Module 10: Wet Lab Applications to Medical Devices

BMES Cell Team

Spring 2021

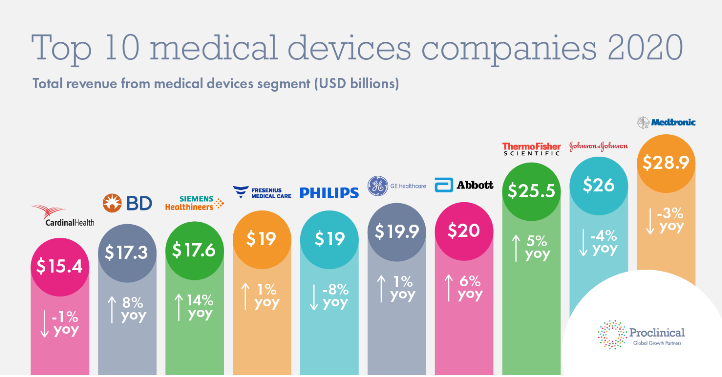
Outline

- Wet Lab meets Dry Lab
    - Industry Applications
- Electrical Engineering Principles
    - Introduction to Circuitry
    - Differential Equations
- Implants
- Bioreactors
- Diagnostics

https://www.universitylabpartners.org/blog/wet-lab-incubator
https://base.imgix.net/files/base/ebm/machinedesign/image/2019/04/machinedesign_20212_medicaldevices_1064981344.png?auto=format&fit=max&w=1200

Why is this important?

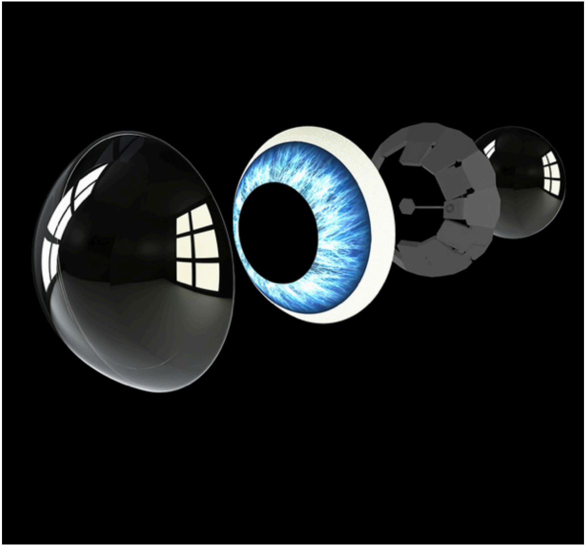
- **Bioengineering exists at the intersection of wet and dry lab**
- **You will likely be applying your technical skills to medical device problems**
  - **1 in 4 biomedical engineers work for a medical manufacturer**
  - Product success depends on good drug absorption and excretion



https://www.proclinical.com/blogs/2020-9/who-are-the-top-10-medical-device-companies-in-the-world

Real Life Example: Intersection of Wet & Dry Lab

Mojo Vision – Augmented Reality Contact Lens



https://www.mojo.vision/mojo-lens

Real Life Example: Intersection of Wet & Dry Lab

Mojo Vision – Augmented Reality Contact Lens

Electrical Engineering & Physics
(LED Circuitry, Batteries, Optics)

Bioengineering
(Wet Lab Testing for Biocompatibility)

Mechanical Engineering
(Computer Aided Design of Lens)

Chemical Engineering
(Material Interactions)

https://www.bbc.com/news/av/technology-51137379

Real Life Example: Intersection of Wet & Dry Lab

Mojo Vision – Augmented Reality Contact Lens

Companies like this one are looking for engineers with your technical skills!

ME Intern

SARATOGA, CA / DESIGN – DESIGN / INTERN

Skillset

- Knowledge of basic product design mechanical engineering. Strong mechanical aptitude focused on small compact electronic product design including integration of PCBs, antennas and power supply within Plastic injection molded housings. Comprehension of thermals, assembly methods and manufacturing processes are a plus.
- Proficient knowledge of 3D CAD programs such as Solidworks and or Fusion 360.
- Previous ME internship or product development support is also a plus.

