CG1111: Engineering Principles and Practice I

Preparation for Week 2, Studio 2

How Systems Get Energy?

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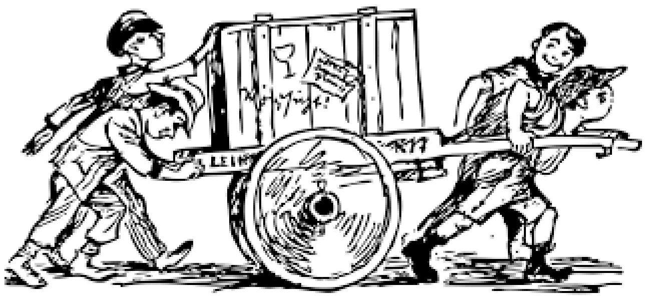
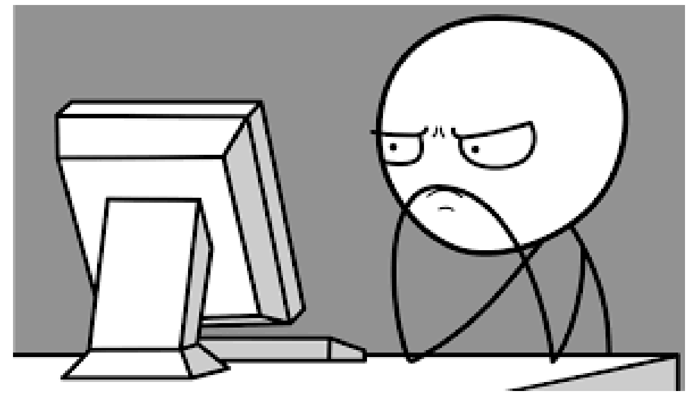
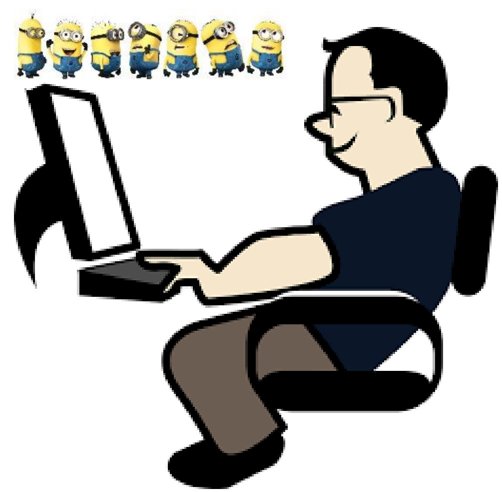
Energy

- Energy is the ability to do work

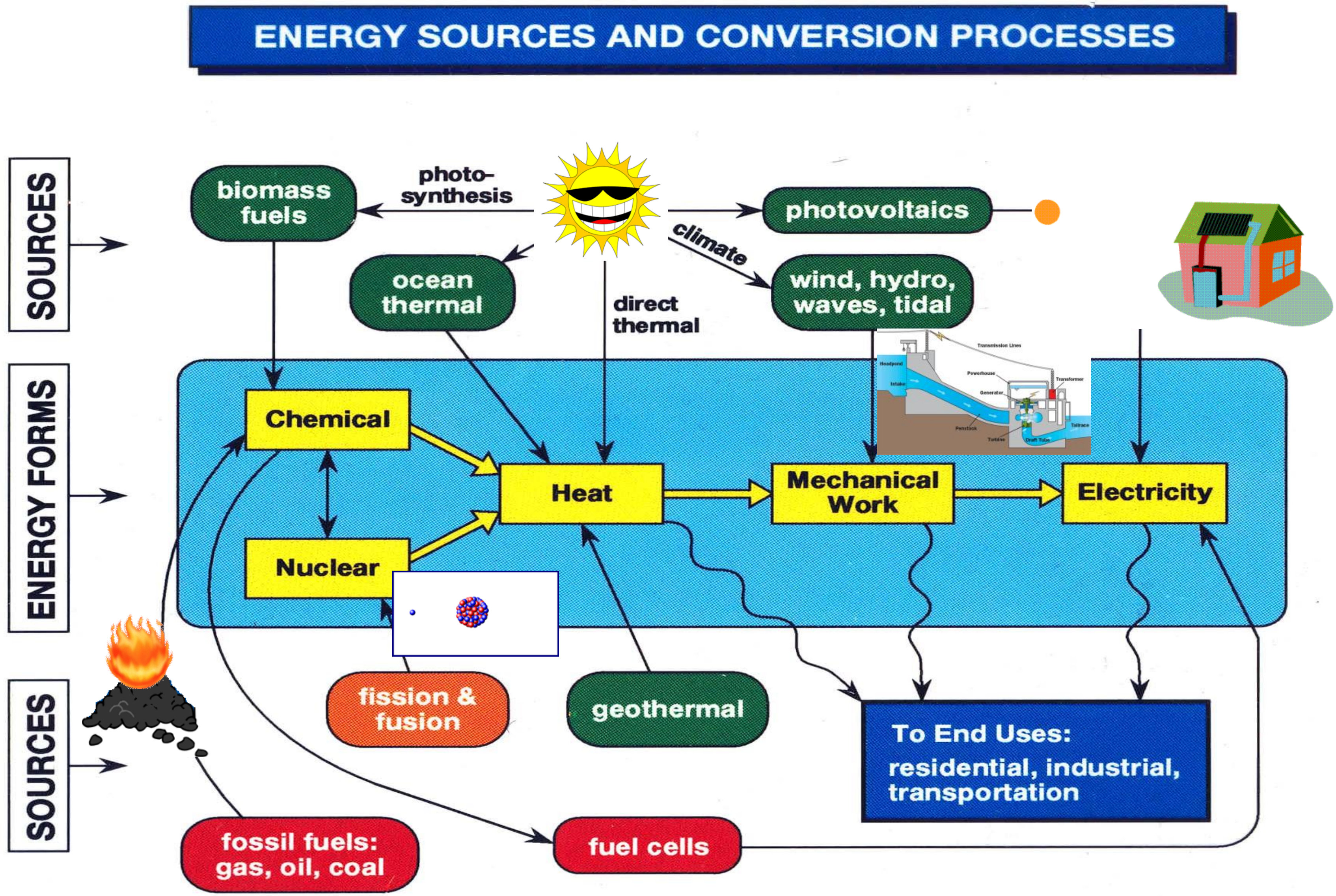




- Energy can be converted from one form to another

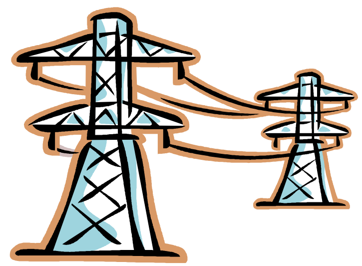


Energy Conversion

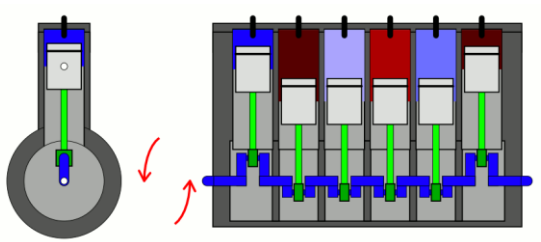


Energy Transmission

- Energy can be transmitted from one part of the system to another
  - Transmission Lines


