Lecture AMH3 – Power considerations

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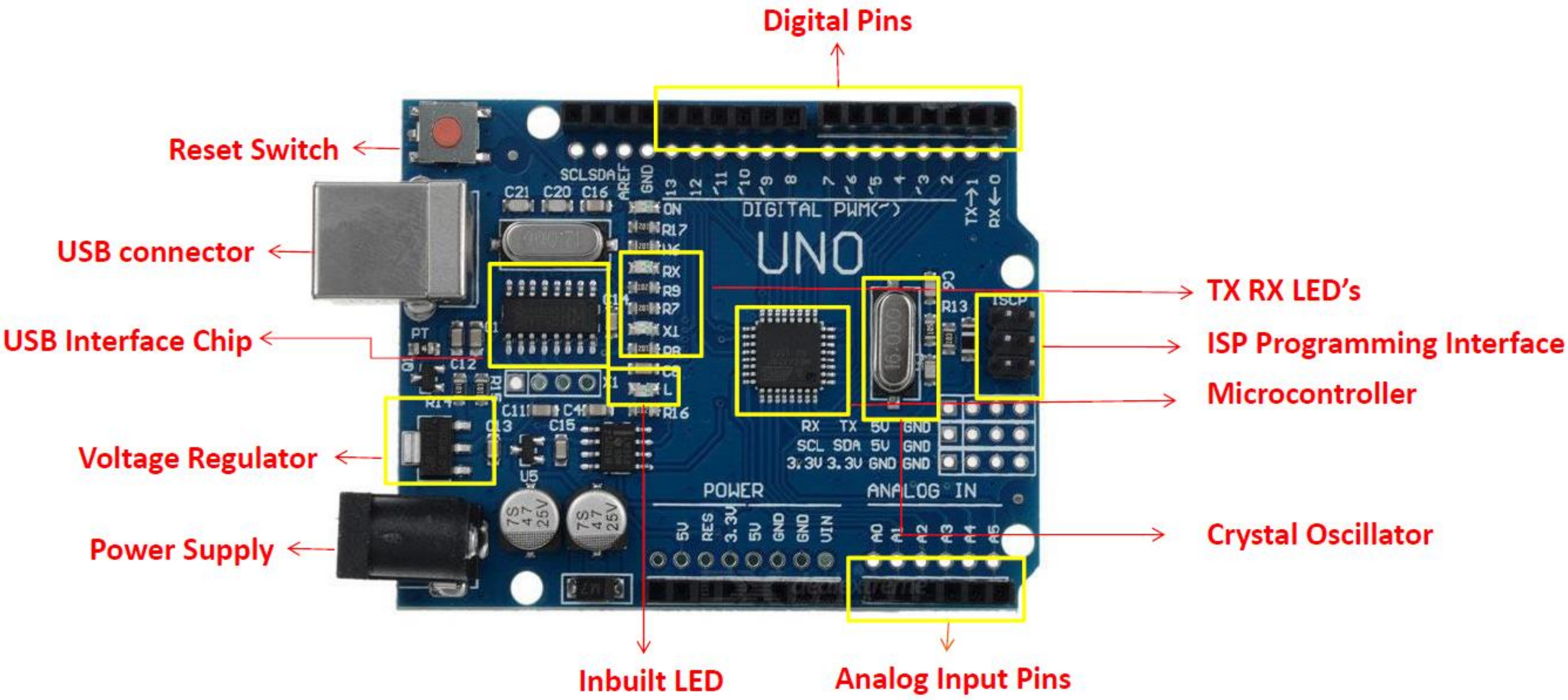
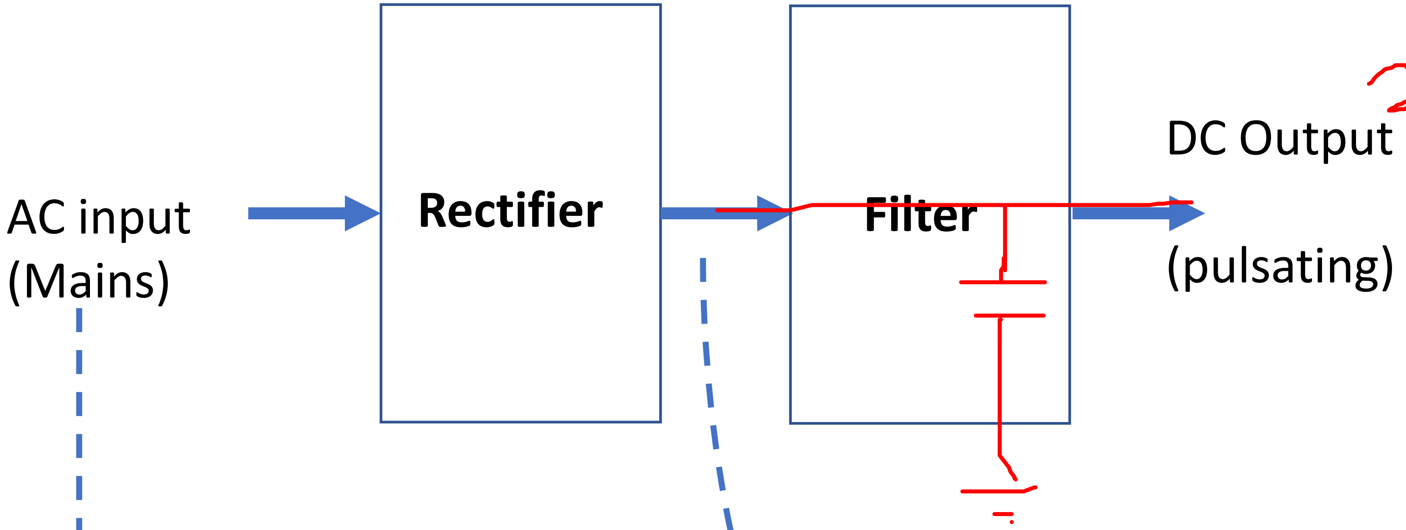
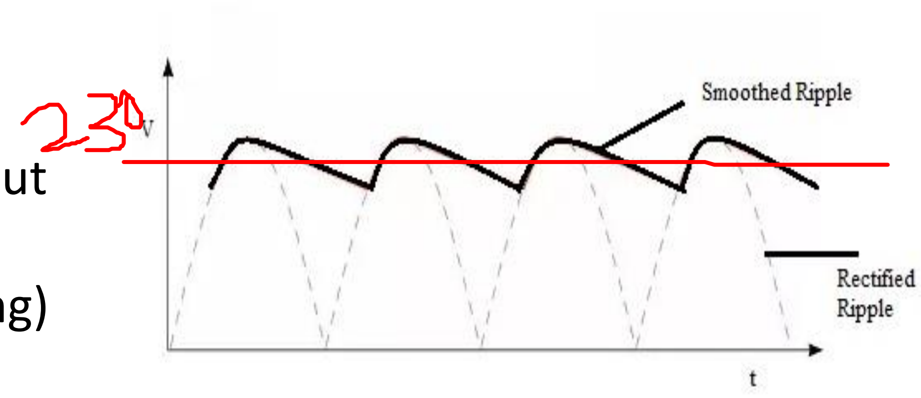
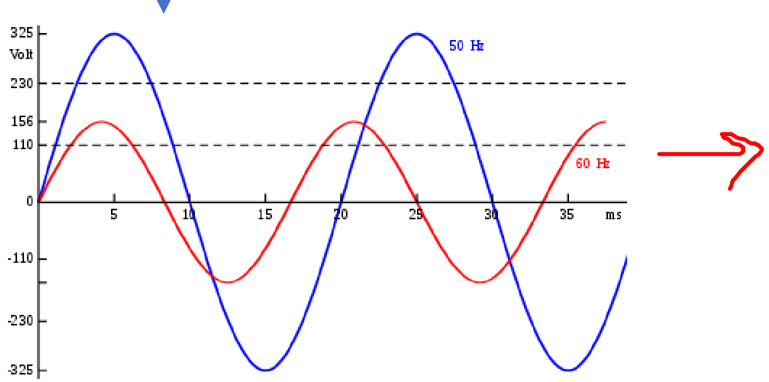
Arduino Uno board