Display Characterization Engineer

SARATOGA, CA / ENGINEERING – PHOTONICS ENGINEERING / FULL-TIME

Required Qualifications

- You have a B.A or M.S. in Electrical Engineer, Physics or related technical field
- You may be a recent graduate with preferably at least 1 year lab experience
- Programming skills in Python and/or MATLAB
- You are able to work independently and bring projects to completion
- Excellent communication skills and an enthusiastic team player

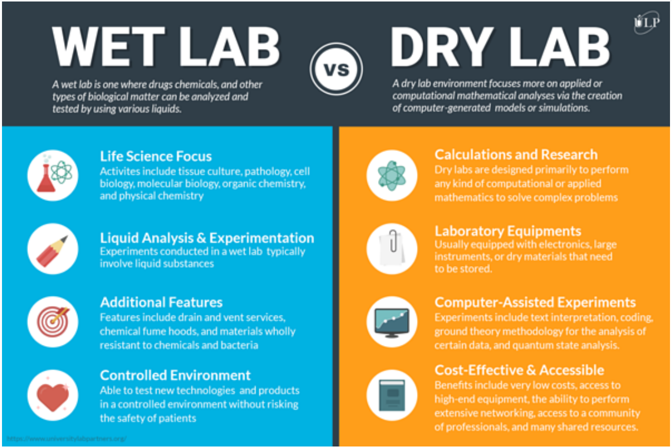
Create Your Own Position

SARATOGA, CA / GENERAL / FULL-TIME

https://jobs.lever.co/mojovision

Wet Lab vs. Dry Lab

- **Definition:** A wet lab involves working with liquid chemicals and other biological hazards to conduct experiments. A dry lab focuses on mathematical and computational analysis of data.



https://www.universitylabpartners.org/blog/wet-lab-vs-dry-lab-for-your-life-science-startup

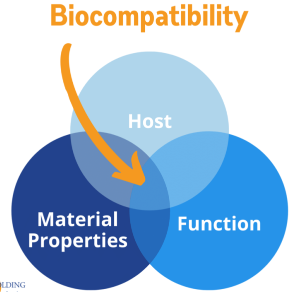
Industry Applications

- Medical Devices are typically developed in the dry lab and tested in the wet lab for biocompatibility

- **Definition:** A material is biocompatible if it is able to serve its therapeutic function without deleterious effects with the human body.

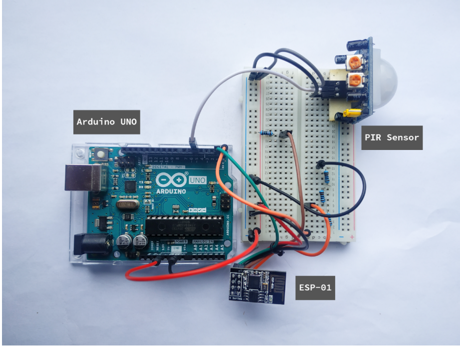
- Materials used in prosthesis, implants, and drug delivery are tested for biocompatibility

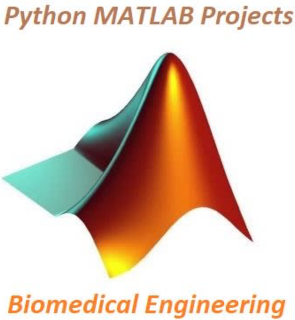
CASCO BAY MOLDING



Role of Electrical Engineering

- Most medical devices require a well designed power supply and programming to support their therapeutic function
    - Bioengineers in the medical device space should have a good understanding of circuitry and coding to support their device design and wet lab validation





Module 10A – Introduction to Circuitry

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April 2021

Outline

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Resistors

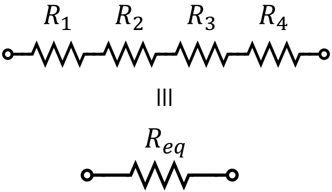
Definition

A **resistor** is a linear, two-terminal circuit element whose function is to reduce current flow along a path.