  - Gears



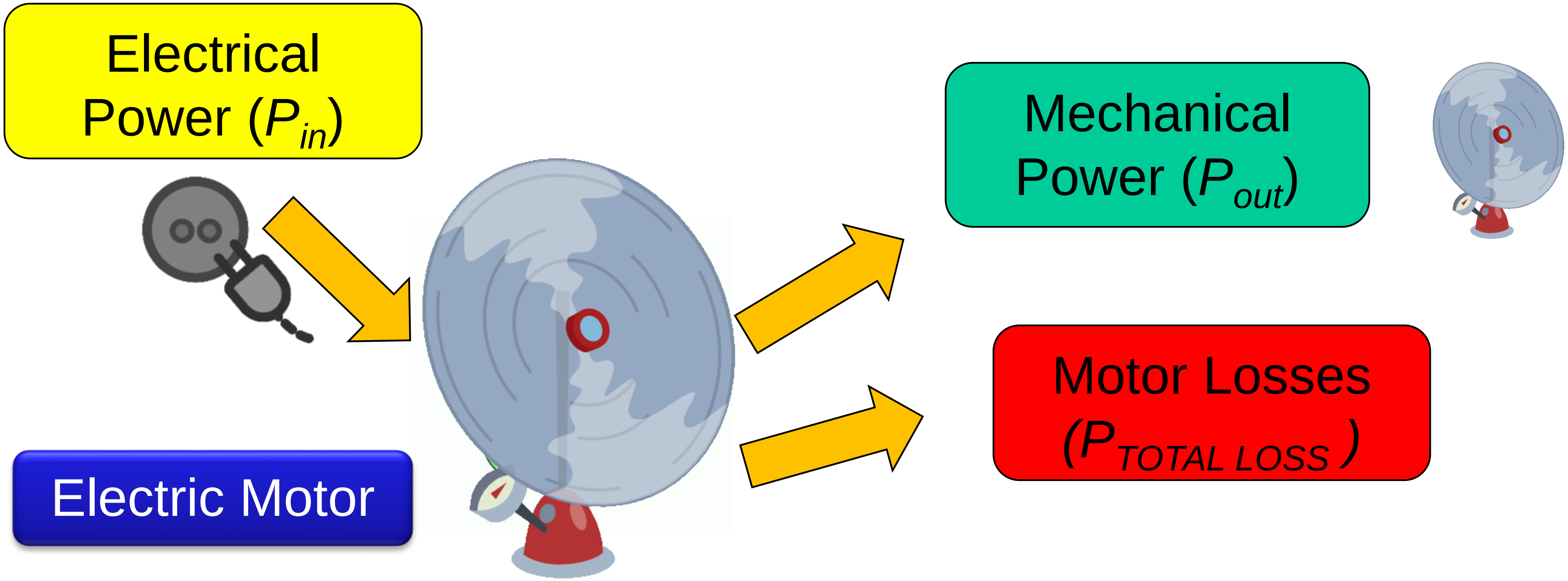
- Can I transmit all the energy???

Instantaneous Power and Efficiency

- The instantaneous power p is the rate of change of transmitted or converted energy:

$$p = \frac{dW(t)}{dt}$$

- The efficiency is defined as $\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out}+P_{Total\ Loss}}$