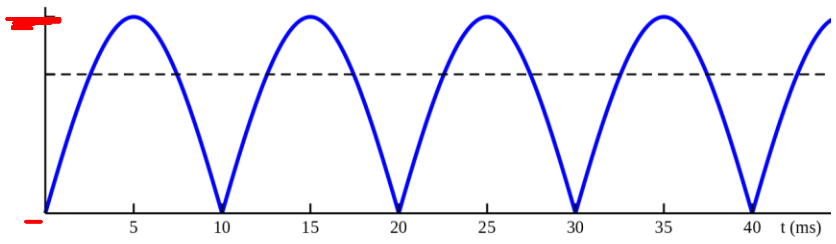


AC to DC conversion







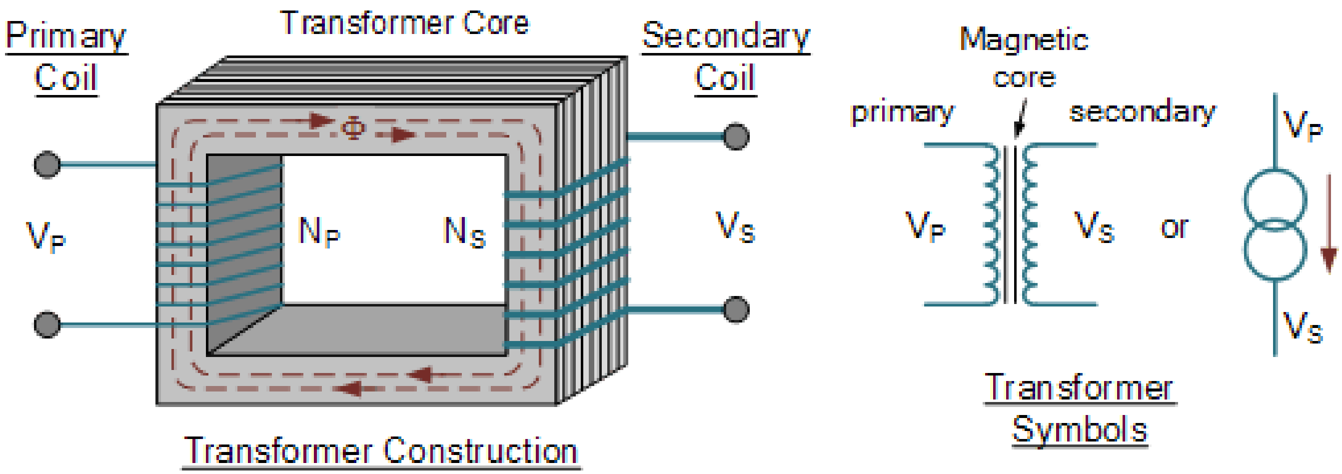


Full wave rectified

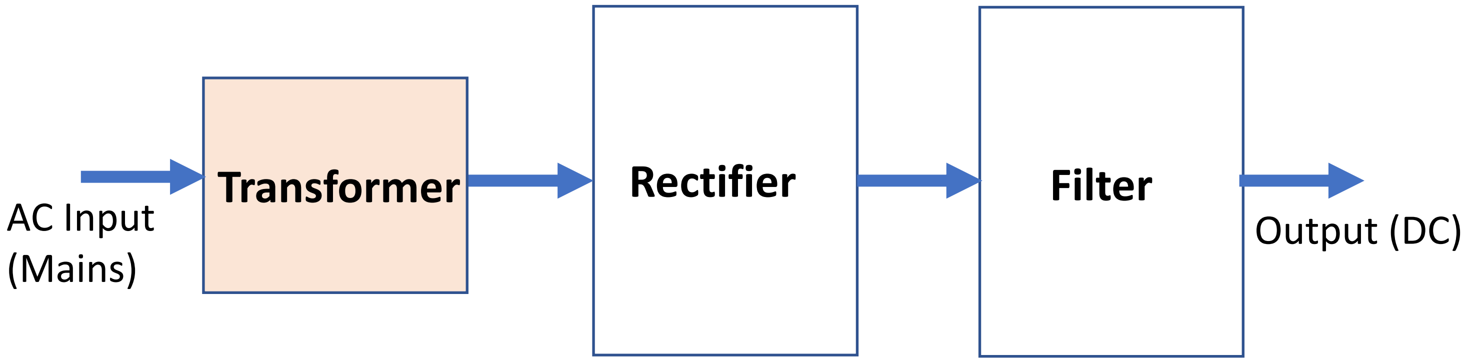
Taking care of different voltage levels

- AC input is 220 V
- Desired DC output << 220 V !
  - 5, 12, 24 V are common

Solution: introduce a block (**transformer**) to reduce the voltage level before the rectifier

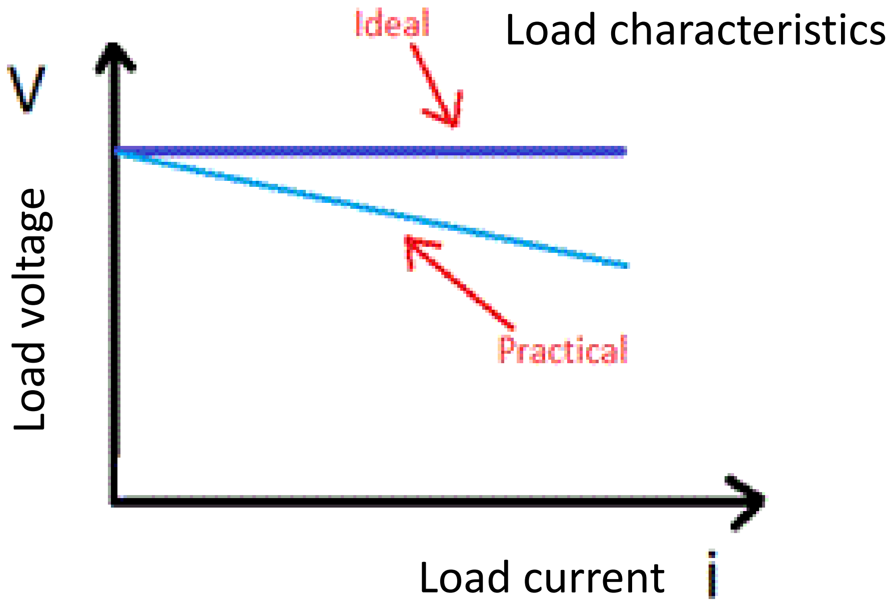


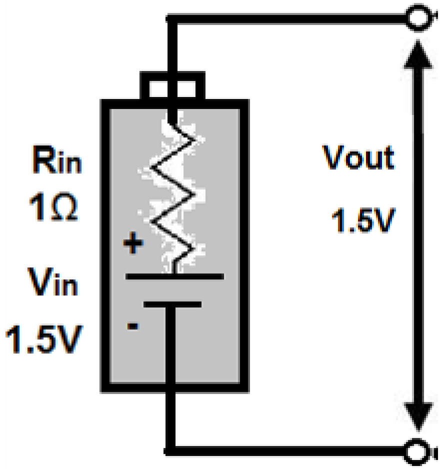
Problem: The transformer is a bulky component



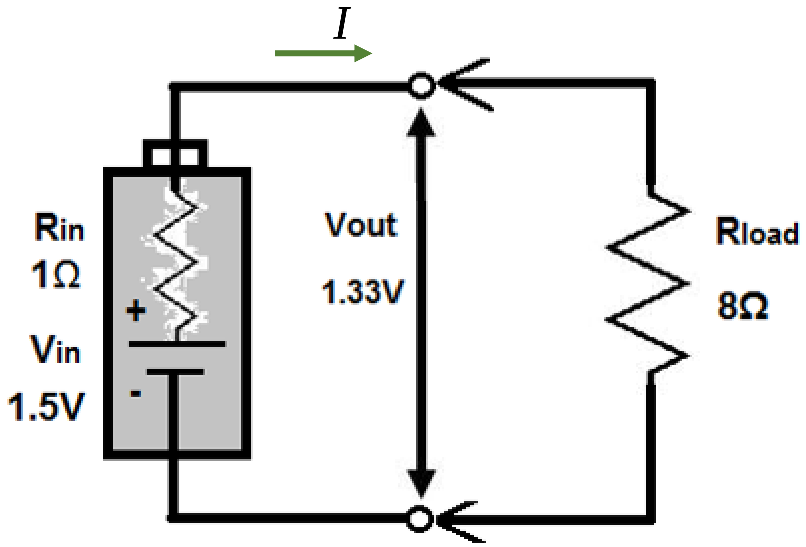
Taking care of varying load conditions

The loading problem: output voltage drops with increased load (current drawn)





