Fundamentals of Corrosion Mathematics and Electricity

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Appalachian Underground Corrosion Short Course

Rules

- Set cell phones to silent operation
- If you get a call, feel free to walk out, and walk back in when you're done
- If you have a question, leave your hand up for about 10 seconds, then use your voice

Disclaimers

- We will be concentrating on some fundamental mathematical and electrical concepts
- Math is like any other skill –
  IT REQUIRES PRACTICE
- I can introduce the information, but you "learn" it by attempting the problems (and struggling) all by yourself.
- This is the "fundamentals" course.

Agenda

- Units
- circuit theory

- Ohms Law
- series and parallel circuit theory

- Evening session (7:00) – do it again

More about “units” than you thought possible

- Introduce “conversion factors” in order to change from one unit system to another.
- Miles to feet
- Tons to pounds
- Years to days
- Millivolts to volts
- Amps to milliamps

Mathematical Concept #1

- ANY number times "1" is always the same number

- EXAMPLE

  5 * 1 = 5

  23 * 1 = 23

  142 * 1 = 142

- You can keep multiplying the number by "one" with no change

- EXAMPLE

  5 * 1 * 1 * 1 = 5

  23 * 1 * 1 * 1 * 1 = 23

Mathematical Concept #2

- A number divided by itself is equal to "1"
- There are some cases where this is not true, but you don't need to worry about it.

EXAMPLES

$$\frac{5}{5} = 1$$

$$\frac{23}{23} = 1$$

$$\frac{142}{142} = 1$$

Concept #2 - elaborated

- I introduced the second concept using pure numbers – 5, 23, 142
- Let's use distance instead of pure numbers.

- If I run 5280 feet.
- And "you" run 1 mile.
- Who runs farther?
- Same distance.
- 1 mile = 5280 feet
- Then:

$$\frac{1 mile}{5{,}280\ feet} = 1$$

Adding "UNITS" makes a difference

$$\frac{1}{5280} = 0.0001894$$

$$\frac{1 mile}{5280\ feet} = 1$$

$$\frac{1}{2000} = 0.0005$$

$$\frac{1 ton}{2000 lbs} = 1$$

$$\frac{1}{24} = 0.0416$$

$$\frac{1 day}{24 hours} = 1$$

Combine concepts 1 and 2 to convert units

- Concept 2 – $\frac{23}{23} = 1$ $\frac{1 mile}{5280\ feet} = 1$
- Concept 1 - 5 * 1 = 5
- How many miles are in 24,362 feet?
- 24,362 feet * $\frac{1\ mile}{5{,}280\ feet}$ = 4.614 miles

Setting up the equation

- You want the unit you HAVE on the bottom of the conversion factor
- You want the unit you NEED on the top of the conversion factor
- 24,362 feet * $\frac{1\ mile}{5{,}280\ feet}$ = 4.614 miles
- When you multiply – the same units on top and bottom cancel, and you're left with the unit you need
- 24,362 ~~feet~~ * $\frac{1\ mile}{5{,}280\ \cancel{feet}}$ = 4.614 miles

A quick note about fractions

- $\frac{15}{690} = \frac{3*\cancel{5}}{69*\cancel{5}*2} = \frac{3}{69*2} = \frac{\cancel{3}}{\cancel{3}*23*2} = \frac{1}{46}$ VALID
- $Cancelling\ only\ works\ when\ multiplying\ fractions$
- $\frac{15}{690} = \frac{\cancel{10}+5}{\cancel{10}+680} = \frac{5}{680} = \frac{1}{136}$ NOT VALID

Examples

- Convert 8.35 miles to feet
- 8.35 miles * $\frac{5{,}280\ feet}{1\ mile}$ = 44,088 feet

- Convert 3.16 tons to lbs
- 3.16 tons * $\frac{2{,}000\ lbs}{1\ ton}$ = 6,320 lbs

- Convert 3.6 years to days
- 3.6 years * $\frac{365.25\ days}{1\ year} = 1{,}314.9\ days$

Let's take the examples further

- Convert 8.35 miles to "millimeters"
- 8.35 miles * $\frac{5{,}280\ feet}{1\ mile} * \frac{12\ inches}{1\ foot} * \frac{25.4\ mm}{1\ inch}$ = 13,438,022 mm
- I don't have to remember how many mm are in a mile
- I used concept #1 to string conversion factors together
- I only need to remember how many mm are in one inch

- Convert 3.16 tons to milligrams
- 3.16 tons * $\frac{2000\ lbs}{1\ ton} * \frac{454\ gms}{1\ lb} * \frac{1{,}000\ mg}{1\ gm}$ = 2,869,280,000 mg

What if you invert the conversion factor?

- 8.35 miles * $\frac{5{,}280\ feet}{1\ mile}$ = 44,088 feet (correct)
- 8.35 miles * $\frac{1\ mile}{5{,}280\ feet}$ = 0.00158 $\frac{mile-mile}{foot}$
- Two clues you got the conversion factor wrong
  - One – you know that 8 miles is more than 1/1000th of a foot
  - Two – very strange unit – mile^2/foot (valid but strange)
    - the units did not cancel

Electrical Units

- Volt – an honorary unit for Count Alessandro Volta
  - Volta invented the modern battery and discovered methane
- 1 Volt = $\frac{1\ kg-m}{Coloumb-s^2}$

- Ampere – an honorary unit for French physicist Andre Ampere
- 1 Amp = $\frac{1\ Coloumb}{s}$

Converting electrical units

- In the cathodic protection field electrical unit conversions are typically limited to:
  Amps to milliamps / milliamps to amps
  and
  Volts to millivolts / millivolts to volts
- The factors look like this:

$$\frac{1\ Amp}{1{,}000\ mA} \qquad \frac{1{,}000\ mA}{1\ Amp} \qquad \frac{1\ Volt}{1{,}000\ mV} \qquad \frac{1{,}000\ mV}{1\ Volt}$$