- The symbol for a resistor is as follows:

- The characteristic equation for a resistor is defined by **Ohm's Law**

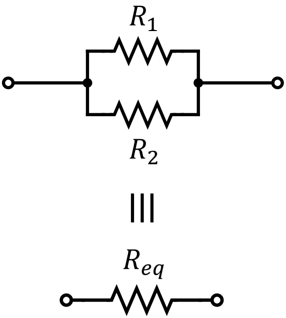
$$v \equiv iR \tag{1}$$



- We can define an equivalent resistor R_{eq} for a set of resistors in series by the following relationship:

$$R_{eq} = R_1 + R_2 + ... + R_N = \sum_{i=1}^{N} R_i \tag{2}$$

Resistors in Parallel



- We can define an equivalent resistor R_{eq} for a set of resistors in parallel by the following relationship:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{1}{R_i} \tag{3}$$

Power Dissipated by a Resistor

- The power dissipated by a resistor is given by:

$$P = iv \tag{4}$$

- Combining equations (1) and (4) gives us two other ways to define power:

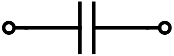
$$P = i^2 R = \frac{v^2}{R} \tag{5}$$

Capacitors

Definition

A **capacitor** is a linear, two-terminal circuit element whose function is to store energy in an *electric* field $\vec{E}$.

- The symbol for a capacitor is as follows:



- The characteristic equation for a capacitor is defined as follows:

$$i \equiv C\frac{dv}{dt} \tag{6}$$

Capacitors in Series and Parallel

- We can define an equivalent capacitor C_{eq} for a set of capacitors in series by the following relationship:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ... + \frac{1}{C_N} = \sum_{i=1}^{N} \frac{1}{C_i} \tag{7}$$

- We can define an equivalent capacitor C_{eq} for a set of capacitors in parallel by the following relationship:

$$C_{eq} = C_1 + C_2 + ... + C_N = \sum_{i=1}^{N} C_i \tag{8}$$

Inductors

Definition

An **inductor** is a linear, two-terminal circuit element whose function is to store energy in a *magnetic* field $\vec{B}$.

- The symbol for a capacitor is as follows:

- The characteristic equation for an inductor is defined as follows:

$$v \equiv L\frac{di}{dt} \tag{9}$$

Inductors in Series and Parallel

- We can define an equivalent inductor L_{eq} for a set of inductors in series by the following relationship:

$$L_{eq} = L_1 + L_2 + ... + L_N = \sum_{i=1}^{N} L_i \qquad (10)$$

- We can define an equivalent inductor L_{eq} for a set of inductors in parallel by the following relationship:

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + ... + \frac{1}{L_N} = \sum_{i=1}^{N} \frac{1}{L_i} \qquad (11)$$

Principle of Duality

- In Physics, the *principle of duality* holds for a lot of concepts and quantities
- The constitutive equations between duals are opposites of one another
- For instance:
  - A parallel circuit is the dual of a series circuit
  - An inductor L is the dual of a capacitor C

$$v_L = L\frac{di}{dt} \iff i_C = C\frac{dv_c}{dt}$$

$$L_{eq,series} = \sum_{i=1}^{N} L_i \iff C_{eq,series} = \sum_{i=1}^{N} \frac{1}{C_i}$$

$$L_{eq,parallel} = \sum_{i=1}^{N} \frac{1}{L_i} \iff C_{eq,parallel} = \sum_{i=1}^{N} C_i$$

Steady State Analysis of DC Circuits

- Capacitors act as an open circuit at $t \to \infty$
  - Will later show this in the derivation of v_c in an RC circuit
- Inductors act as a short circuit at $t \to \infty$