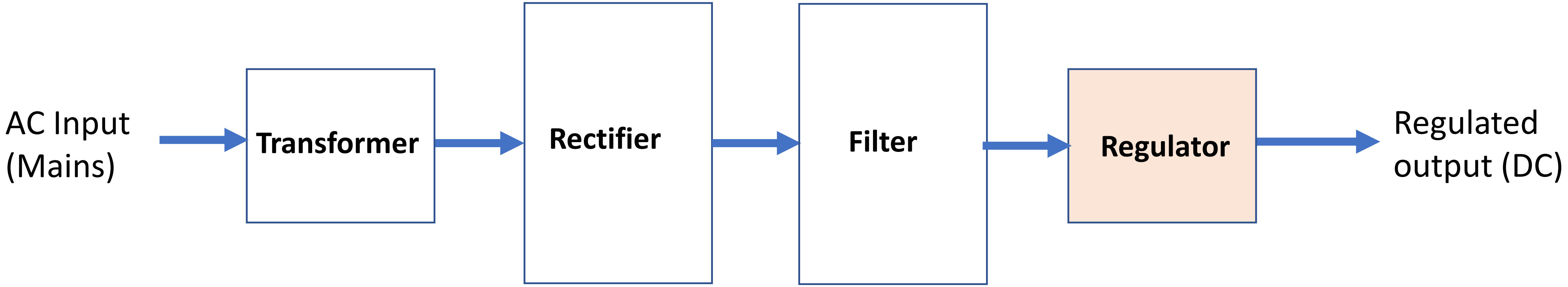
No load



With load

$$V_0 = V_{in} - IR_{in} \; = V_{in}\left(\frac{R_{load}}{R_{load} + R_{in}}\right)$$

Regulated power supply



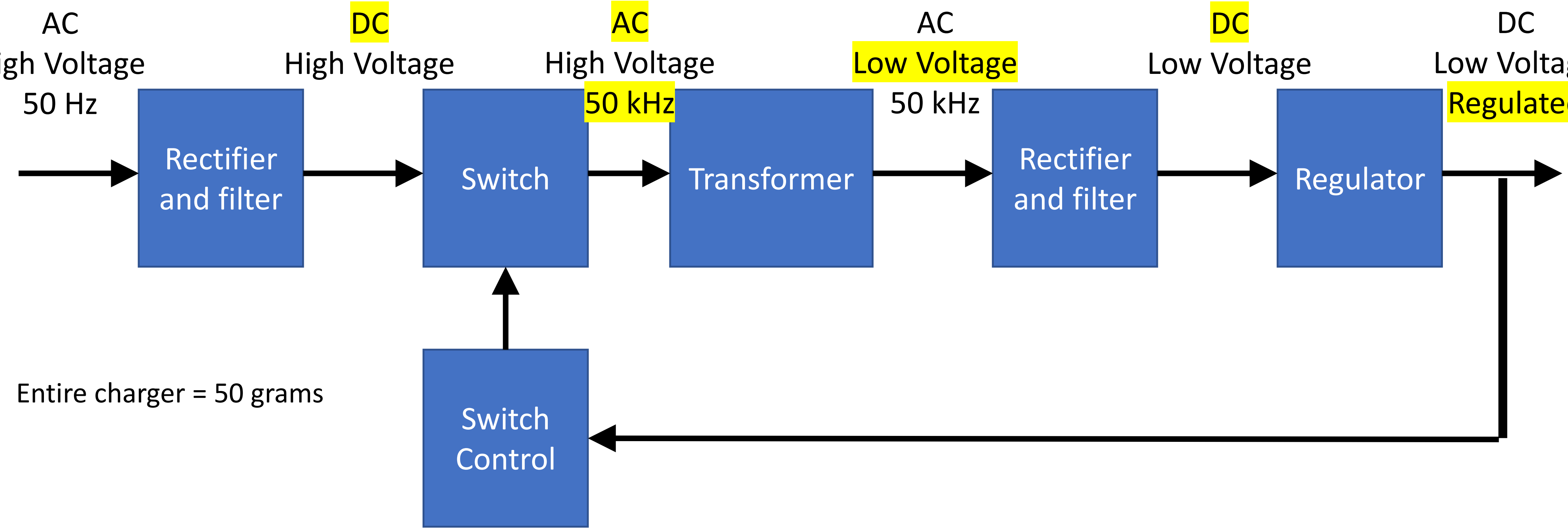
Evolution of the regulated power supply

- Need to have 'interoperability', i.e. build systems anywhere for use anywhere
  - 110V, 60HZ vs. 220V, 50HZ mains supply, different plug/sockets

- Is it possible to **just change the plug**? Yes with SMPS

- Xerox's Alto (1973)
- First computer to use an OS supported GUI
  - *10 yrs before desktop PC became popular*
- First to use a power supply that is 'interoperable'

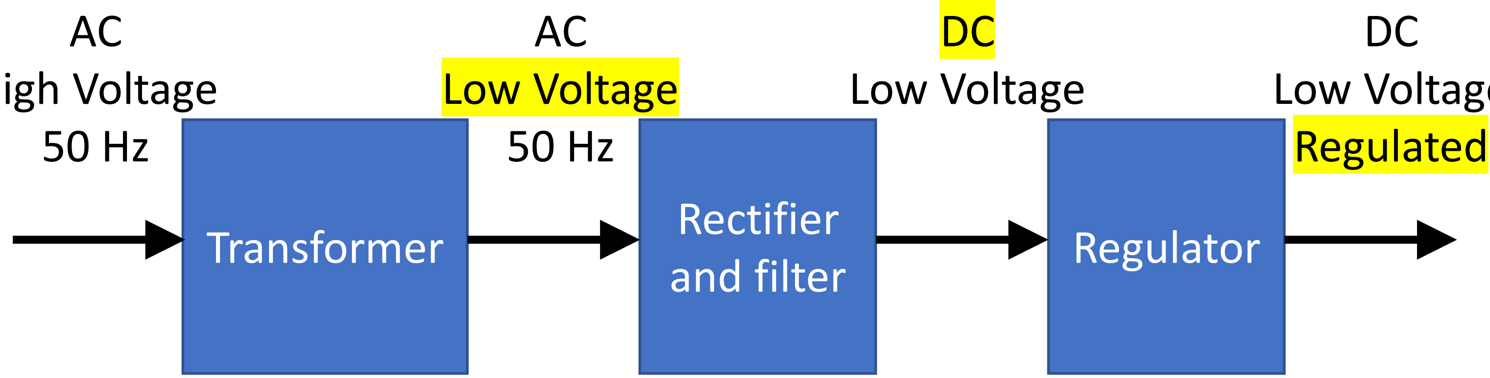
SMPS – basic idea



Entire charger = 50 grams

Transformer Weight
= 160 grams

Traditional Design ->



Why is the charger light-weight?