Volt and Amp Conversion Examples

$$630mA * \frac{1A}{1000mA} = 0.63A$$

$$0.542\ V * \frac{1{,}000\ mV}{1\ V} = 542\ \text{mV}$$

$$-823mA * \frac{1A}{1000mA} = -0.823A$$

$$2.81\ V * \frac{1{,}000\ mV}{1\ V} = 2{,}810\ \text{mV}$$

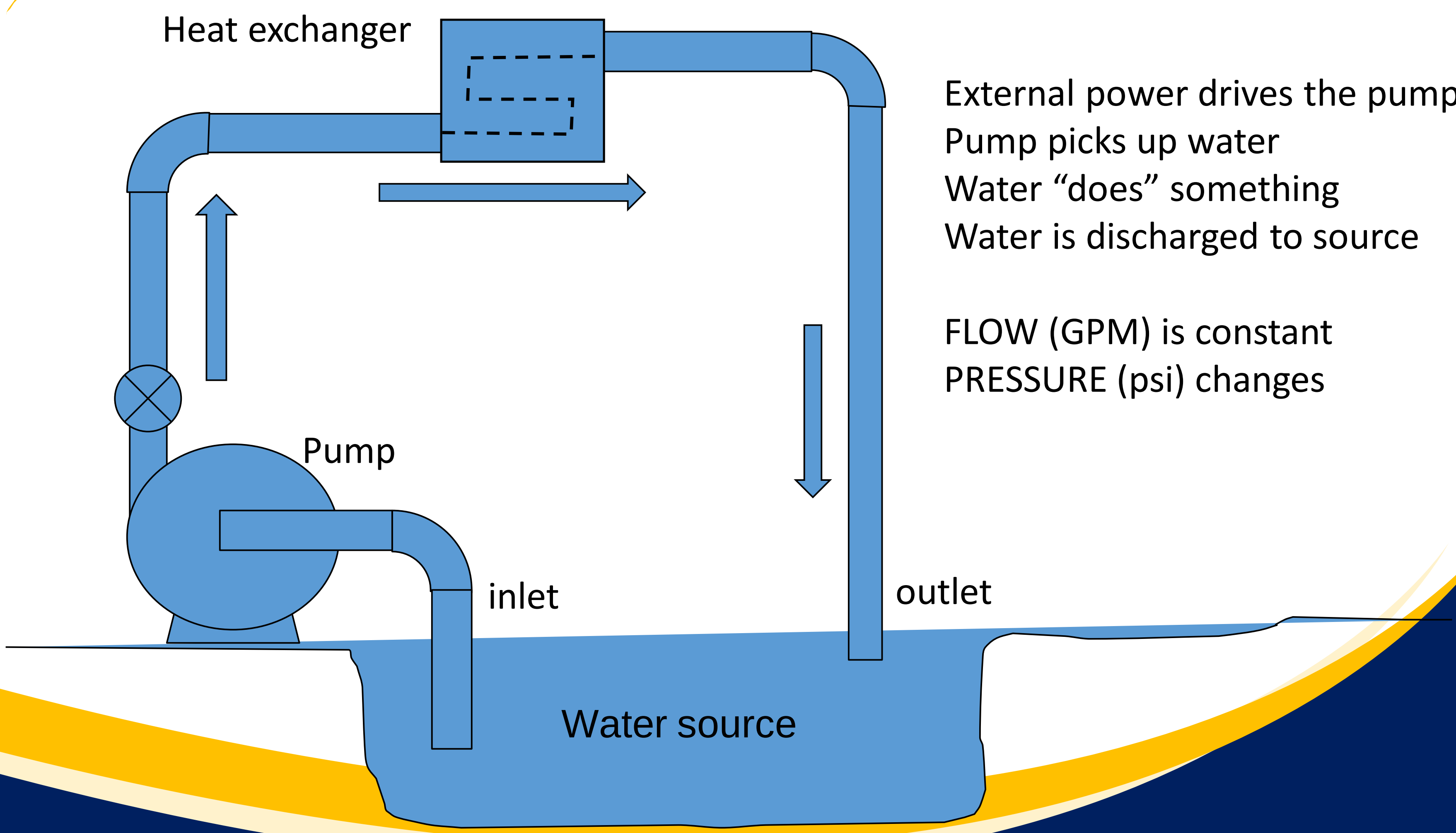
$$-1.71A * \frac{1000mA}{1A} = -1710mA$$

$$0.79\ mV * \frac{1\ V}{1{,}000\ mV} = 0.00079\text{V}$$

$$2.5A * \frac{1000mA}{1A} = 2500mA$$

$$39.6\ mV * \frac{1\ V}{1{,}000\ mV} = 0.0396\ \text{V}$$

A Fluid Circuit



External power drives the pump
Pump picks up water
Water “does” something
Water is discharged to source

FLOW (GPM) is constant
PRESSURE (psi) changes

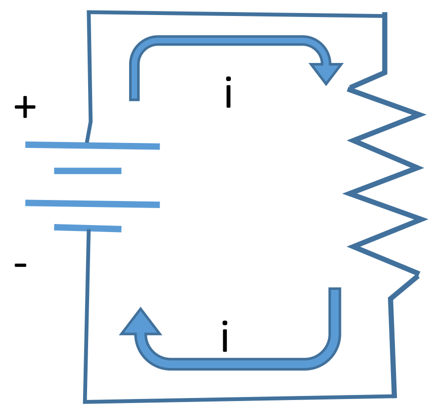
Measurement in a fluid circuit

- Pressure can be measured without interrupting the flow.
  - Pressure gauge in a tap
- Flow rate is measured by making all the fluid go through a meter.   Flow is diverted
  - Ultrasonic meters do not divert flow

An Electrical Circuit

Current is the same at all points
Voltage changes throughout circuit

Voltage Source – current flows out of the "+" side



Resistor – described in "ohms"

Current flowing clockwise in this illustration – denoted by "i"

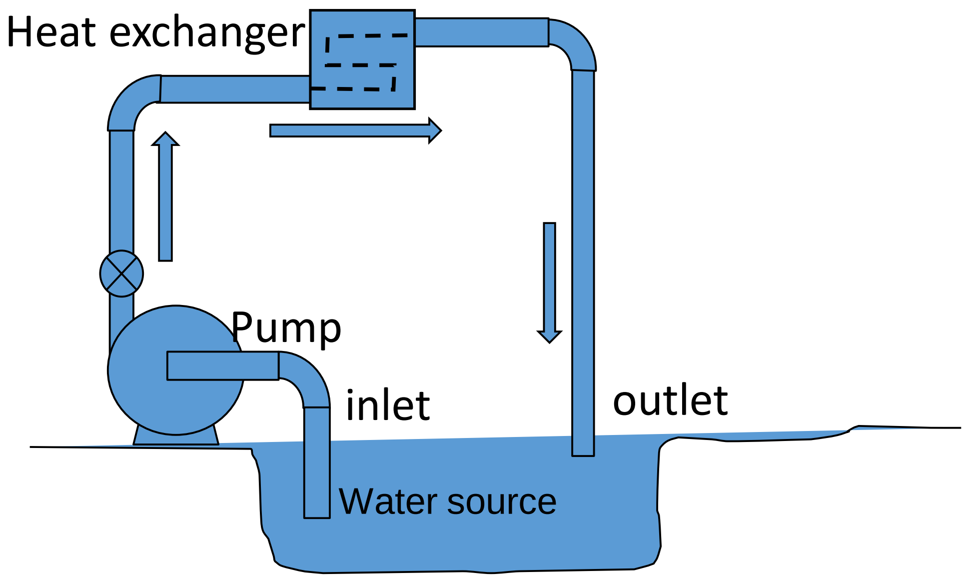
Measurement in an electrical circuit

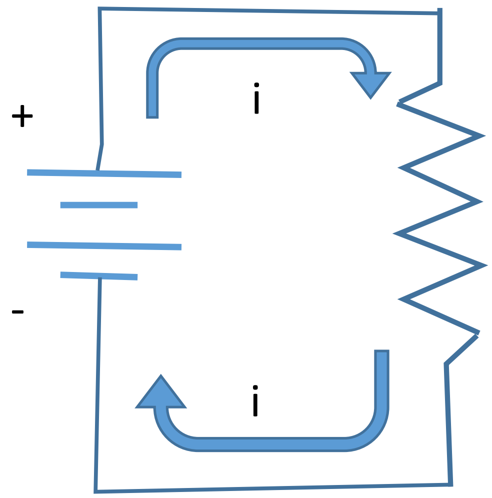
- Voltage can be measured without interrupting the flow.
  - Similar to pressure in a fluid circuit
- Current is measured by making all the current flow through a meter.   Flow is diverted.