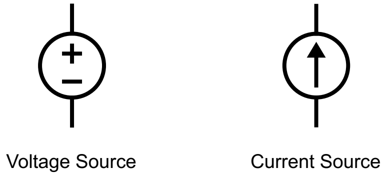
Outline

Background

- Kirchoff's Laws are used as the starting point for derivations of complex circuits
- After combining Kirchoff's Laws with the characteristic equations described in (1), (6), and (9), we end up with an ordinary differential equation
- This differential equation can be used to solve for voltage and current at certain points in the circuit

Voltage and Current Sources

- Batteries are the source for voltage and current in a circuit
- Typically, only one quantity is given and not the other



- For a voltage source, the current travels through the circuit from the positive end to the negative end
- For a current source, the current travels in the direction of the arrow

Kirchoff's Voltage Law

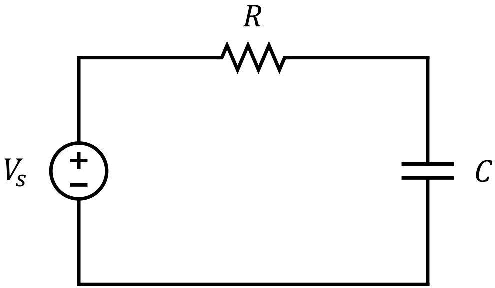
Definition

Kirchoff's Voltage Law (KVL) states that the sum of all voltage drops around a loop is equal to zero.

$$\sum_{\circlearrowright} v_j = 0$$

KVL Example

- For the circuit below, write down the characteristic differential equation using Kirchoff's Voltage Law as a starting point.



Kirchoff's Current Law

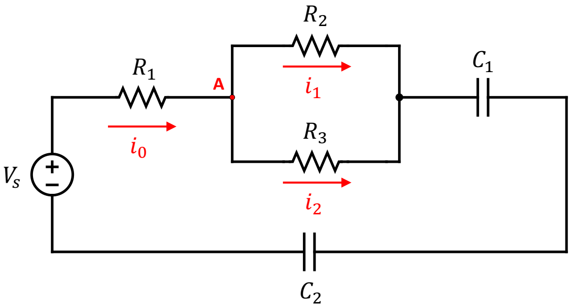
Definition

Kirchoff's Current Law (KCL) states that the sum of all currents entering or leaving a node is equal to zero.

$$\sum_{\perp} i_j = 0$$

KCL Example

- For the circuit below, write down the KCL equation for node A in terms of i_0, i_1, and i_2.



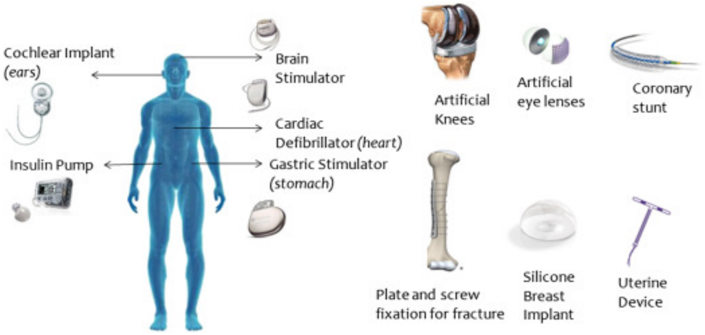
Applications of Kirchoff's Laws

We will derive the characteristic equations for the following circuits in the slides to come.

- 1st Order Circuits
  - RC Circuits
  - RL Circuits
- 2nd Order Circuits
  - RLC Circuits