At 50 Hz

At 50 kHz

Lecture AMH3 – Energy storage

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The need for a battery

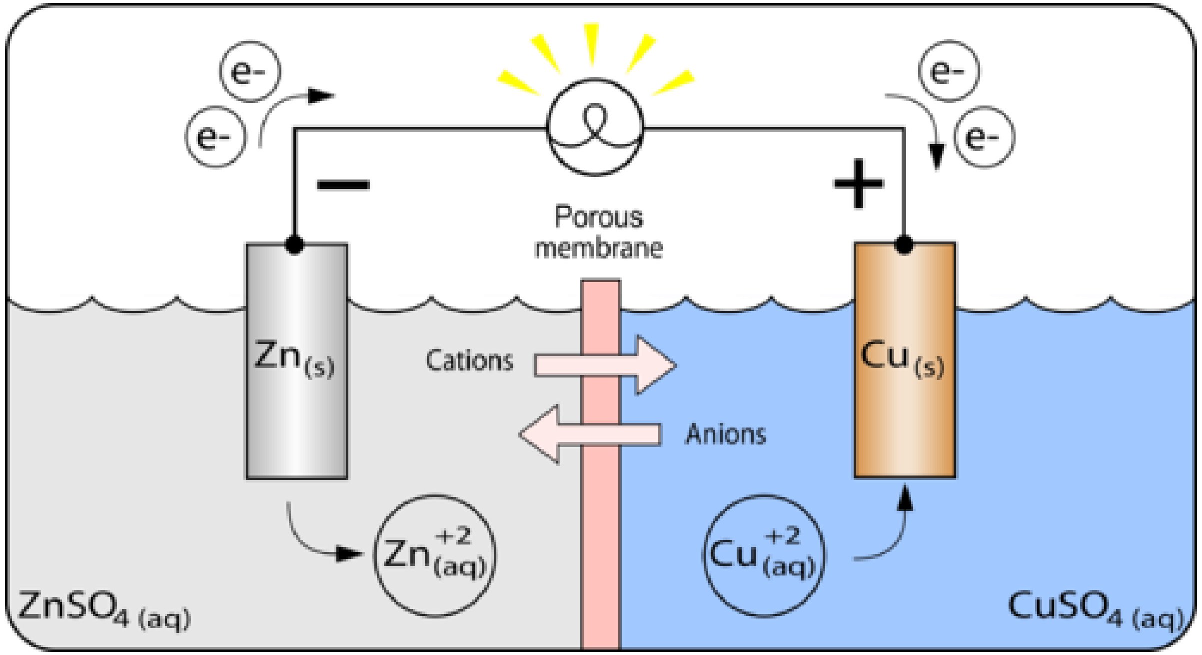
- The biggest concern with the thin film source of energy such as photovoltaic, triboelectric, piezoelectric and thermoelectric is that they are intermittent sources of power
- Thus, the power being generated through these methods may not be available at the time when the electrical work needs to be performed
- Further, the quality and quantity of power produced using these methods may not match the requirements of the load
- This problem can be solved using energy storage solutions
- Indeed, even at the grid level, the push for renewable energy sources requires the development of substantial energy storage capacity to compensate for the intermittent nature of solar and wind power
- Typically, the electrical energy is converted into another form of energy for storage, and then converted back to electrical energy when needed

The need for a battery

- Because of the recent push for renewable energy sources, there has been a great interest in developing large scale energy storage solutions
- These include diverse avenues for storing the energy, such as mechanical energy (flywheel technology), gravitational energy (water pump, stacking of concrete blocks), chemical energy (batteries), electrical energy (capacitors), thermal energy (chilled water), and so on
- There are advantages and disadvantages associated with all of these technologies, however, thin film batteries are gaining momentum
- These include the electrical cell (or battery), where energy is stored as electrochemical potential; a capacitor, where energy is stored in the form of surface charge density; and a supercapacitor, where both electrochemical and surface charge storage is utilized

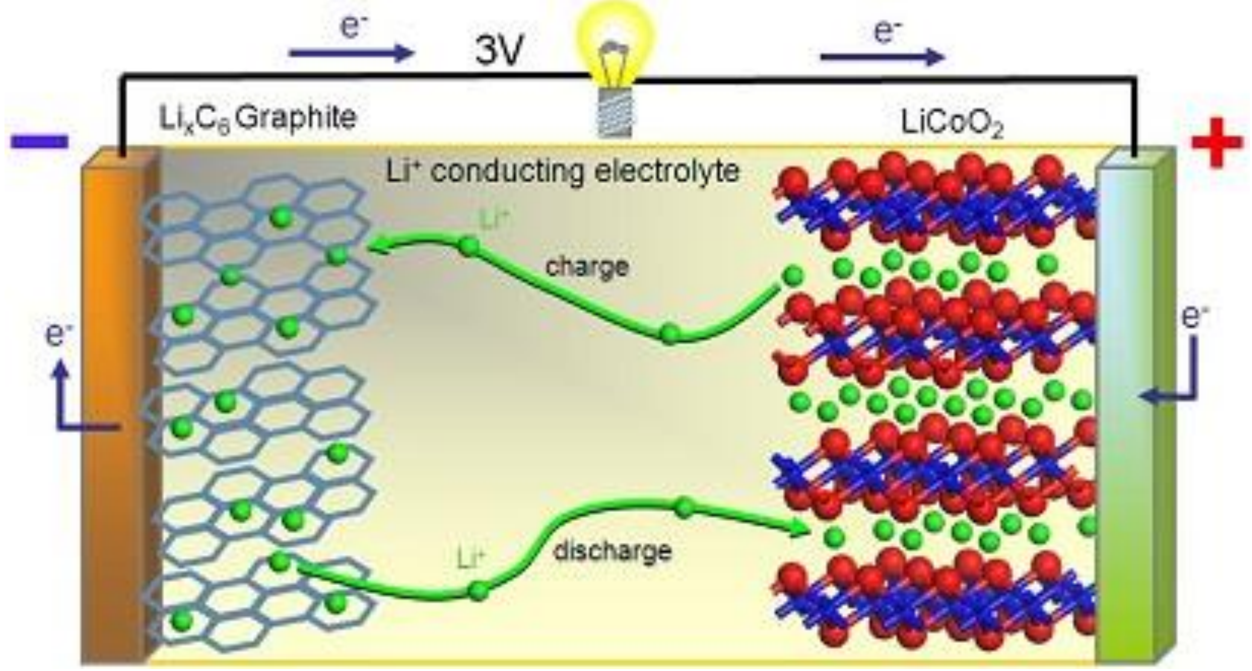
Electrical cell

- Electrical batteries can produce an electric current using chemical reactions and vice versa
- The fundamental principle of operation in most rechargeable batteries is a redox reaction occurring because of the application of electric current (electrolytic cell) and the same redox reaction leading to the generation of electric current (Galvanic cell)
- The basic components of any battery are the anode and cathode electrodes and an electrolyte that conducts ions from anode to cathode and back



Li ion cell

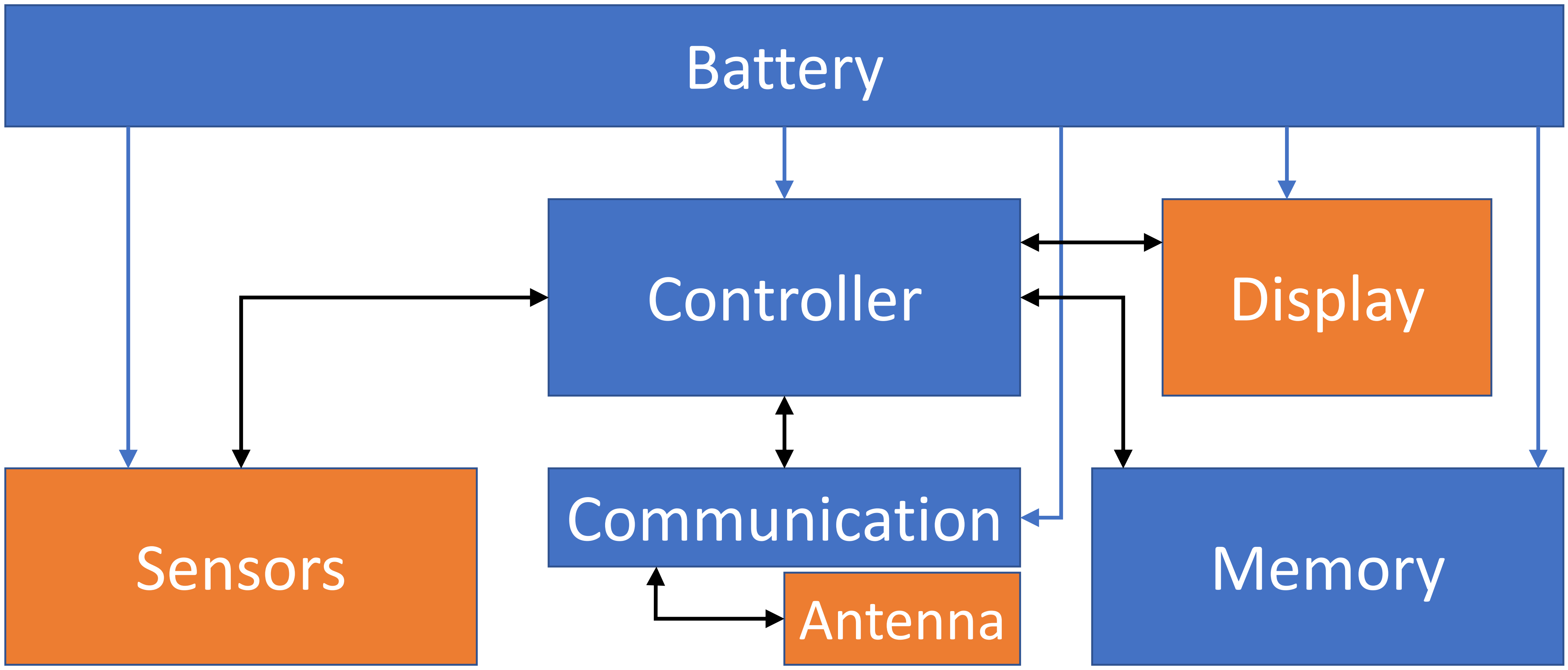
- Li-ion batteries are the darling of the electronics world these days
- They work on intercalation of the lithium atom in a lattice (typically graphite) – The battery has lithium+ cathode and graphite anode with a lithium salt electrolyte
- During discharge, Li atoms given up an electron (low electron affinity) and the ions migrate to cathode
- The electrons travel through the circuit (do electrical work) and are collected by the Co^{4+} in the cathode
- The Li-ion batteries provide high energy and power density, low energy leakage, and scalability (Li-ion batteries with capacities ranging from 1 mAh to 150 MWh have been produced)