Equivalence – Fluid to Electricity

PRESSURE (psi)
FLOW (gpm or cfs)

POTENTIAL (volts)
CURRENT (amps)





Pressure changes around circuit
Flow rate is constant

Potential changes around circuit
Current is constant

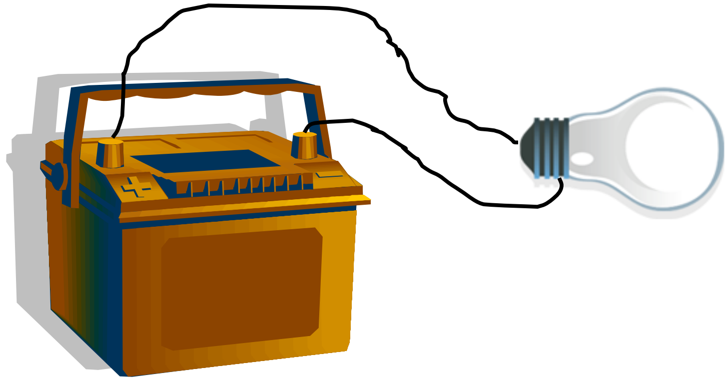
Equivalence

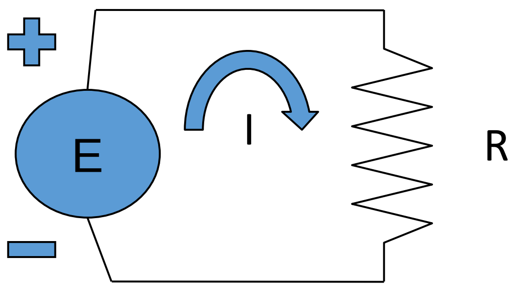
- FLUIDS
- Pressure
  - Pounds per square inch
  - Measure without diverting flow
- Flow
  - Gallons per minute
  - Measured by diverting flow

- ELECTRICITY
- Potential
  - Volts
  - Measured without diverting current
- Current
  - Amps (coulombs / sec)
  - Measured by diverting the current

A simple circuit

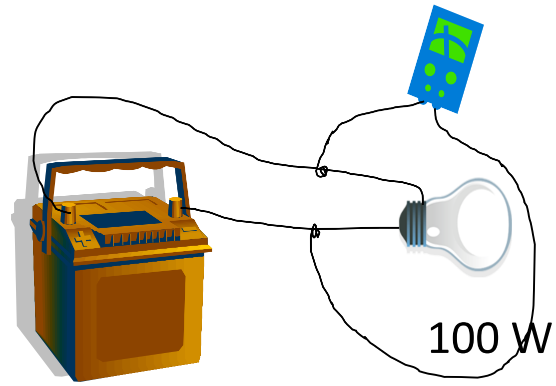
- 12 V car battery attached to a light bulb
- Current flows out of the (+) terminal and returns to the (-) terminal

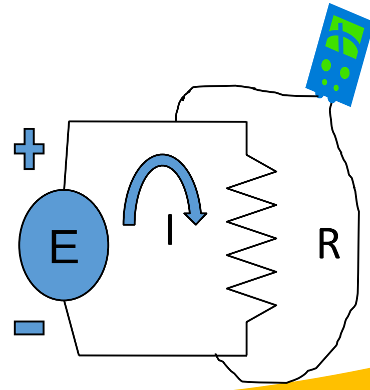




Measuring electrical potential

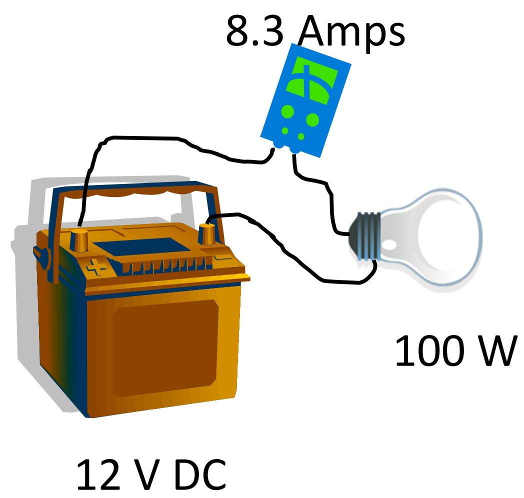
- Measuring potential, no current goes through the meter
- High internal resistance meter
- Meter is separate from current flow

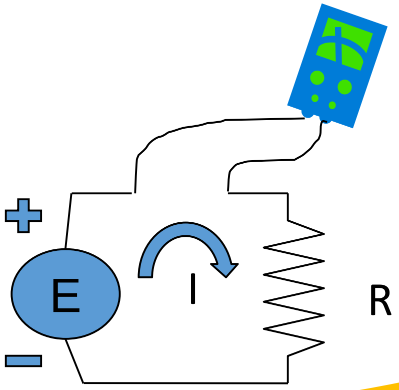




Measuring electrical current

- In order to measure current, all current goes through the meter.
- Meter becomes part of the circuit
- Current meters have very low internal resistance