Implants

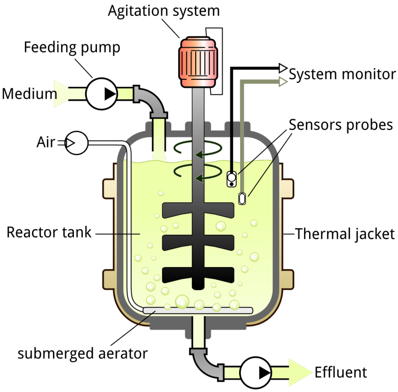
- **Definition:** An implant is a device placed inside or on the surface of the body in order to replace a missing or nonfunctional body part



https://www.sciencedirect.com/science/article/pii/B9780128190456000066

Bioreactors

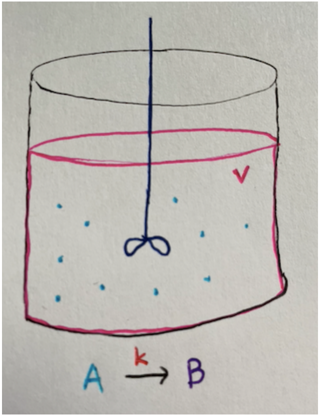
- **Definition:** A bioreactor is a device that supports a biologically active environment. A bioreactor is typically a vessel used to create a desired biological product (ex: bacteria, cells, pharmaceutical compounds).



Dr. Kamei
2020 BE 110

Types of Bioreactors

- Batch Reactor
  - No inlet or outlet liquid streams
  - Inlet and outlet gas streams to provide oxygen and remove carbon dioxide

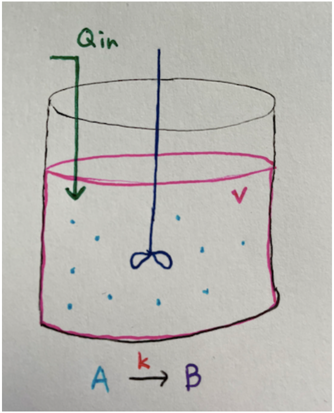


- volume is constant
  - $\frac{dV}{dt} = 0$

- moles of compound A at time t = moles of compound A at start – moles of compound A consumed
  - $n_A(t) = n_A(t_0) - n_B(t)$
    - Assuming $n_B(t_0) = 0$
  - $\frac{dn_A}{dt} = -kC_A V$
    - $C_A = \frac{moles\ of\ A}{volume}$

Types of Bioreactors

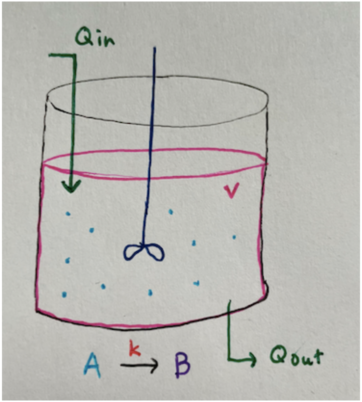
- Fed-Batch Reactor
  - Inlet and outlet gas streams
  - Inlet liquid streams to bring reactants in
    - Cannot attain steady state



- volume increases over time
  - $\frac{dV}{dt} = Q_{in}$
    - $Q_{in} = \frac{Liters\ into\ tank}{time}$
- moles of compound A at time t = moles of compound A at start – moles of compound A consumed
  - $n_A(t) = n_A(t_0) - n_B(t)$
    - Assuming $n_B(t) = 0$
  - $\frac{dn_A}{dt} = Q_{in}C_{A,in} - kC_AV$
    - $C_{A,in} = \frac{moles\ of\ A\ going\ in}{volume}$

Types of Bioreactors

- Continuous Stirred-Tank Reactor (CSTR)
  - Inlet and outlet gas streams
  - Inlet and outlet liquid streams
    - Can attain steady state
  - A CSTR that cultivates cells is called a **chemostat**



- volume changes over time
  - $\frac{dV}{dt} = Q_{in} - Q_{out}$
- moles of compound A changes over time
  - $n_A(t) = n_A(t_0) - n_B(t)$
    - Assuming $n_B(t) = 0$
  - $\frac{dn_A}{dt} = Q_{in}C_{A,in} - Q_{out}C_{A,out} - kC_AV$
    - $C_{A,out} = \frac{moles\ of\ A\ out}{volume}$

Diagnostics

- **Definition:** A diagnostics device uses patient samples to determine whether or not the patient has a medical condition.

- Integration of wet-lab testing into a user product

https://www.who.int/in-vitro-diagnostic/en/