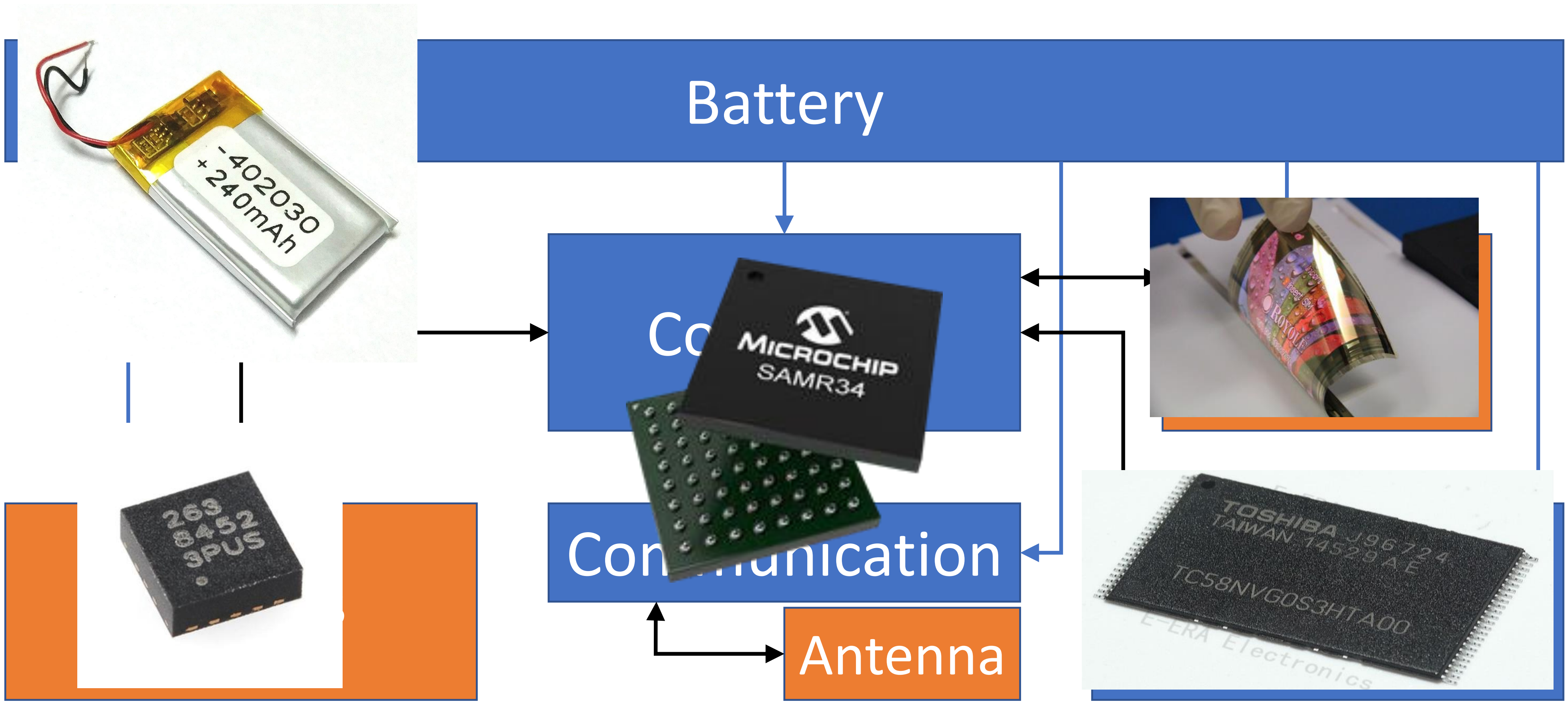
Anode

Cathode

The basic electronic system…



The basic electronic system…



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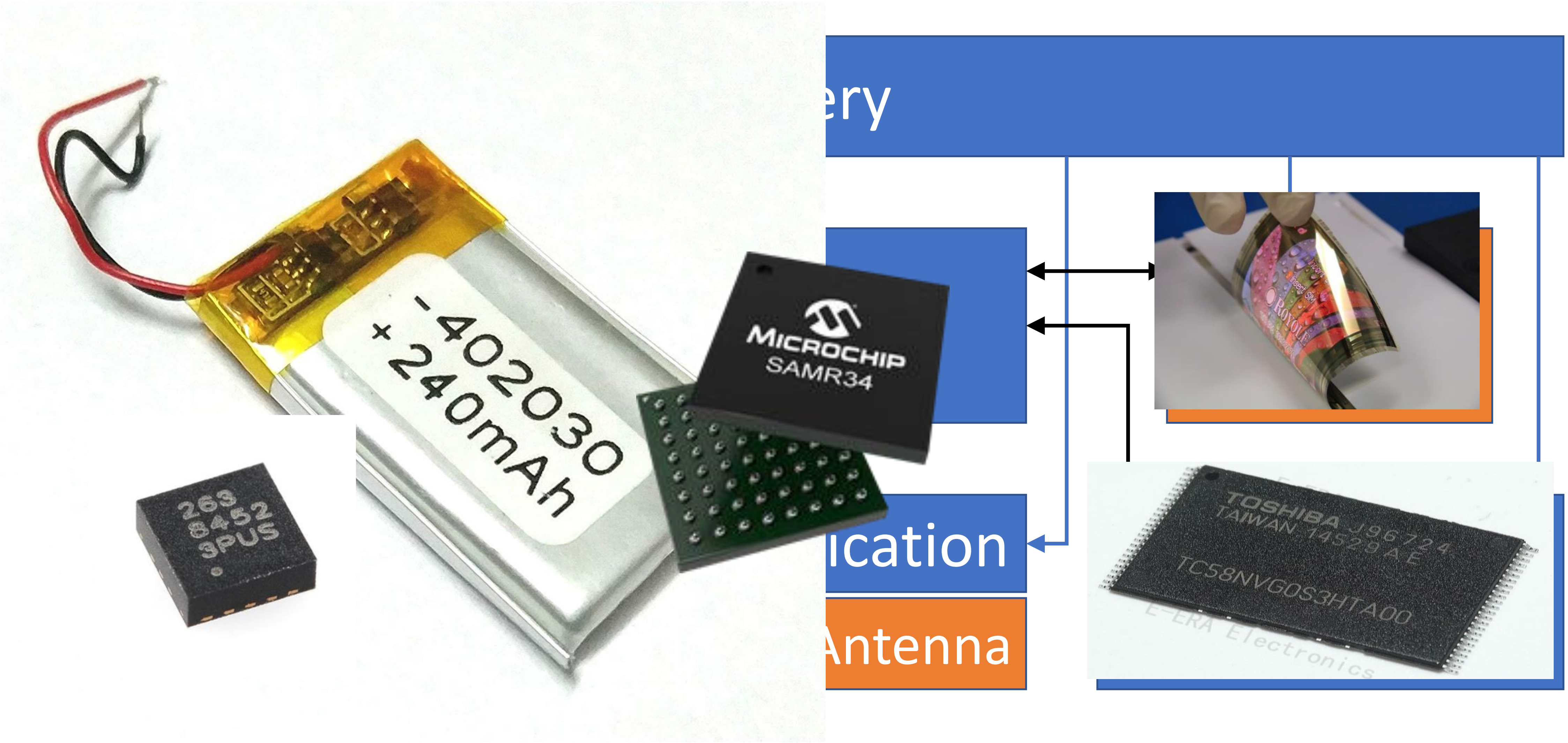