Energy Balance in Engineering Systems

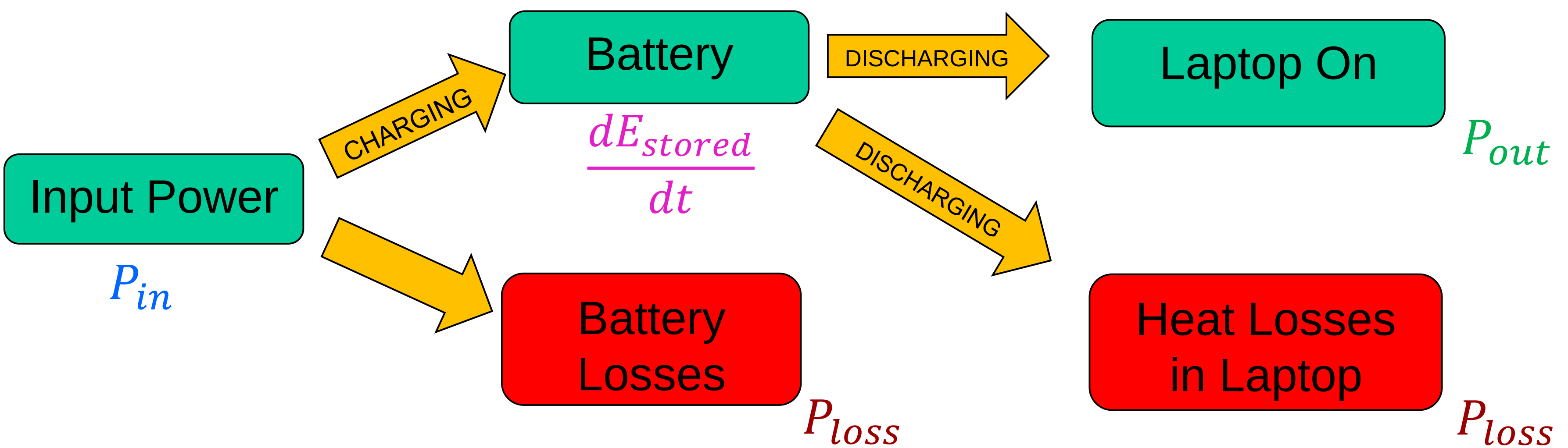
- Energy Balance Equation

$$\sum E_{in} = \sum E_{out} + \sum E_{stored} + \sum E_{lost}$$

- Power is the rate of energy flow $P = \dfrac{dE}{dt}$

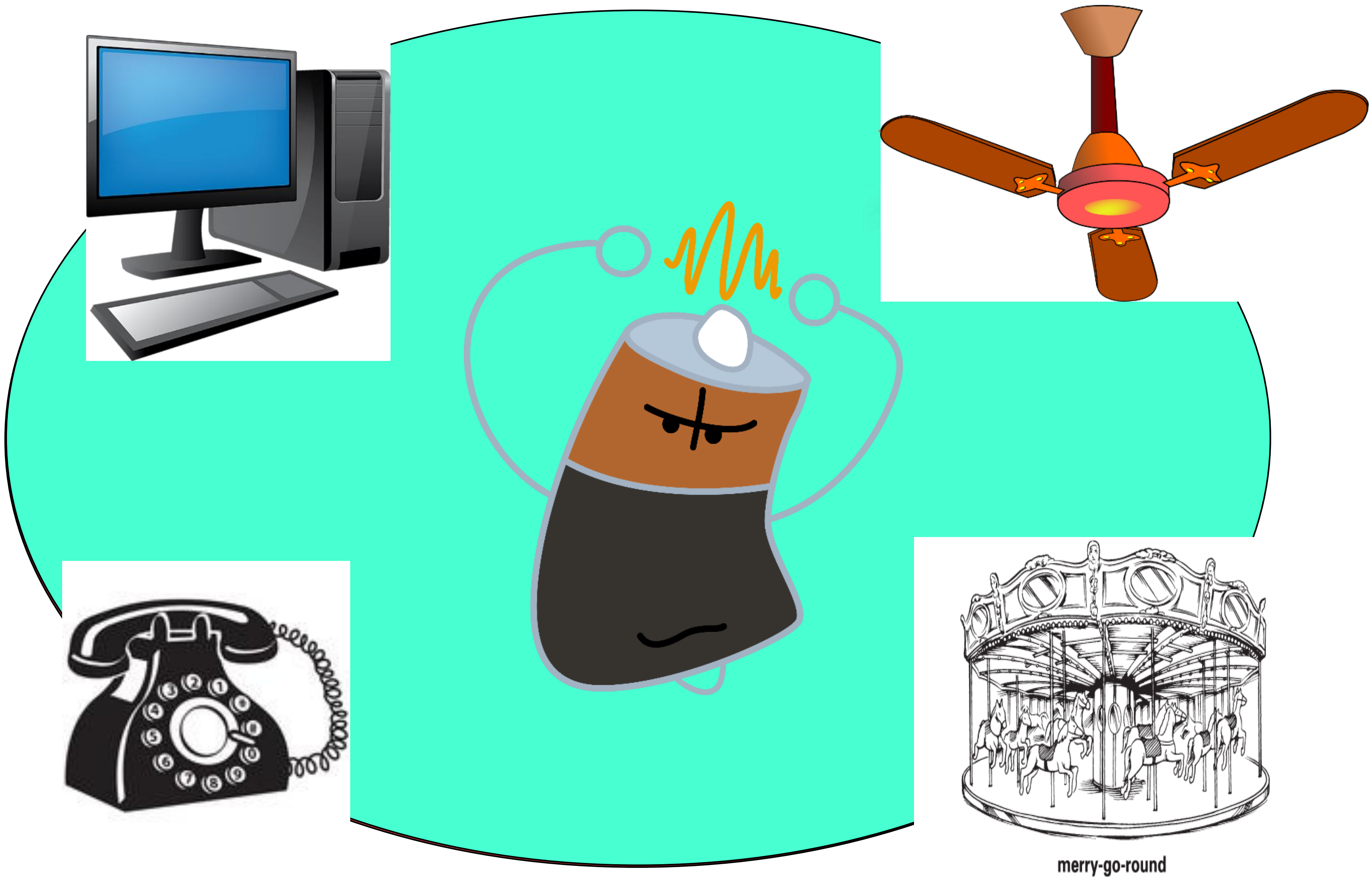
'er Balance Equation

- Power Balance in a Laptop



Batteries!!!

- Why do we need batteries??



ACTIVITY 1

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Battery Characteristics

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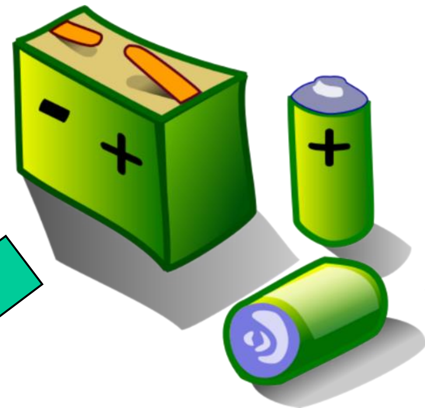
Batteries!!!

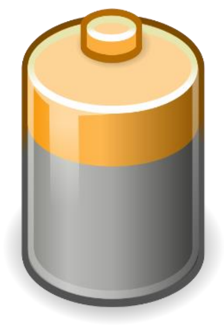
- Chemical energy → Electrical energy



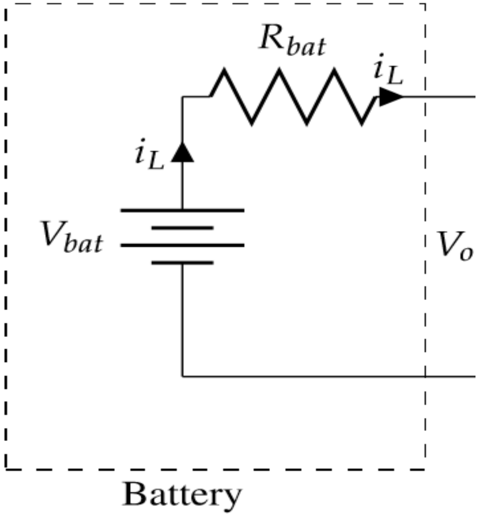
Primary Batteries: Non-rechargeable	Secondary Batteries: Rechargeable

Battery Equivalent Circuit

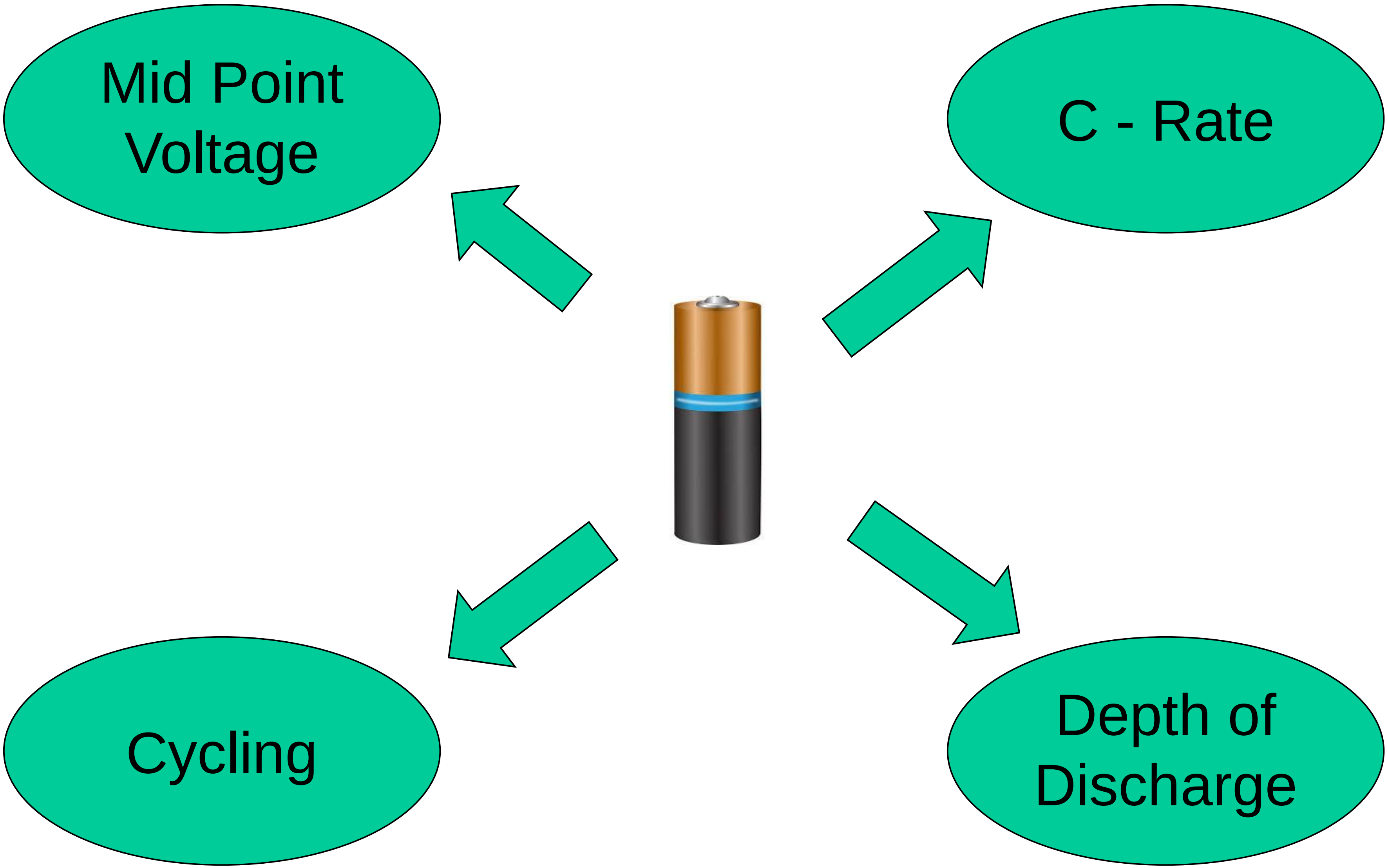
- Battery Parameters
  - Open Circuit Voltage: Voltage across the battery terminals when nothing is connected across it
  - Battery Capacity: product of current drawn from battery and time. Units: Ampere Hours/ milliAmpere Hours