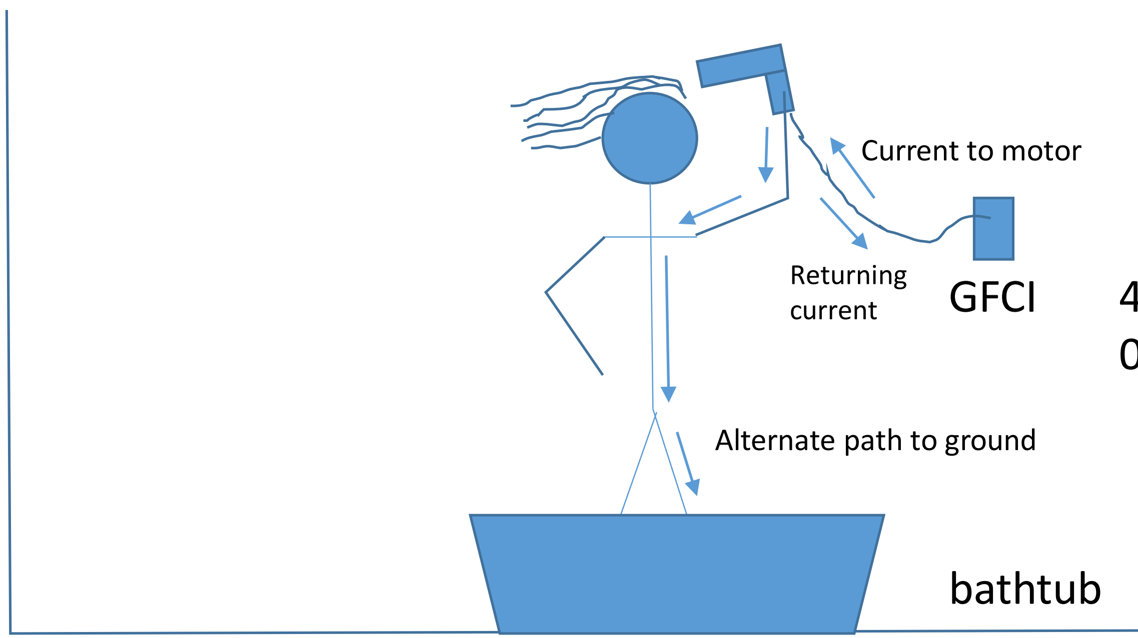




Circuits around the house

- A GFCI (in outlets around moisture) operates (and protects you) on the principal that “current is the same at all points in a circuit”.
- A normal breaker – like in your main breaker box opens (breaks the circuit) when TOO MUCH current is flowing.
- A ground fault circuit interrupter opens when current on one side of the circuit is different from the current on the other side.

Ground Fault Circuit Interrupter



4 – 5 mA
0.1 seconds

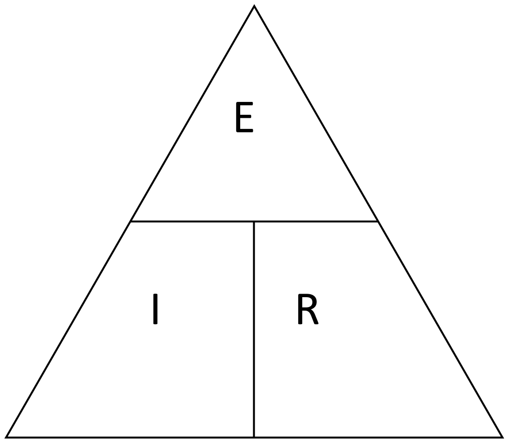
Ohm's Law

A potential of 1 volt across a resistance of 1 ohm causes 1 amp of current to flow

E = I * R

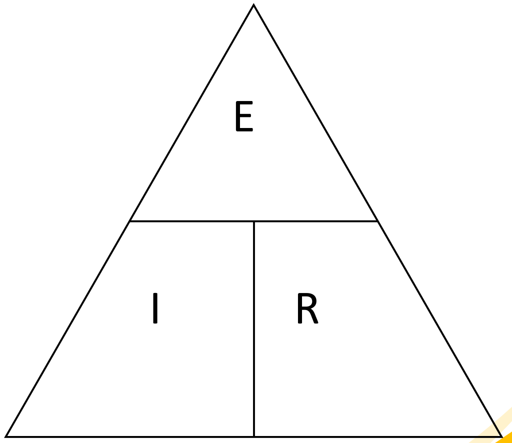
I = E / R

R = E / I



Ohm's Law

- Using the triangle.
- Cover the variable that you need to find.
- The "known" variables will be in the configuration you need.
- Need to know "I"?
- Cover the I and you're left with $\frac{E}{R}$.



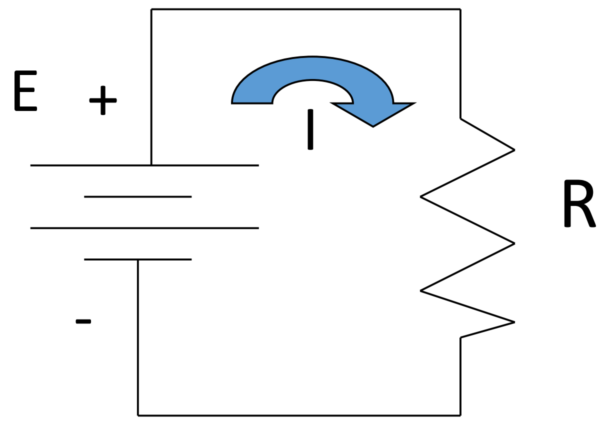
- Therefore I = $\frac{E}{R}$

Units and Ohm's Law

- ALWAYS convert units to Amps, volts, and Ohms.
- Do NOT use milliamps, millivolts, or kilo-ohms.

Ohm's Law Example 1

- If the voltage (E) is 10.5 Volts and the resistance (R) is 5 ohms, how much current (I) is flowing?

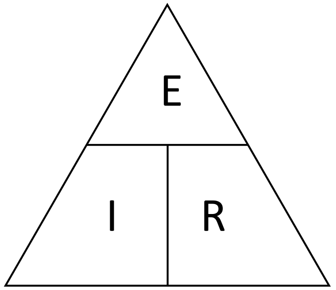


- I = E/R = E ÷ R
- I = 10.5V ÷ 5ohms
- I = 2.1 Amps

E = IR

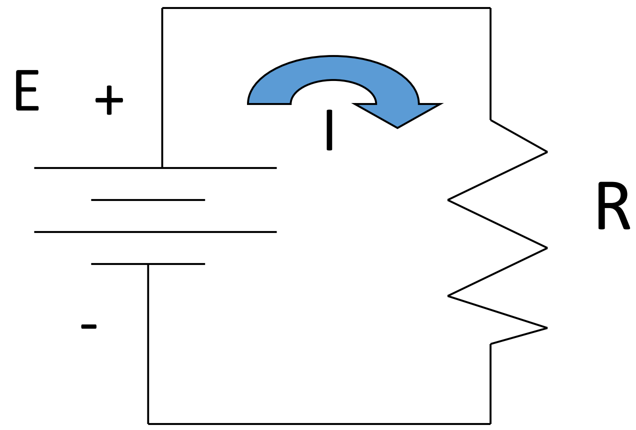
R = E/I

I = E/R



Ohm's Law Example 2

- If the voltage (E) is 1.6 Volts and the current (I) is 2 amps, what is the resistance in the circuit?