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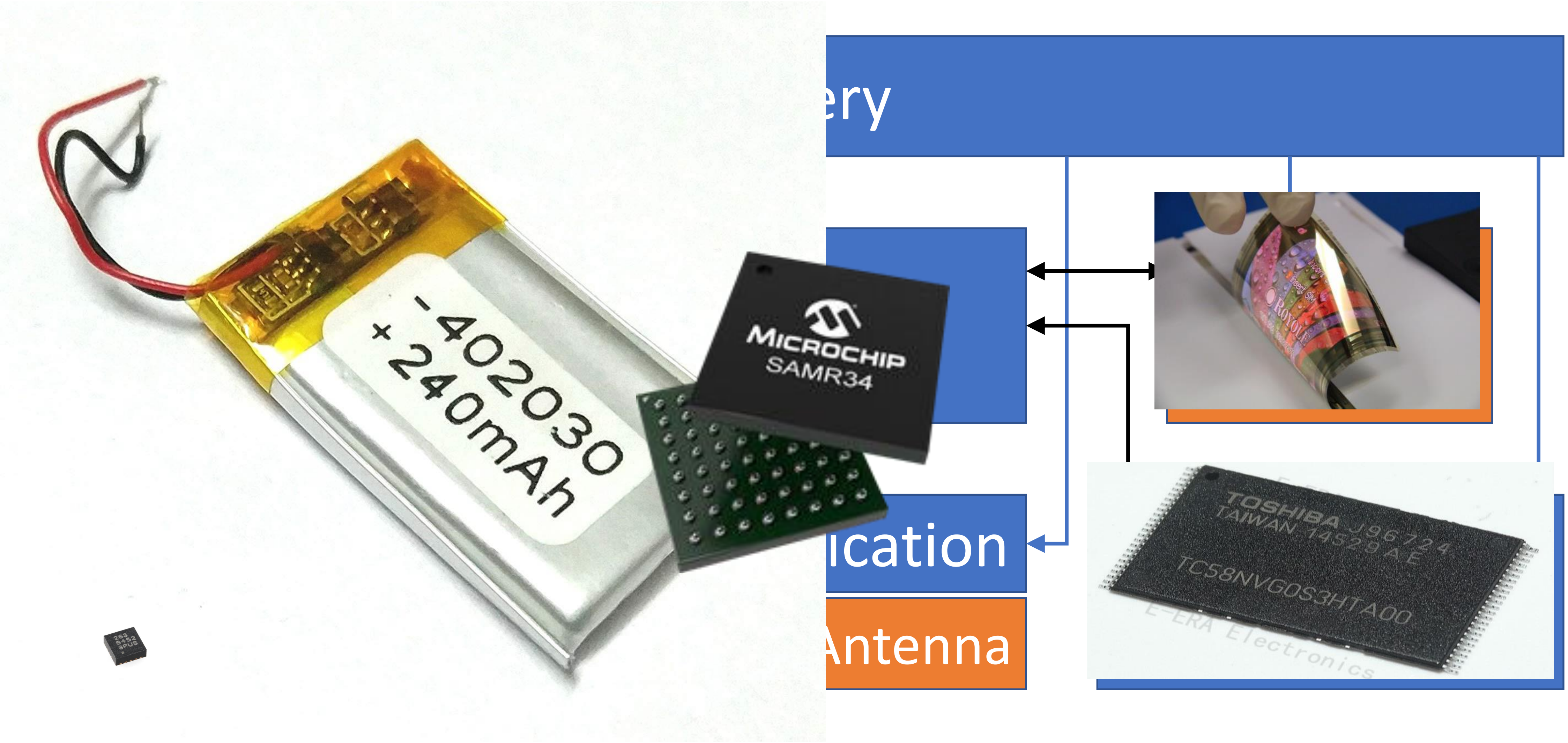