- Battery Equivalent Circuit
  - V_{bat} : Voltage of Battery
  - R_{bat} : Internal Resistance of Battery
  - R_L : Load Resistance
  - I_L : Load Current

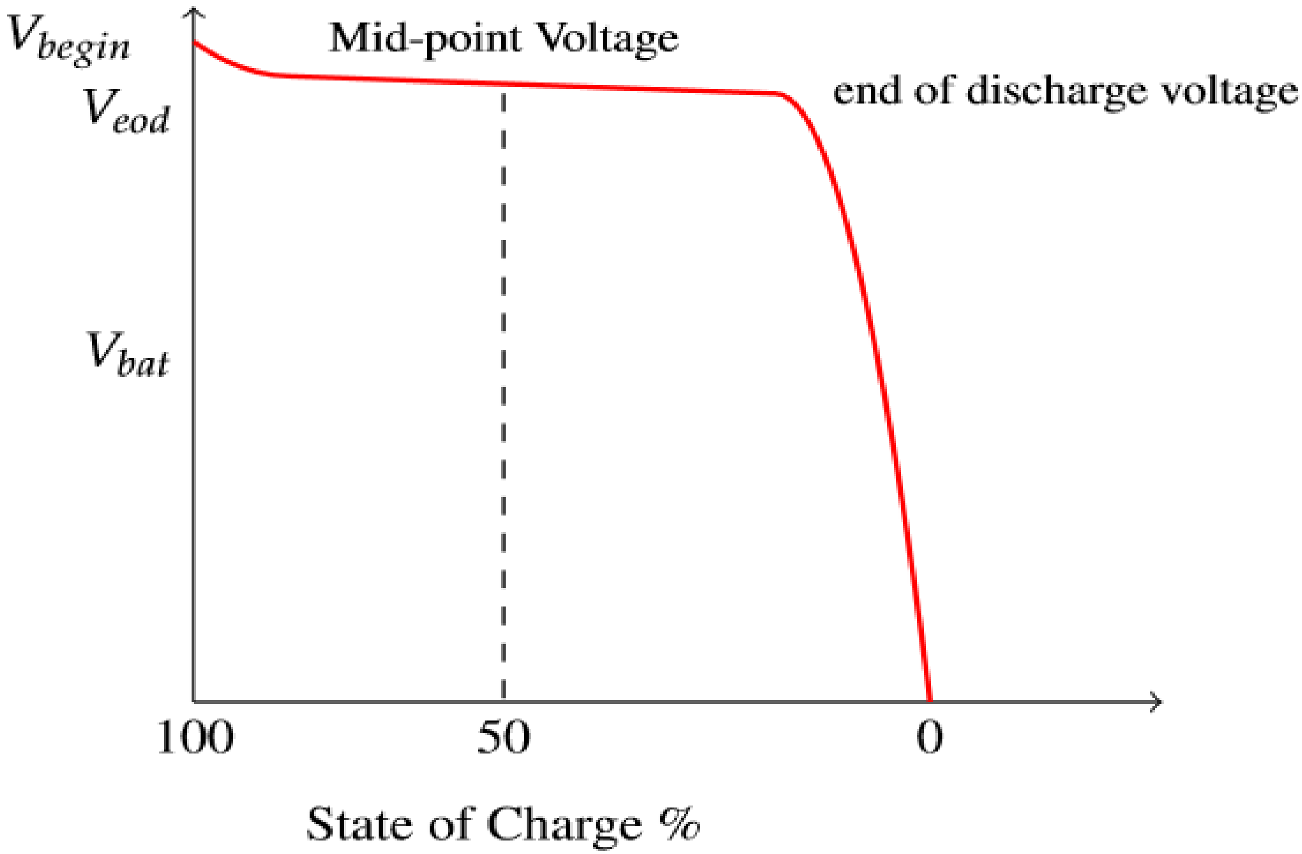


Battery Discharge Characteristics



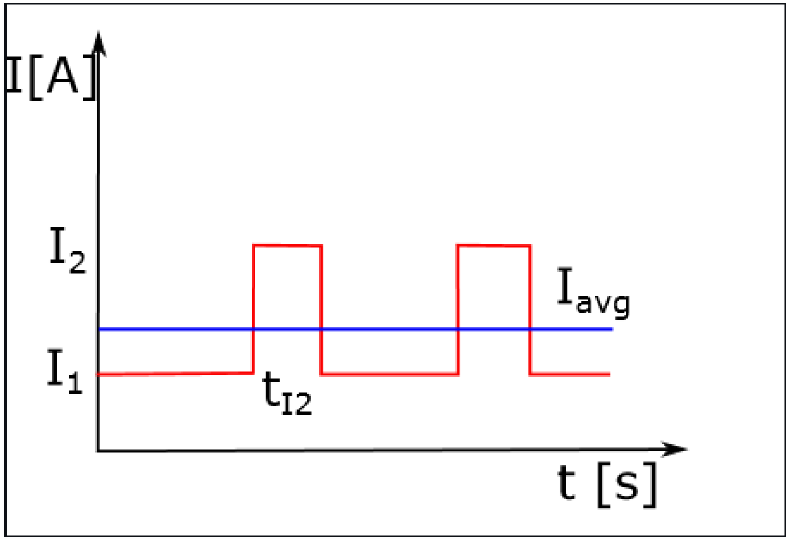
Mid-Point Voltage

- Approximate Operational Voltage of Battery



Cycling

- If the battery is not discharged at constant current, but the load or applications needs less current for some time and then a large current for another time period