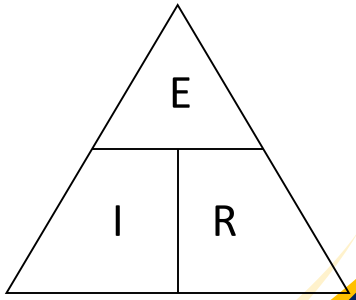


- R = E ÷ I
- R = 1.6V ÷ 2 amps
- R = 0.8 ohms

E = IR

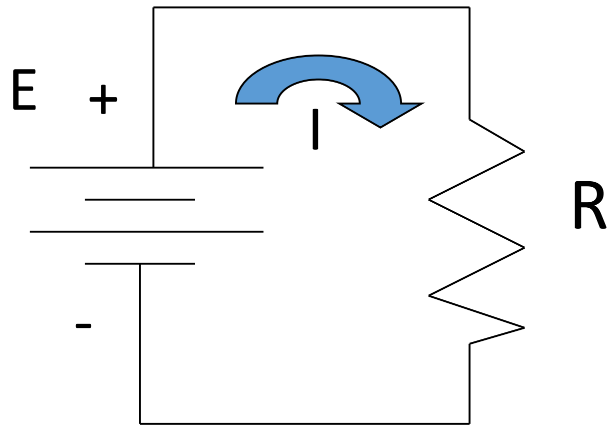
R = E/I

I = E/R



Ohm’s Law Example 3

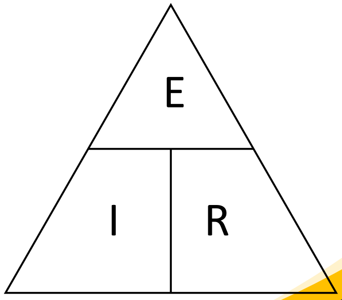
- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?
- E = I*R
- I = 100 mA = 0.1A
- R = 1.5 ohms
- E = 0.1 * 1.5
- E = 0.15V



E = IR

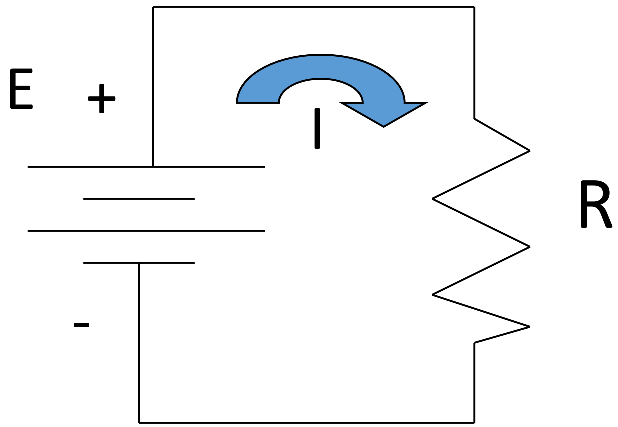
R = E/I

I = E/R



Ohm’s Law Example 3 – mistake included

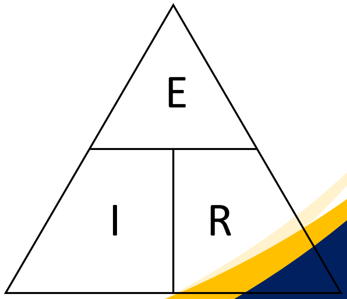
- If the current (I) is 100 mA and the resistance (R) is 1.5 ohms, what is the voltage across the resistor?
- E = I*R
- I = 100 mA
- R = 1.5 ohms
- E = 100 * 1.5
- E = 150 V (not 0.15V)



E = IR

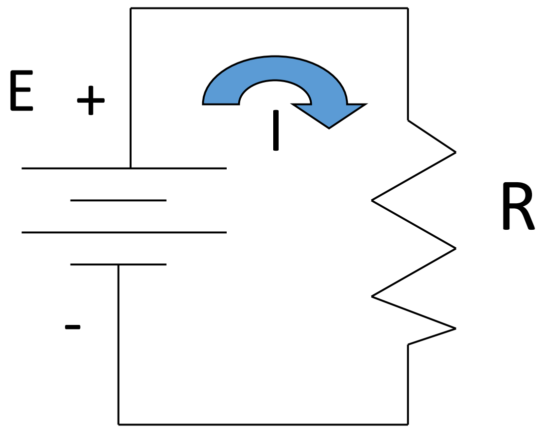
R = E/I

I = E/R



Ohm's Law Example 4

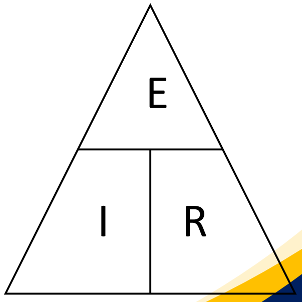
- If the current (I) is 2.5 mA and the voltage (E) is 2.5 volts, what is the resistance of the circuit?
- R = E ÷ I
- I = 2.5 mA = 0.0025A
- E = 2.5 volts
- R = 2.5 ÷ .0025
- R = 1000 ohms



E = IR

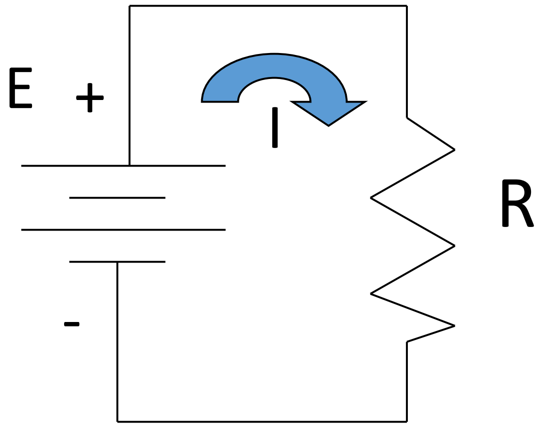
R = E/I

I = E/R



Example 4 – mistake included

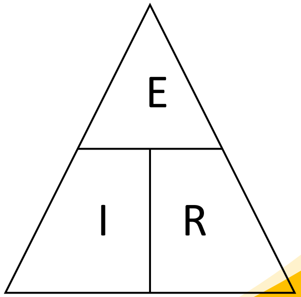
- If the current (I) is 2.5 mA and the voltage (E) is 2.5 volts, what is the resistance of the circuit?
- R = E ÷ I
- I = 2.5 mA
- E = 2.5 volts
- R = 2.5 ÷ 2.5
- R = 1 ohm (wrong)



E = IR

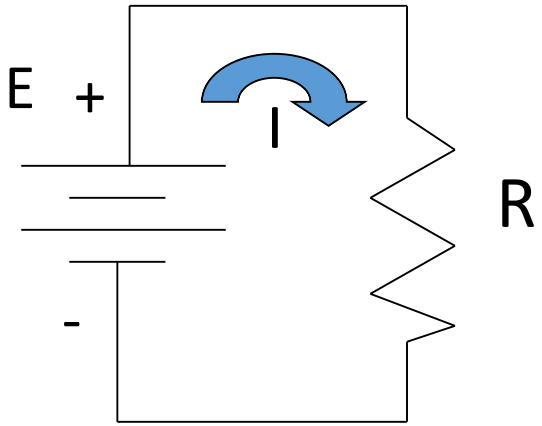
R = E/I

I = E/R



Ohm's Law Example 5

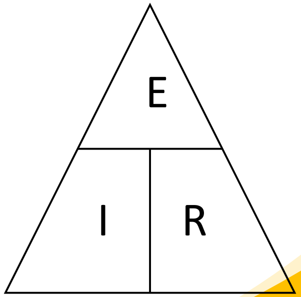
- If the current (I) is 20 A and the resistance (R) is 2 ohms, what is the voltage across the resistor?
- E = I*R
- I = 20 A
- R = 2 ohms
- E = 20 * 2
- E = 40 V