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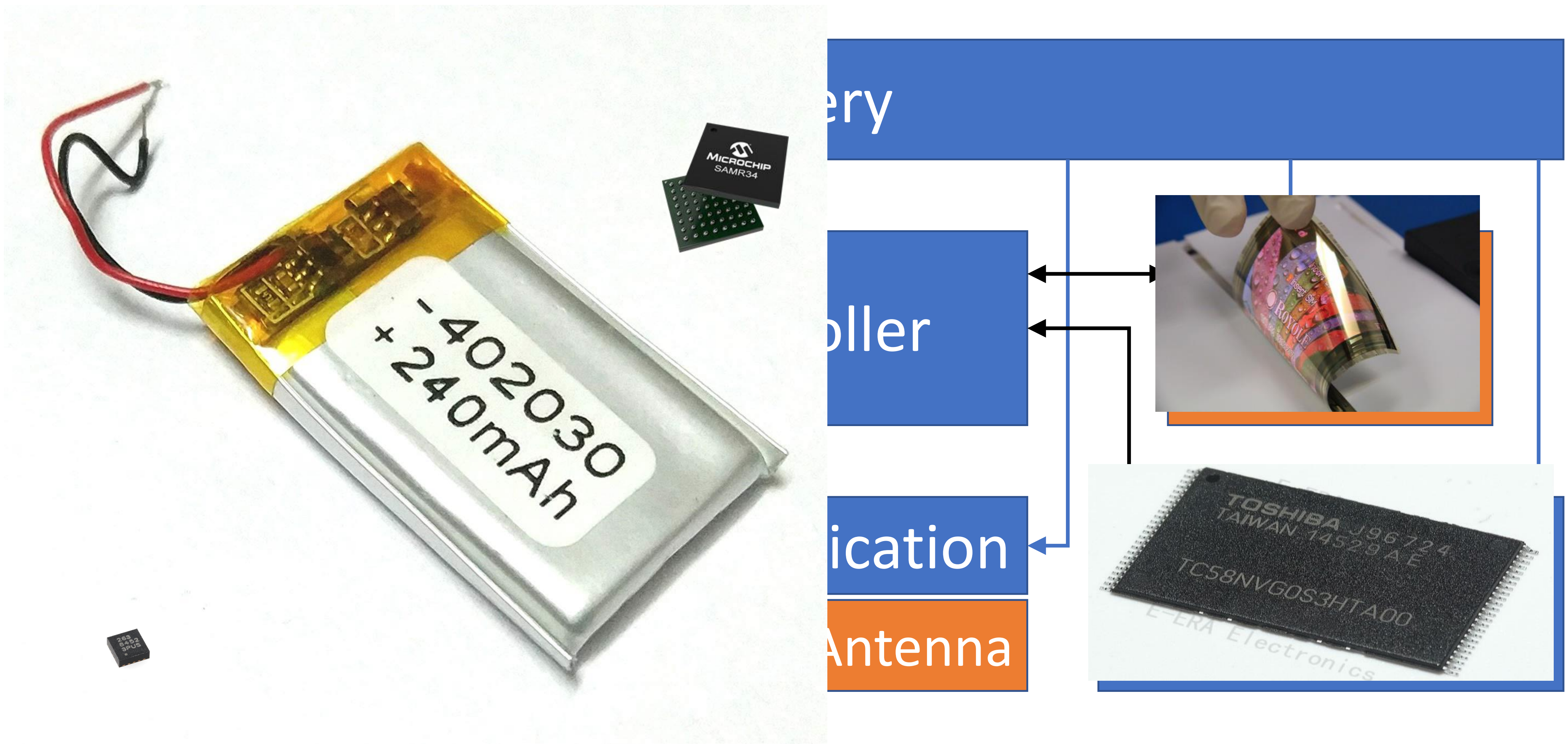
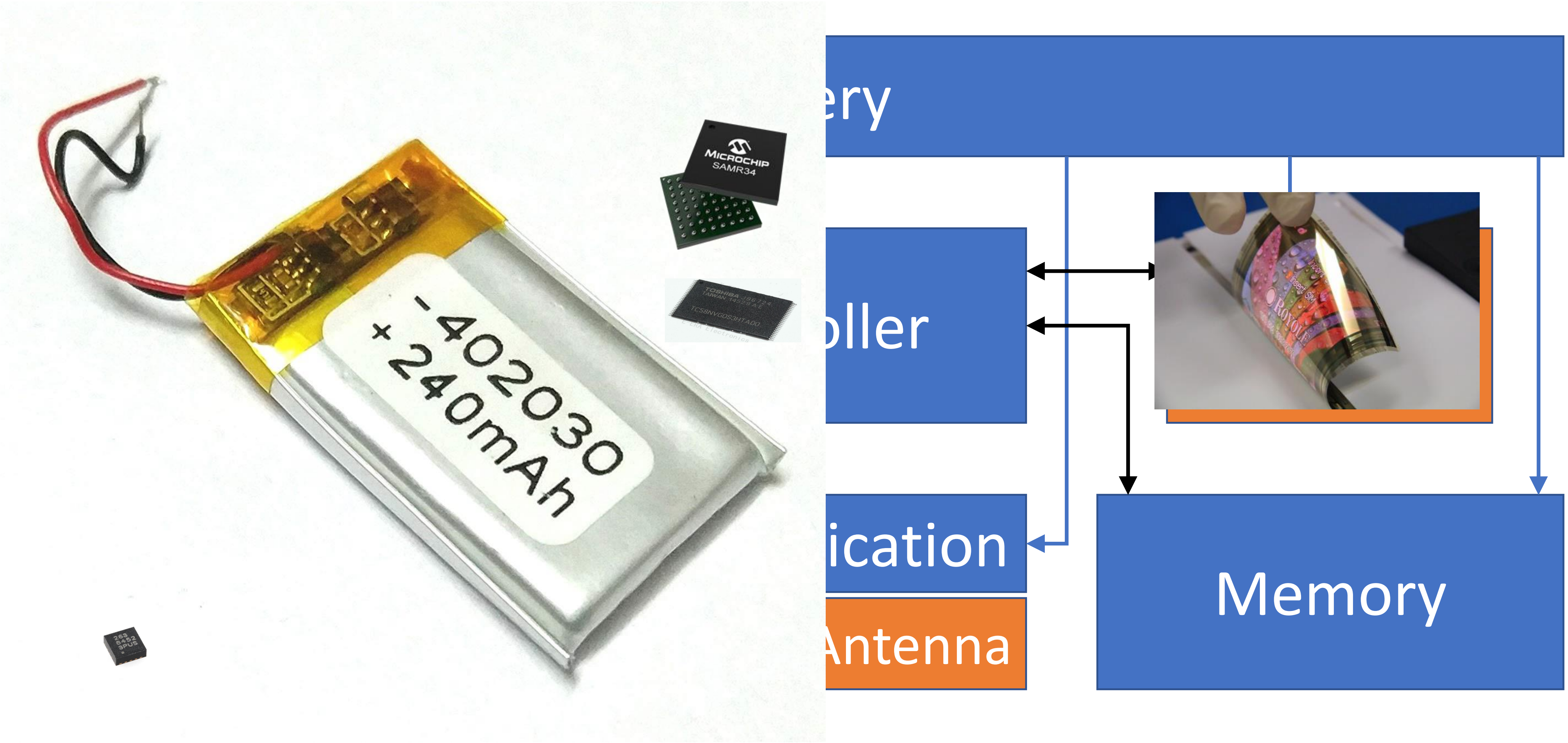


The basic electronic system…



Li ion batteries

- Thus, battery size is a major issue in many IoT applications
- The performance of a battery is best measured in the energy density it can store (amount of energy in a unit volume or mass)
- Here is a reference for energy densities:

Material	Energy density (MJ/kg)
Li-ion battery	0.36–0.875

Li ion batteries

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Lead-acid battery	0.17

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Wood	18

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Coal	24-35

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Coal	24-35
Petrol	46.4

Li ion batteries

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Material	Energy density (MJ/kg)
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Wood	18
Coal	24-35
Petrol	46.4
Uranium	80,620,000

Li ion batteries

- The performance of a battery is best measured in the energy density it can store (amount of energy in a unit volume or mass)
- Here is a reference for energy densities:
- So, Li-ion batteries have very poor energy density… or do they?

Material	Energy density (MJ/kg)
Li-ion battery	0.36–0.875
Lead-acid battery	0.17
Dry cow dung	15.5
Wood	18
Coal	24-35
Petrol	46.4
Uranium	80,620,000
Antimatter	89,875,517,874

5000 mAh

Charge = 5000 mAh

Energy = 4 V * 5000 mAh

Energy = 20,000 mWh

Energy = 20 Wh

Energy = 20*3600 J

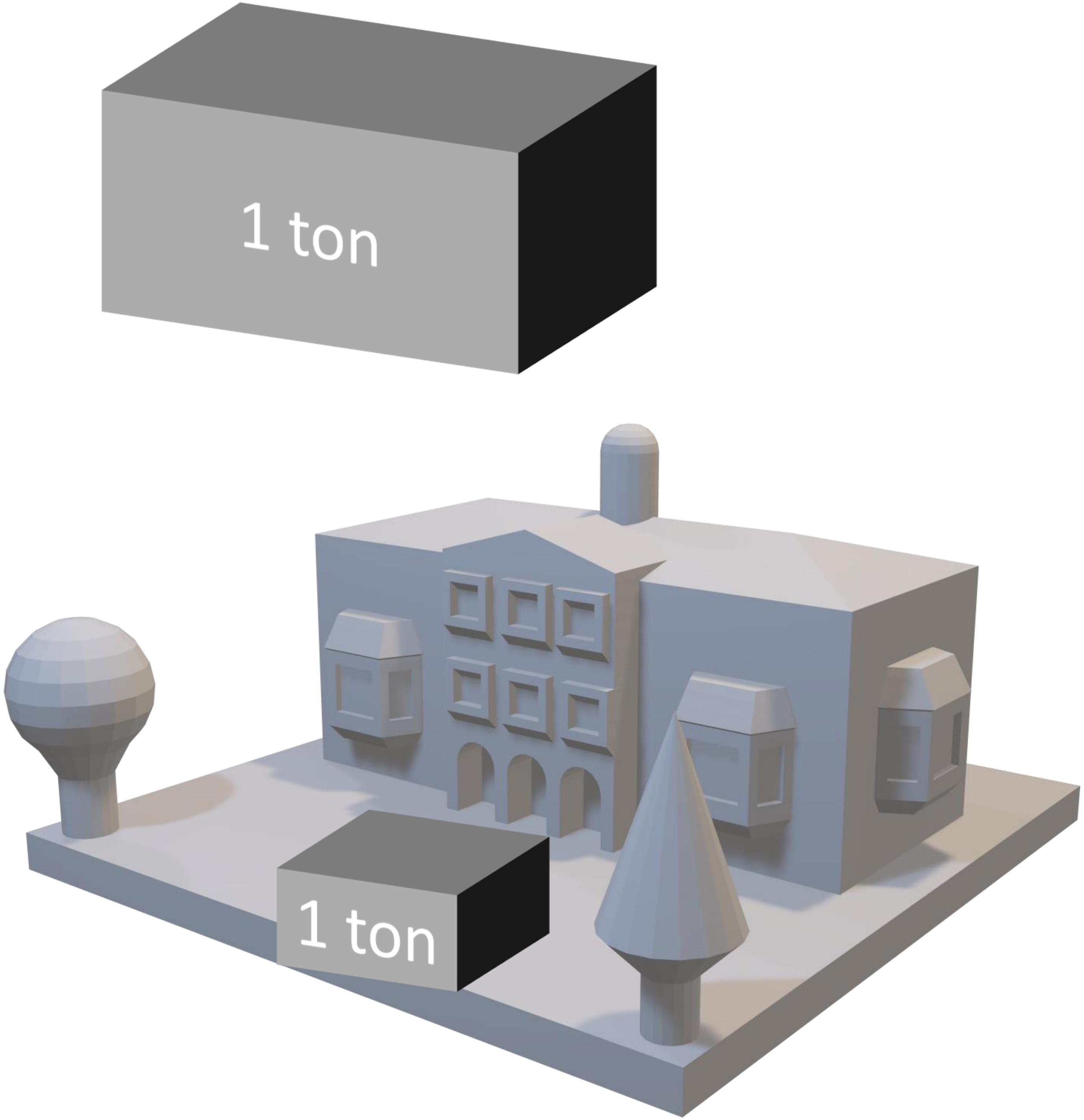
Energy = 72000 J

Height = E/mg

Height = 72000/(1000*10)

Height = 7.2 meters!