- $I_{discharge} = I_{avg} = I_1 + (I_2 - I_1)\frac{t_{12}}{T_s}\ if\ \frac{t_{12}}{T_s} < 0.65$
- $I_{discharge} = I_2\ if\ \frac{t_{12}}{T_s} > 0.65$
- $I_{discharge}$ is the approximated discharge current that we use to calculate C-rate

C-Rate of Battery

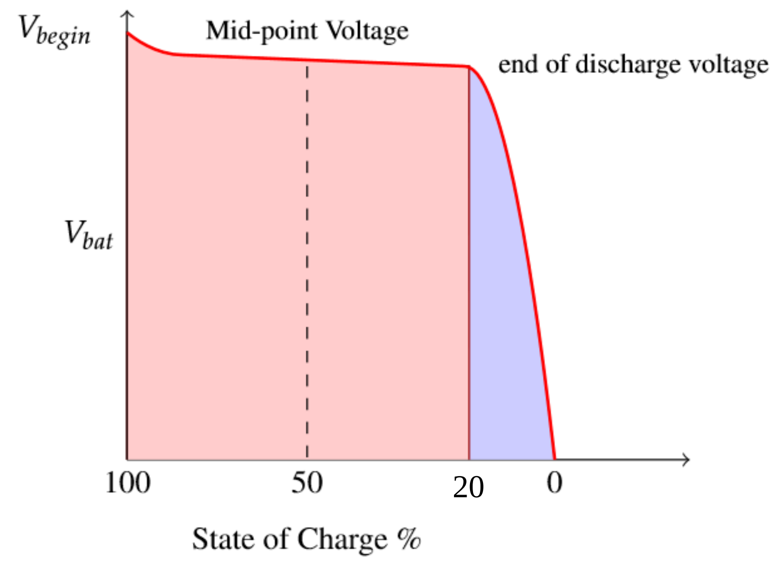
- C-rate is a commonly used terminology to indicate the amount of current drawn from the battery
- A "1C" **rate** means that the discharge current will discharge the entire battery in 1 hour.
  - 1 C rate for a 1000mA-h battery means, it is being discharged by 1 A current for 1 hour
  - For the 1000mA-h battery, '5C' would mean it is being discharged at 5 x 1= 5A

  ➔Discharge Time = 60/5= 12 minutes
  - '0.5C' means it is being discharged at 0.5 x 1= 0.5A

  ➔ Discharge Time = 60/0.5= 120 minutes or 2 hours
- As C-rate increases, battery capacity decreases

Depth of Discharge

- When we draw a current from a battery we discharge the battery
- It is advisable not to discharge the battery completely as it reduces the life of the battery
- If we discharge the battery to 60% of its total capacity, the depth of discharge 'DoD' is said to be 60%
- The Depth of Discharge is a complement of State of Charge
- V_{eod}: End of Discharge Voltage



Series Connection of Batteries

If both batteries have capacity of 1000 mAh, what is the capacity of series connection?

- If no R_L, $i_L=0$ (Open Circuit)

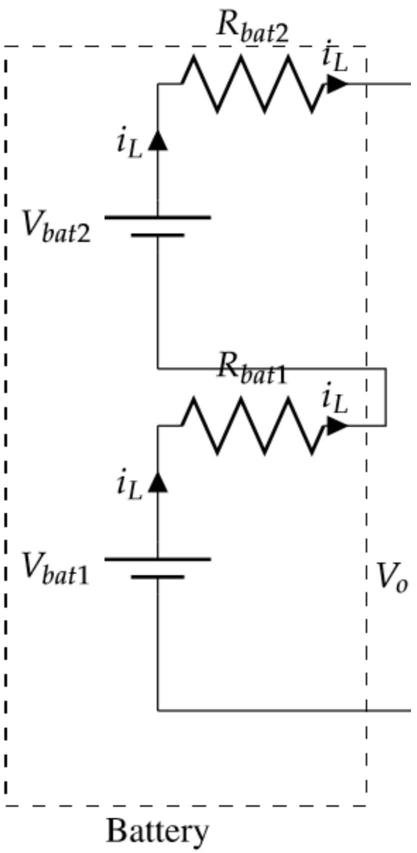
→ Open Circuit Voltage $V_{o,i_L=0} = V_{bat1} + V_{bat2}$

- If R_L is connected, i_L flows

→ $V_o = V_{bat1} + V_{bat2} - i_L(R_{bat1} + R_{bat2})$

- Same current through both the batteries
- Capacity (Ah) in Series→ Remains the same

→ The available voltage has doubled



Two Batteries connected in Series double the voltage but have the same capacity

Parallel Connection of Batteries

If both batteries have capacity of 1000 mAh, what is the capacity of parallel connection?

- If no R_L, $i_L=0$ (Open Circuit)

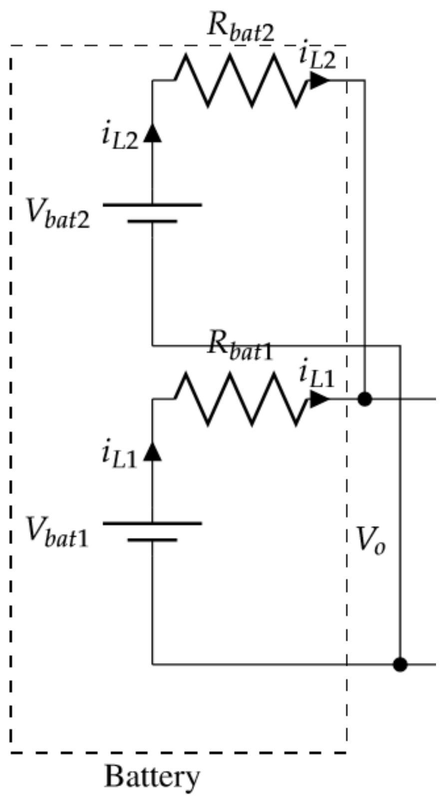
→ Open Circuit Voltage $V_{o,i_L=0} = V_{bat1} = V_{bat2}$

- If R_L is connected, i_L flows

→ $V_o = V_{bat1} - i_{L1}R_{bat1} = V_{bat2} - i_{L2}R_{bat2}$

- Total Current adds up $i_L = i_{L1} + i_{L2}$
- Capacity(Ah) in Parallel→ Increases (Doubles)

→ Voltage of parallel combination → Same



Two Batteries connected in Parallel double the capacity but have the same voltage