E = IR

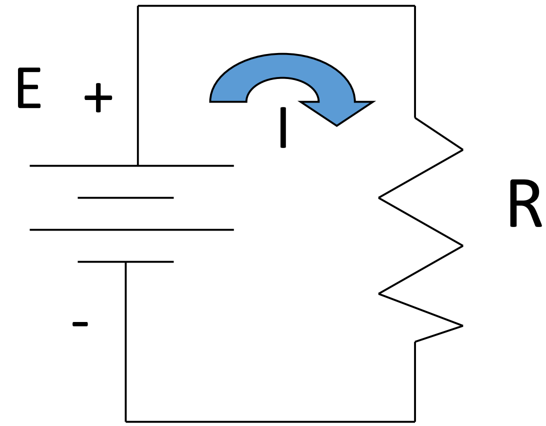
R = E/I

I = E/R



Ohm’s Law Example 6

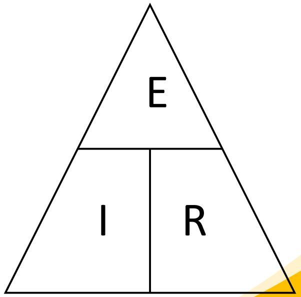
- If the voltage (E) is 12 Volts and the resistance (R) is 4 ohms, how much current (I – in milliamps) is flowing?
- I = E ÷ R
- I = 12V ÷ 4 ohms
- I = 3 Amps
- I = 3 A * (1000mA/1A)
- I = 3000 mA



E = IR

R = E/I

I = E/R

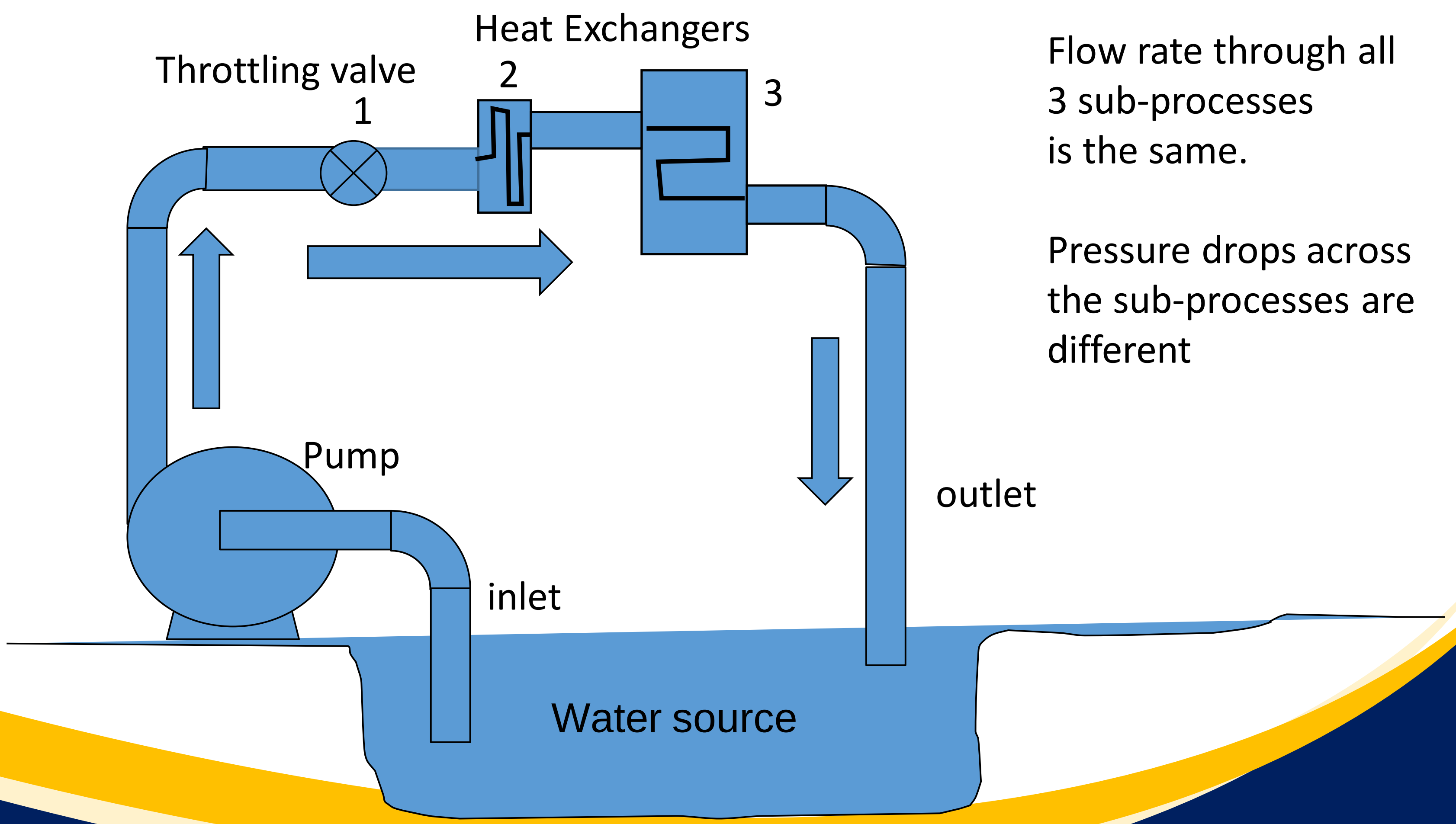


Electric Circuit Analysis

- Resistors in a circuit can be connected in <u>series</u>
  - Current is the same through all resistors
  - Voltage drop across different resistances is different

- Resistors in a circuit can be connected in <u>parallel</u>
  - Current through different resistors is different
  - Voltage drop across all resistors is the same

Fluid Circuit with “resistance” in series

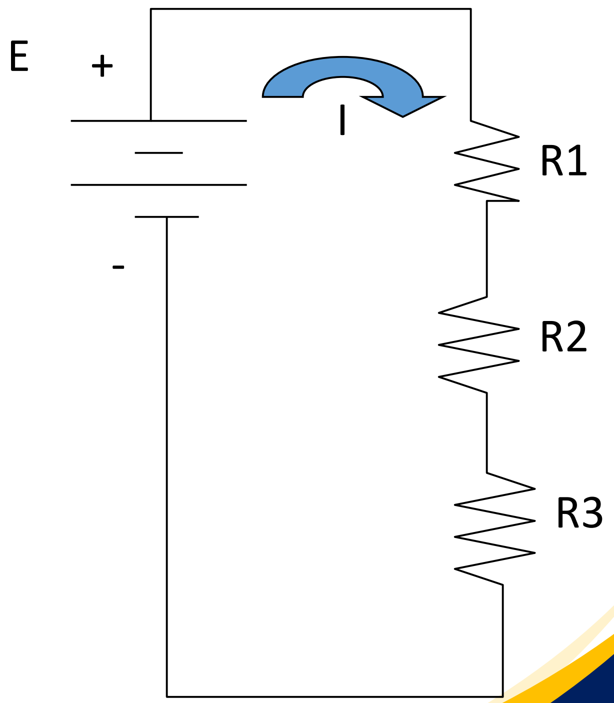


Flow rate through all 3 sub-processes is the same.

