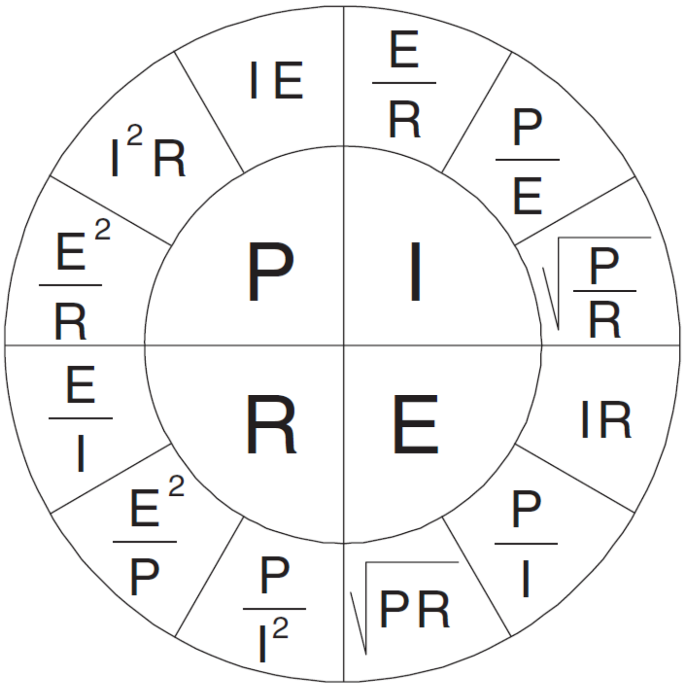

FIGURE 3–2 PIRE wheel.

Power (cont'd)

Proof 1: Show that $P = I^2 R$

$$P = I\,E$$ ← Power equation

$$E = I\,R$$ ← Ohms Law

$$P = I\,(I\,R)$$ ← Sub in Ohms Law for E

$$P = I^2 R$$ ← Rearrange (associative)

Proof 2: Show $I = \sqrt{\frac{P}{R}}$

$$P = I^2 R$$ ← From above proof

$$I^2 = \frac{P}{R}$$ ← Rearrange Equation

$$I = \sqrt{\frac{P}{R}}$$ ← Take square root

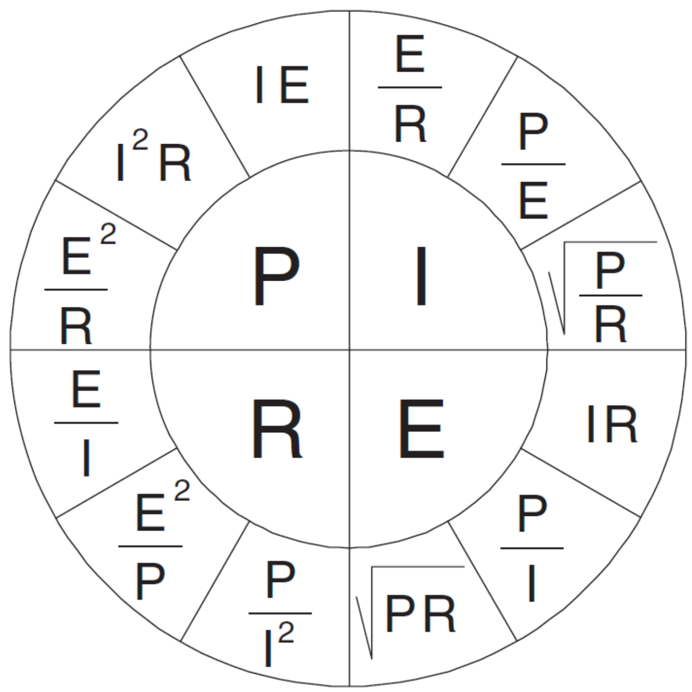

FIGURE 3–2 PIRE wheel.

Power (cont'd)

Example: An electric heater draws 15 A of current. What is the resistance of the heating element if the electric heater is rated for 2.25 kW?

Power (cont'd)

Example: An electric heater draws 15 A of current. What is the resistance of the heating element if the electric heater is rated for 2.25 kW?

$$R = \frac{P}{I^2}$$ ← Equation for resistance, given current and power

$$I = 15\ A$$ ← Current through heater

$$P = 2.25\ kW$$ ← Power rating of heater

$$R = \frac{2250\text{W}}{15\text{A}^2}$$

$$R = 10\ \Omega$$ ← Heater element resistance

Energy

- Book definition: Energy is the ability to do work
- Cannot be destroyed or consumed (at least for our purposes)
- Forms of energy are light, heat, mechanical, electrical and chemical
- Energy conversion is used to perform work

Energy (cont'd)

- Units of Measure
  - SI: Joule (J) – same as work
  - Others: BTU, kWh
- BTU → energy required to heat 1 lb water by 1°F
  - Often used in power generation
- kWh is standard in electrical distribution systems
  - See your electric bill
  - 1 BTU = 0.29 Wh
  - 1 kWh = 3600 kJ

Energy (cont'd)

- Relationship with Power
  - If Power not constant with time $Energy = \int P(T)\,dT$
  - If Power constant $Energy = PT$

- System Efficiency:

$$\%\,\text{Eff} = \frac{\text{Useful energy output}}{\text{Total energy input}} \times 100 \quad \text{(Eq. 3.9)}$$

$$\%\,\text{Eff} = \frac{\text{Power output}}{\text{Power input}} \times 100 \quad \text{(Eq. 3.10)}$$

Energy / Power Example

An electric motor has a rated current of 30 A when powered from a 240 V supply. (a) What is the power input to the motor? (b) If the motor is run for 5 hours, what is the total energy input? (c) If the motor has an efficiency of 80%, what is the total output energy?