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Battery Design

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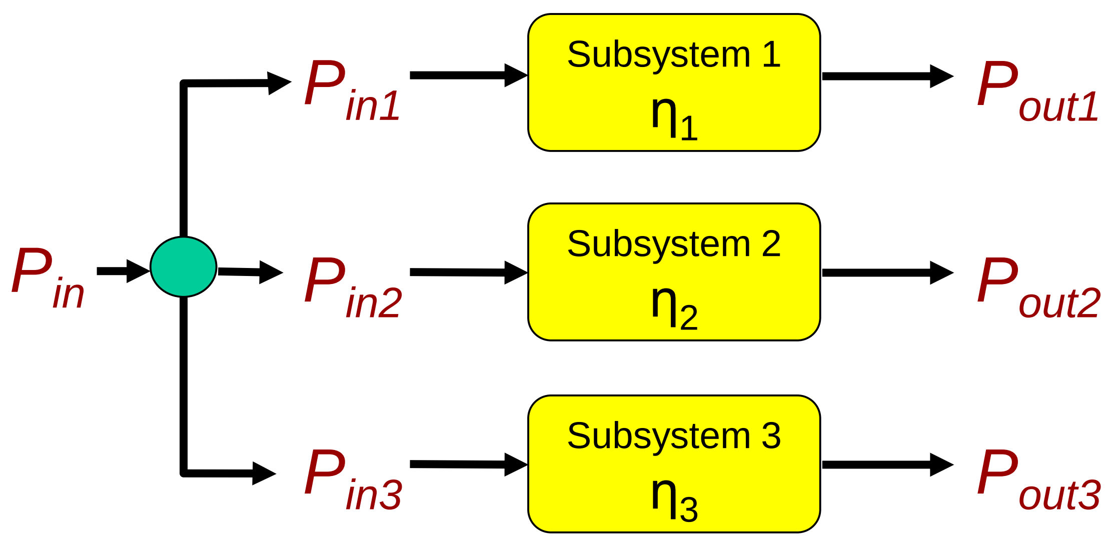
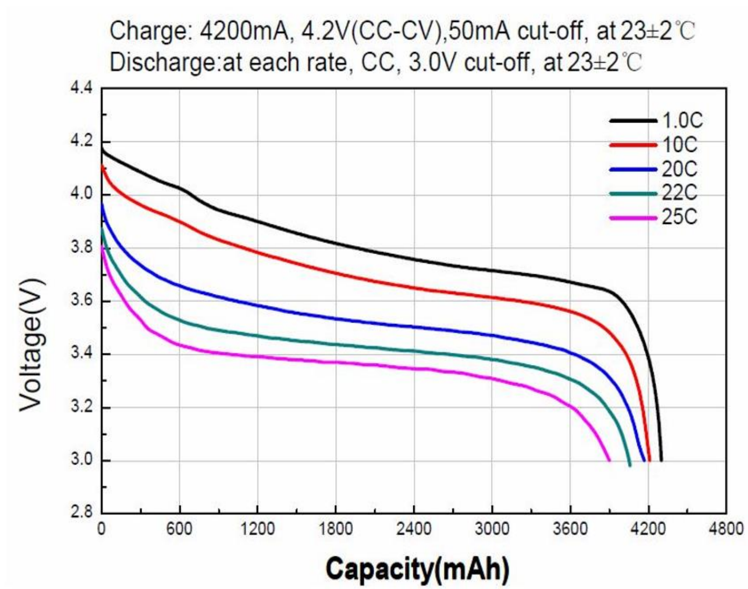
Battery Design

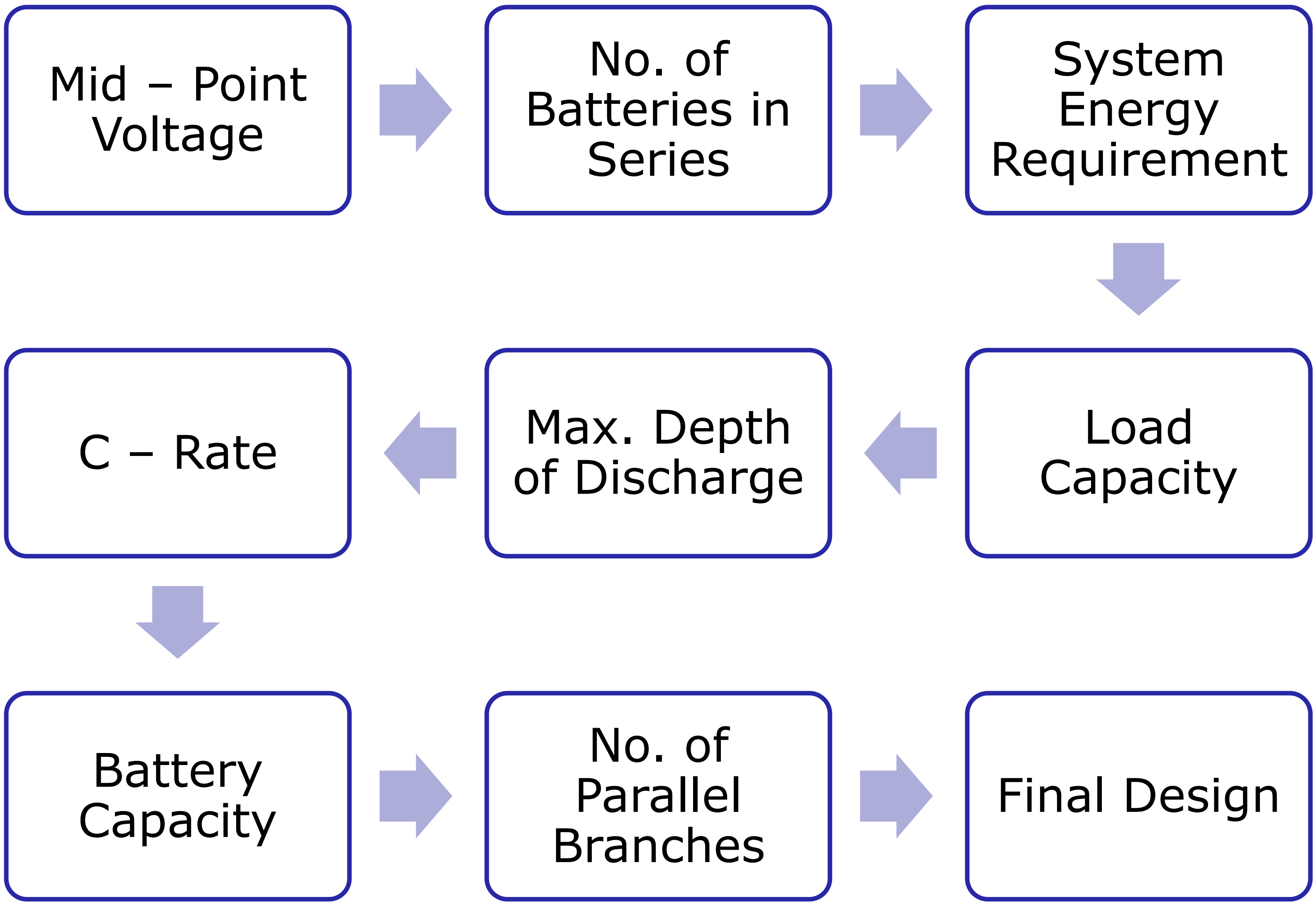
Design a battery pack for an electronic system consisting of LiIon batteries, to last a period of 6 hours with characteristics shown below and a C-Rate of 10C. The laptop has 3 subsystems working in parallel and an operating voltage of 25V