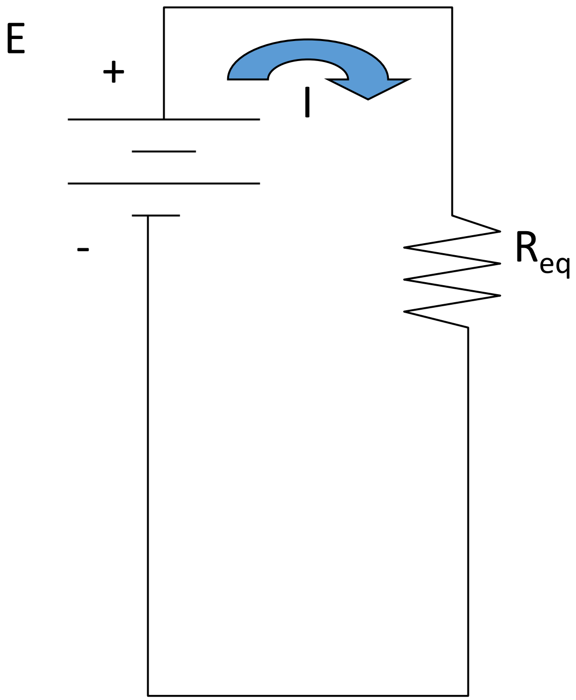
Pressure drops across the sub-processes are different

Resistors in Series

- All the current flows through all the resistors
- Depending on the resistance values, the voltage drop across each R is different.
- What is the equiv R?



Resistors in Series
what is the equivalent resistance?



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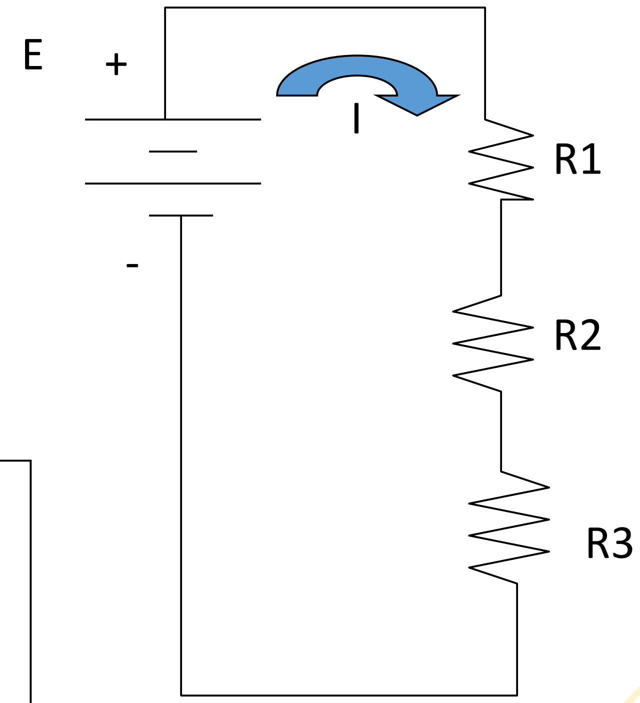


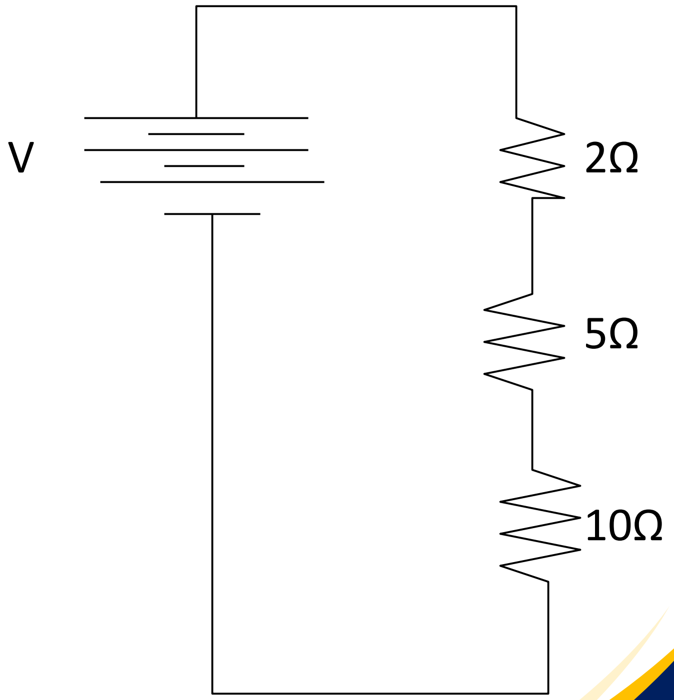
R_{eq} = R1 + R2 +R3

The equivalent resistance is greater than the largest resistor.