Energy / Power Example

An electric motor has a rated current of 30 A when powered from a 240 V supply. (a)What is the power input to the motor? (b)If the motor is run for 5 hours, what is the total energy input? (c)If the motor has an efficiency of 80%, what is the total output energy?

(a) (b) (c)

$$P = I\,E$$

$$P = 30\text{A} * 240\text{V}$$

$$P = 7.2\,kW$$

Energy / Power Example

An electric motor has a rated current of 30 A when powered from a 240 V supply. (a)What is the power input to the motor? (b)If the motor is run for 5 hours, what is the total energy input? (c)If the motor has an efficiency of 80%, what is the total output energy?

(a)

$$P = I\,E$$

$$P = 30\text{A} * 240\text{V}$$

$$P = 7.2\,kW$$

(b)

$$Energy = P\,T$$

$$Energy = 7.2\text{kW} * 5\text{h}$$

$$Energy = 36\,kWh$$

(c)

Energy / Power Example

An electric motor has a rated current of 30 A when powered from a 240 V supply. (a)What is the power input to the motor? (b)If the motor is run for 5 hours, what is the total energy input? (c)If the motor has an efficiency of 80%, what is the total output energy?

(a)

$$P = I\,E$$
$$P = 30\text{A} * 240\text{V}$$
$$P = 7.2\,kW$$

(b)

$$Energy = P\,T$$
$$Energy = 7.2\text{kW} * 5\text{h}$$
$$Energy = 36\,kWh$$

(c)

$$Eff = \frac{Energy\,out}{Energy\,in}$$
$$Energy\,out = Eff * Energy\,in$$
$$Energy\,out = 80\% * 36\text{kWh}$$
$$Energy\,out = 28.8\,kWh$$

Mechanical Transmission of Power

- Driving machine
  - Delivers power to the machine being driven
  - Examples: gasoline engines, steam turbines, electric motors

- Driven machine
  - Receives power
  - Examples: presses, lathes, elevators, pumps and saws

Mechanical Drives

- Connections between driving machines and driven machines
- Examples: pulleys, chains on sprockets, gear assemblies, and direct drives
- Speed Requirements
  - If speeds of both machines are the same, may use direct drive
  - If not, require a mechanical drive

Mechanical Drives (cont'd)

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- Pulleys: Speed of machine determined by size of pulleys.

Diameter motor pulley 2

Speed machine 1

$$\frac{N_1}{N_2} = \frac{D_2}{D_1}$$

Diameter motor pulley 1

Speed machine 2

- Gears: Speed determined by number of teeth in gears.

Num. teeth motor gear 2

$$\frac{N_1}{N_2} = \frac{T_2}{T_1}$$

Num. teeth motor gear 1

Mechanical Drives (cont'd)

Mechanical Power:

- Equation considering SI units:

$$P = \tau \omega$$

Angular speed (radians/s)

Torque (N-m)

Power (W)

- Equation given in book:

$$\text{hp} = \frac{TN}{5252} \qquad \text{(Eq. 3.13)}$$

where hp = horsepower
T = torque, in pound-feet (lb ft)
N = speed, in revolutions per minute (r/min)

Mechanical Drives (cont'd)

Example: What is the torque of an electric motor rated at 10 hp if the speed of the machine is 1200 RPM?

Mechanical Drives (cont'd)

Example: What is the torque of an electric motor rated at 10 hp if the speed of the machine is 1200 RPM?

$$hp = \frac{T\,N}{5252}$$

$$T = \frac{5252\,hp}{N}$$

$$T = \frac{5252 * 10}{1200}$$

$$T = 43.8\,lb\ ft$$

What about using standard equation:

$$\omega = \frac{2\pi}{60} N = 126\,rad/s$$

$$P = 746\text{hp} = 7.46\,kW$$

$$T = P/\omega$$

$$T = 59.2\,N-m$$

Conversion factor:
1 lb ft = 1.35 N-m

Other Mechanical Considerations

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- Starting Torque
  - Torque developed at instant motor is energized
- Starting Current
  - Current drawn from motor at the instant it is energized.
- Other Factors:
  - Size, weight, efficiency (heat management), shaft type

Motor Sizing

- Depends on speed, torque, and efficiency
- Downsides to undersizing or oversizing

$$\text{hp} = \frac{Wh}{33{,}000 \times \text{Eff}} \qquad \text{(Eq. 3.14)}$$

where hp = mechanical power, in horsepower
W = weight lifted, in pounds (lb)
h = height lifted, in feet per minute (ft/min)
Eff = efficiency, in percent (%)

Homework

Chapter 3:

Answer the **multiple choice** questions 1 through 10.

Solve problems 3, 6, 8, 9, 12, 19.

Due: Week from today. Wednesday 9/11/13