- Subsystem 1: $P_{out1} = 120W$, $\eta_1=60\%$
- Subsystem 2: $P_{out2} = 80W$, $\eta_2=80\%$
- Subsystem 3: $P_{out3} = 90W$, $\eta_3=90\%$



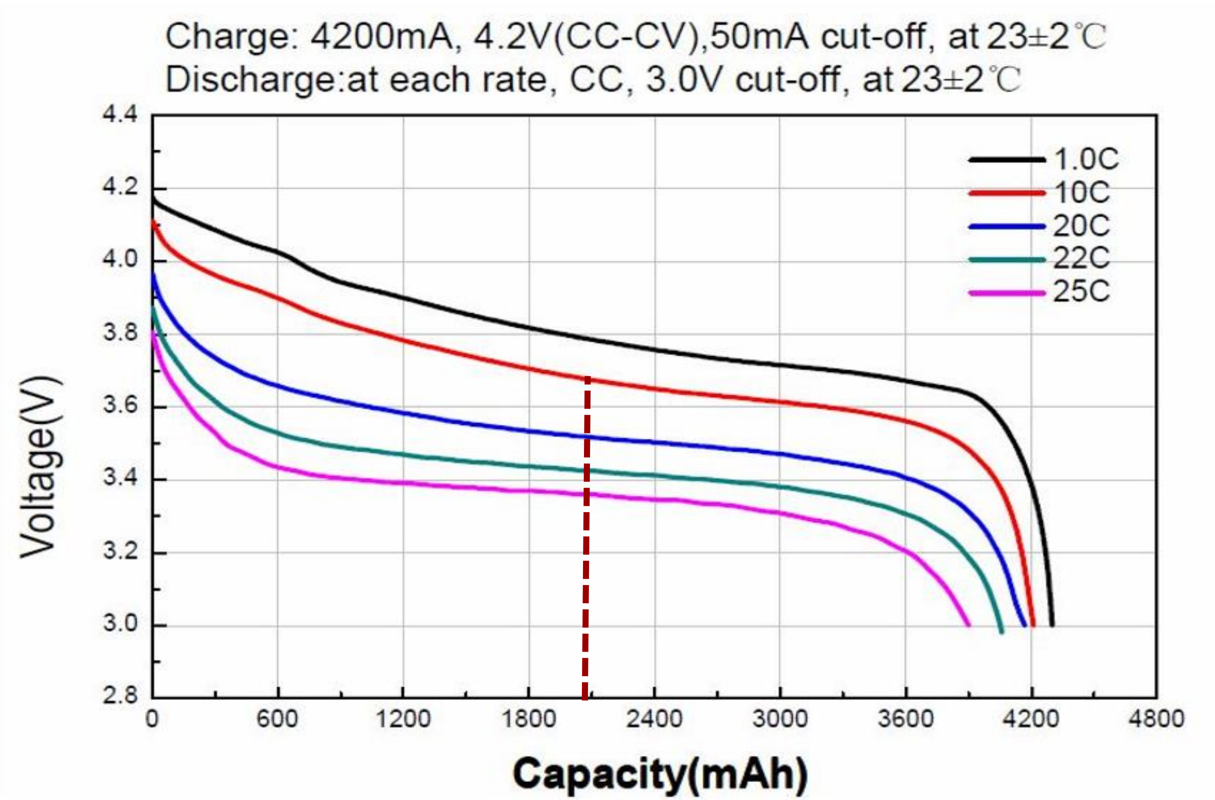


Battery Design



Mid-Point Voltage

- Calculate the mid-point voltage at given C-rate
- If C-rate is not given assume 1C



Mid Point Voltage at 10C ≈ 3.65V

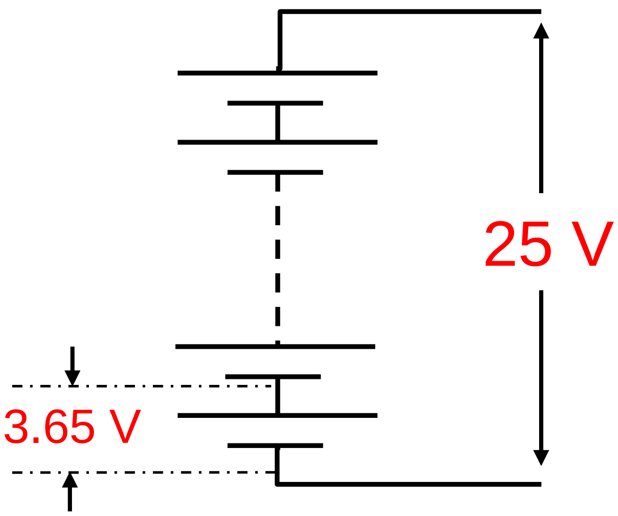
Mid-Point Voltage → **No. of Batteries in Series** → Power Requirements → Load Capacity → Depth of Discharge → C-Rate → Battery Capacity → No. of Parallel Branches → Final Design

No. of Batteries in Series

- Find the operating voltage of the load
- Use the operating voltage of the load and the mid-point voltage of each battery to estimate the number of batteries to be connected in series
- $n_s = \dfrac{Operating\ Voltage\ of\ Load}{Mid\text{−}Point\ Voltage}$