Series Circuit Example

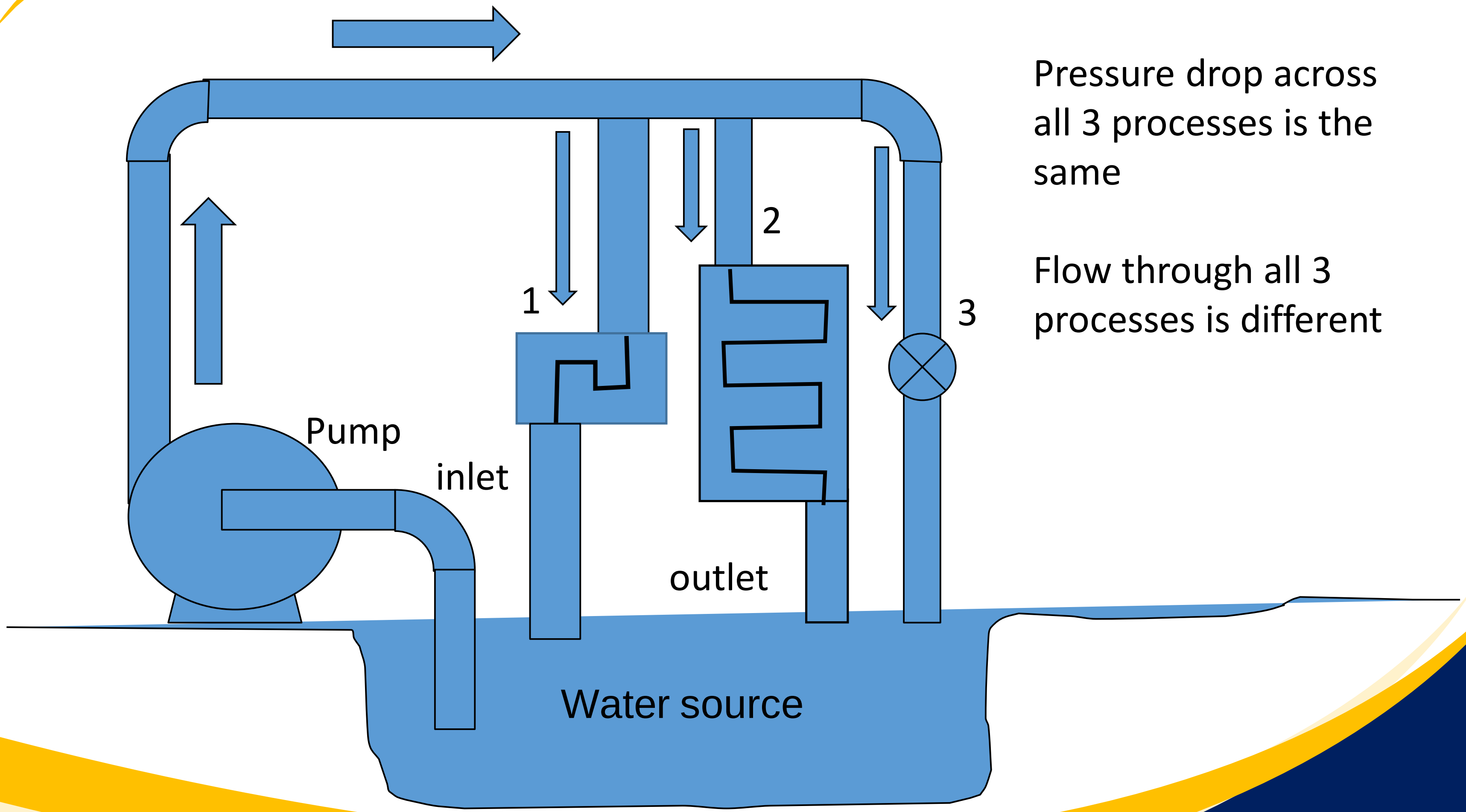
Req = 2 Ω + 5 Ω + 10 Ω

Req = 17 Ω



The equivalent resistance is HIGHER than the highest individual resistor.

Fluid circuit with “resistance” in parallel

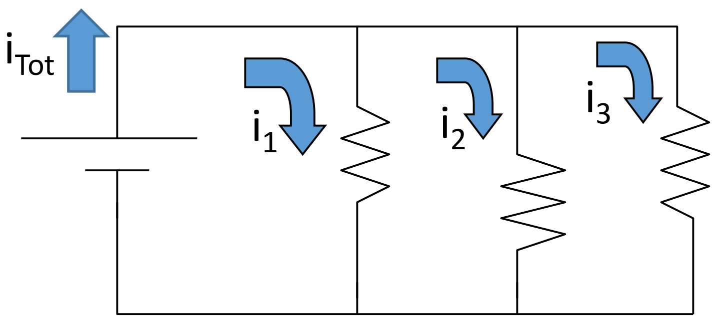


Pressure drop across all 3 processes is the same

Flow through all 3 processes is different

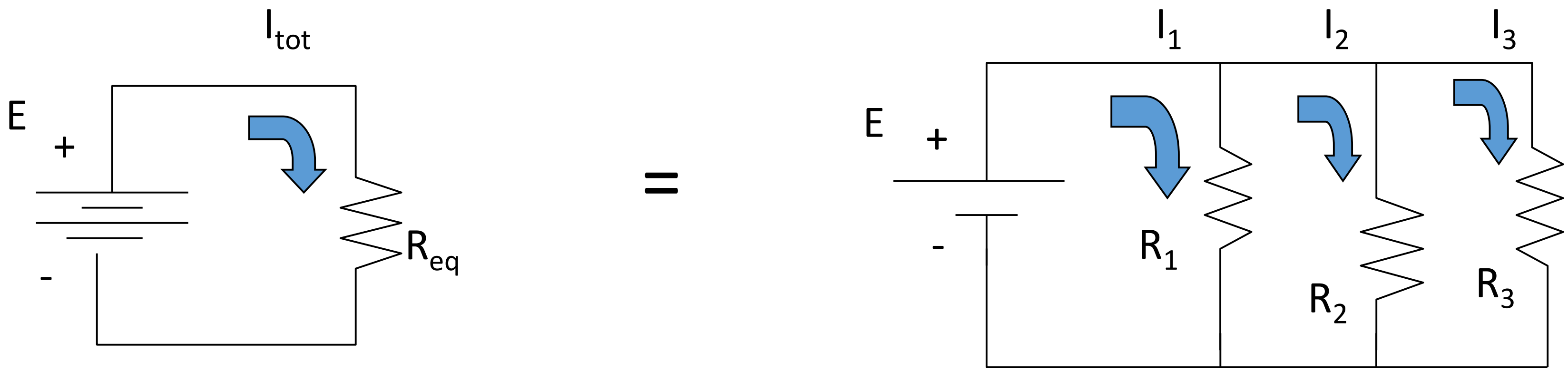
Resistors in Parallel

- Different currents flow through the resistors
- The voltage drop across each R is the same.
- What is the equiv R?



$$i_{Tot} = i_1 + i_2 + i_3$$

Resistors in Parallel



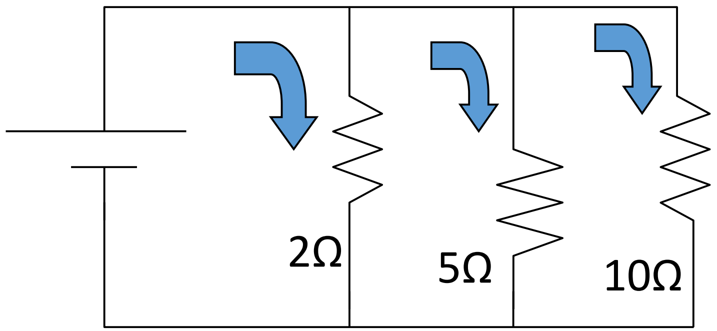
$I_{total} = I_1 + I_2 + I_3 \quad I = E/R$

$E/R_{eq} = E/R_1 + E/R_2 + E/R_3$

$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$

Numerical Example of Parallel Resistors

$$\frac{1}{Req} = \frac{1}{2\,\Omega} + \frac{1}{5\,\Omega} + \frac{1}{10\,\Omega}$$



$$\frac{1}{Req} = 0.5\ \Omega^{-1} + 0.2\ \Omega^{-1} + 0.1\ \Omega^{-1}$$

$= 0.8\ \Omega^{-1}$ $R_{eq} = 1/0.8 = 1.25\ \Omega$

The Equivalent resistance is LOWER than the lowest resistance.

End of Presentation