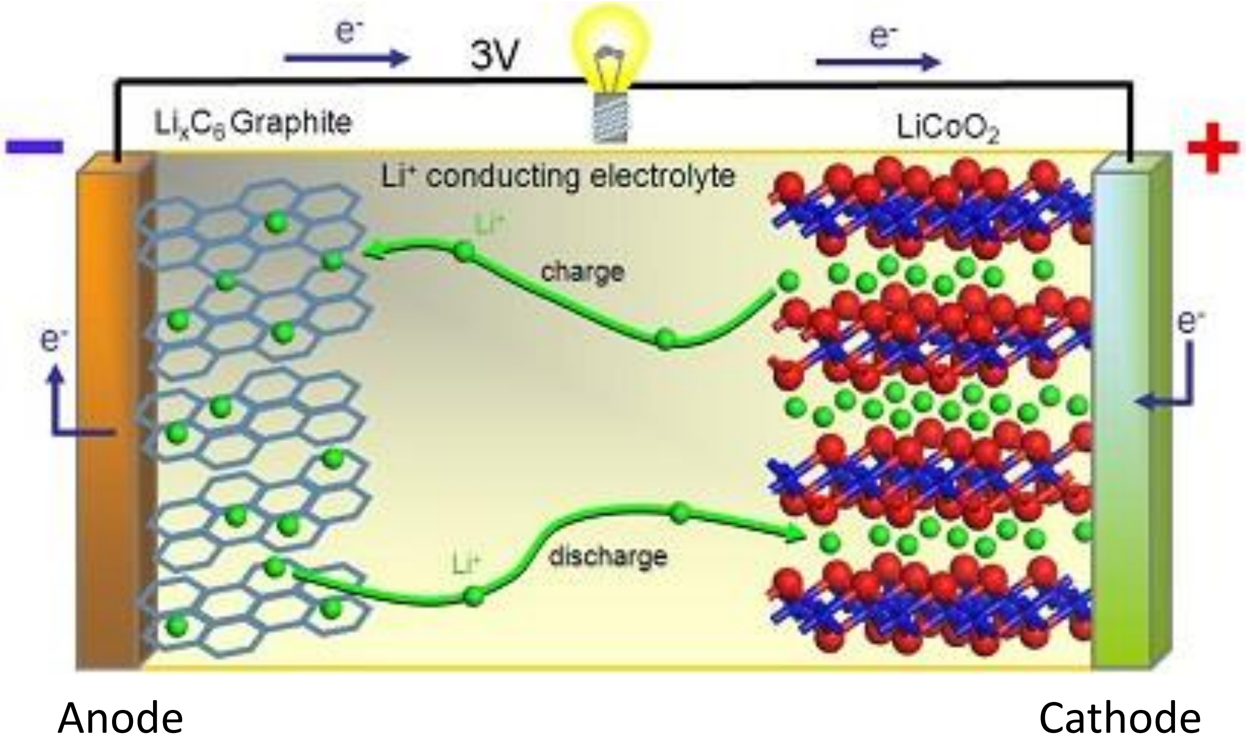
Height = roughly 3 stories!!



Li ion cell

- Problems:

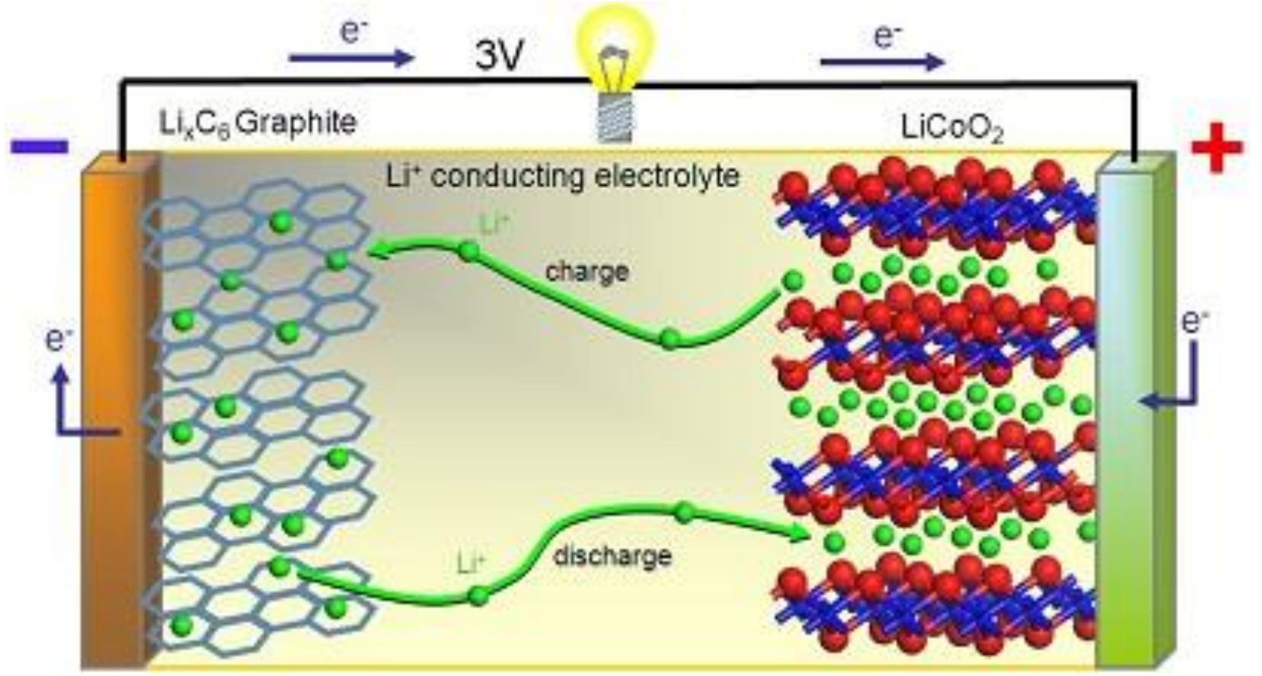
1. Lithium is a rare metal, ~0.002% in the Earth's crust
   - The demand for Li can outstrip supply making Li the new oil and some countries (like Bolivia) the new Saudi Arabia
   - Major geopolitical shifts!
2. The charge holding capacity of the battery depends on the intercalation capacity of the anode



Li ion cell

- Various research directions:

1. Lithium intercalation in silicon – silicon can intercalate 10x more lithium per gram than graphite, however, its volume grows by 400% during intercalation
2. Graphene/silicon composites – a middle ground between silicon intercalation capacity and graphite stability
3. Na-ion batteries? – not more energy dense than lithium, but sodium is earth abundant, ~2.3% of the Earth's crust
4. a thin film Li-ion battery – li-polymer batteries use polymer electrolyte as opposed to solid state electrolytes. This makes them flexible and lowers costs



Anode

Cathode

Supercapacitors

- Supercapacitors are capacitive structures that use an electrolyte to create much larger electric fields compared to conventional capacitors
- The structure consists of the two electrodes in contact with an electrolyte and uses the build-up of ions in the electrolyte upon application of an external electric potential
- The buildup of charge on the metal electrode attracts the ions of opposite polarity from the electrolyte, leading to a buildup of the oppositely charged ions at the metal surface
- This double-layer capacitance is used to store energy