→ $n_s = \dfrac{25V}{3.65V} = 6.85$

→ $n_s \approx 7$

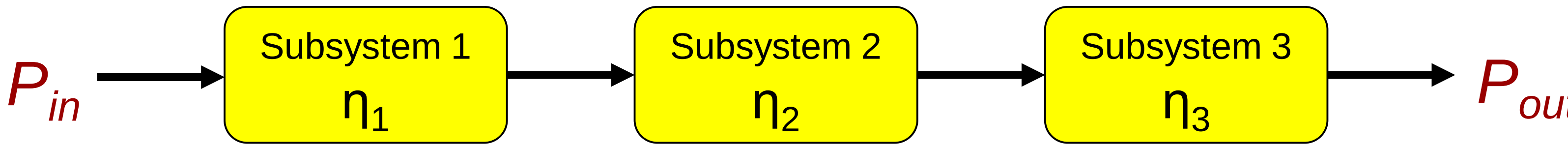


No. of Batteries in Series n_s= 7

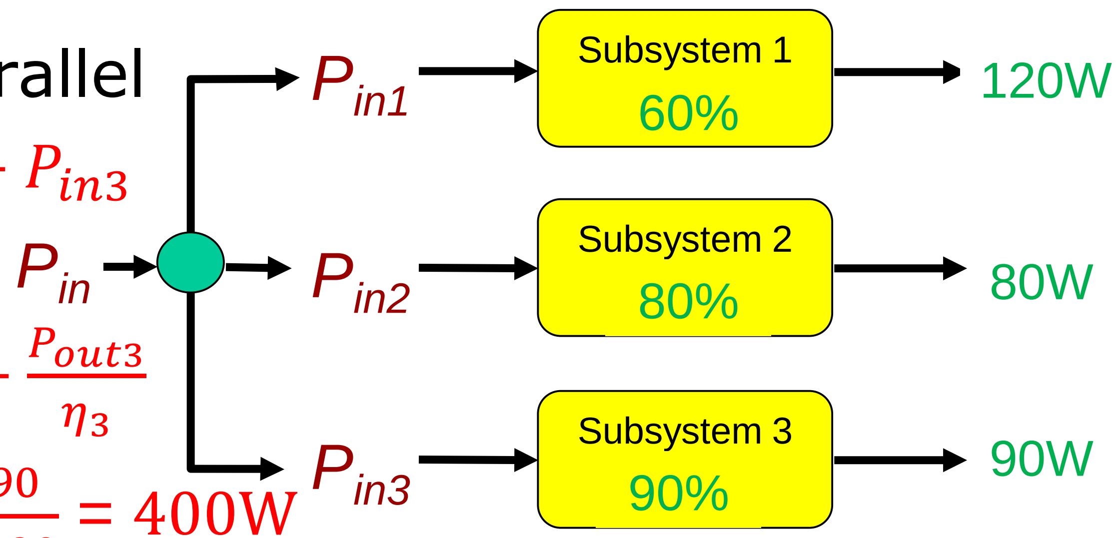
Power Requirements

Block Diagram Method to calculate power requirements

- Subsystems in Series $P_{in} = \dfrac{P_{out}}{\eta_1 . \eta_2 . \eta_3}$



- Subsystems in Parallel
  - $P_{in} = P_{in1} + P_{in2} + P_{in3}$
  - $P_{in} = \dfrac{P_{out1}}{\eta_1} + \dfrac{P_{out2}}{\eta_2} + \dfrac{P_{out3}}{\eta_3}$
  - $P_{in} = \dfrac{120}{0.60} + \dfrac{80}{0.80} + \dfrac{90}{0.90} = 400W$



Power Requirement P_{in} = 400W

Load Capacity

- Find the Battery Bank Operating Voltage (V_{BB})

→ $V_{BB}=n_s$*mid point voltage = 7*3.65= 25.55V

- Calculate Load Energy = P_{in} * time

→ Load Energy = 400W* 6 hours = 2400Wh

- Load Energy = V_{BB}*Load Capacity

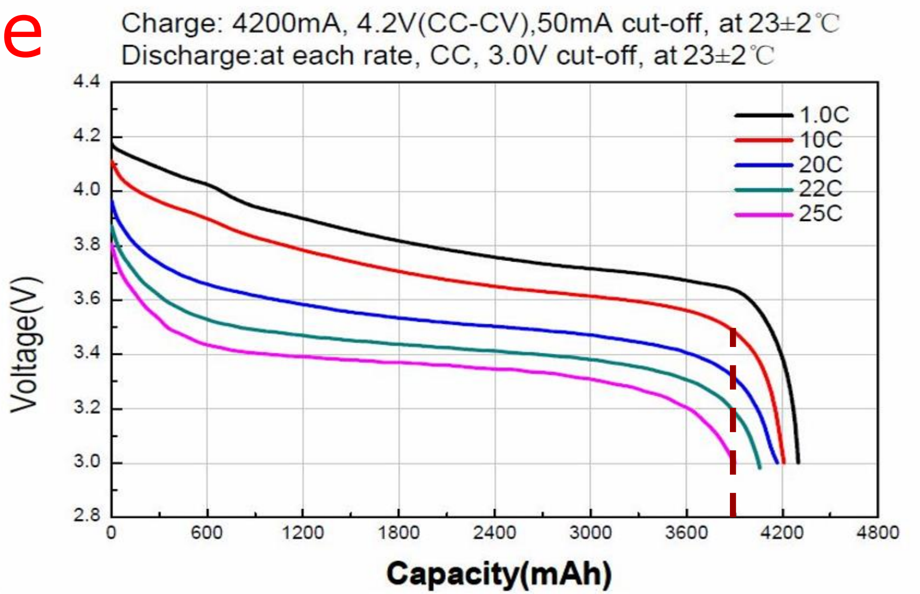
→Load Capacity = 2400/25.55 = 93.93 Ah

→Load Capacity = 93930 mAh

Load Capacity = 93930 mAh

Max. Depth of Discharge, C – Rate & Battery Capacity

- Choose the curve corresponding to the system C-Rate (10 C) and estimate the battery capacity at the Max. Depth of Discharge



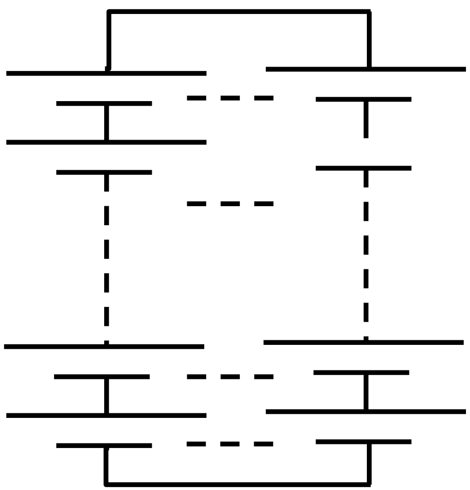
Single Battery Capacity = 3800 mAh

No. of Parallel Branches

- Find the load capacity
- Use the load capacity and the battery capacity of one battery (3800 mAh)to estimate the number of branches to be connected in parallel
- $n_p = \dfrac{Load\ Capacity}{One\ Battery\ Capacity}$

→ $n_p = \dfrac{93930\ mAh}{3800\ mAh} = 24.71$

→ $n_p \approx 25$

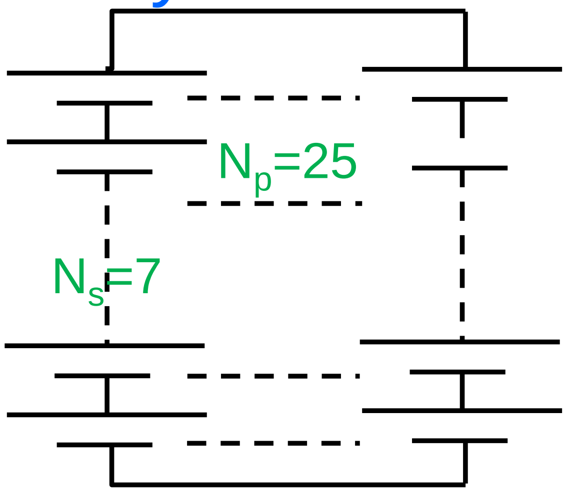


No. of Parallel Branches n_p = 25

Mid-Point Voltage → No. of Batteries in Series → Power Requirements → Load Capacity → Depth of Discharge → C-Rate → Battery Capacity → No. of Parallel Branches → Final Design

Final Battery Design

- Operating Voltage : 25.55 V
  - 7 batteries connected in series with mid-point Voltage of 3.65V at 10C
- Load Capacity: 93930 mAh
  - 25 branches of 7 series connected batteries connected in parallel with each battery capacity of 3800 mAh
- Total number of batteries
  - 25* 7= 175 Li-Ion batteries



ACTIVITY 2

THANK YOU