## Introducing important battery terminology

- This week, we study topics concerning how electrochemical (battery) cells work, as fundamental preparation for knowing how to use them optimally in an application
- This lesson very quickly covers a lot of background re. battery terminology
- Later lessons will discuss battery function, and general application
- Even later (especially in the second course of the specialization), we will cover much more depth in some mathematical understanding of how cells work, and greater detail in particular areas





## Cells

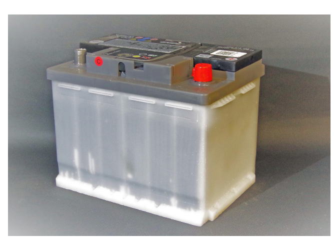
- Cells are the smallest individual electrochemical unit, and deliver a voltage that depends on the cell chemistry
  - There are primary (single use) and secondary (rechargeable) cells
  - A cell is different from a battery, but many people (including me at times!) use the term “battery” to describe any electrochemical energy source, even if it is a single cell, and this can lead to confusion

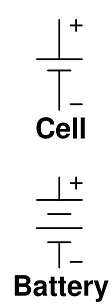




## Batteries

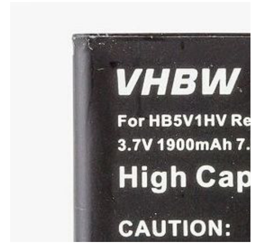
- Batteries and battery packs are made up from groups of cells
  - These cells can be wired together in series, in parallel, or in some combination of both
  - Sometimes they are packaged in a single physical unit
    - For example, automotive 12 V lead-acid batteries comprise six 2 V cells in series
  - Other times, the connections are external to the cells
- We use schematic symbols to represent cells and batteries in a circuit diagram.





## Nominal voltage and capacity

- <u>Cell (nominal) voltage</u> depends on the combination of active chemicals used in the cell.
  - For many nickel-based cells, it is 1.2 V (e.g., NiCad, NiMH)
  - For many lithium-based cells, this is over 3 V
  - Nominal voltage is often printed on the cell package
  - Nominal voltage is different from cell voltage under load—it is more of an average or typical voltage




- <u>Cell (nominal) capacity</u> specifies the quantity of charge, in ampere hours (Ah) or milliampere hours (mAh), that the cell is rated to hold





## C rate

- The <u>C rate</u> is a *relative* measure of cell electrical current
- It is the constant-current charge or discharge rate that the cell can sustain for one hour
  - A 20 Ah cell should be able to deliver 20 A (“1C”) for 1 h or 2 A (“C/10”) for about 10 h (but, the relationship is not strictly linear)
  - If the cell is discharged at a 10C rate, it will be completely discharged in about six minutes

  Example: The 1C rate of the example to the right is 1.9 A

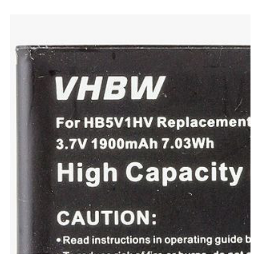





## Energy and power

- A cell stores <u>energy</u> in electrochemical form, which it can later release to do work
  - The total energy storage capacity of a cell is roughly its nominal voltage multiplied by its nominal capacity (mWh, Wh, or kWh)

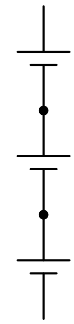
  Example: The nominal energy storage capacity of the example to the right is $3.7\,\text{V} \times 1.9\,\text{Ah} = 7.03\,\text{Wh}$




- The energy release rate is the cell’s instantaneous <u>power</u> (mW, W, or kW)

## Cells connected in series

- When cells are connected in <u>series</u>, the battery voltage is the sum of the individual cell voltages
- However, battery capacity is equal to individual cell capacity since the same electrical current passes through all of the cells (charging and discharging all cells at the same rate)



Example: A battery constructed from three 3 V, 20 Ah cells in series will have:

- A nominal voltage of $3 \times 3\,\text{V} = 9\,\text{V}$
- A nominal capacity of $1 \times 20\,\text{Ah} = 20\,\text{Ah}$
- A nominal energy capacity of $3 \times 3\,\text{V} \times 20\,\text{Ah} = 180\,\text{Wh}$



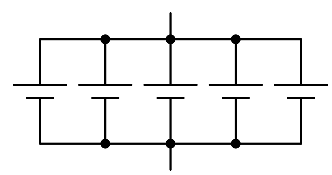


## Cells connected in parallel

- When cells are connected in <u>parallel</u>, the battery voltage is equal to the cells' voltage
- However, battery capacity is the sum of the cells' capacities, since the battery current is the sum of all the cell currents

Example: A battery constructed from five 3 V, 20 Ah cells in parallel will have:

- A nominal voltage of $1 \times 3\,\text{V} = 3\,\text{V}$
- A nominal capacity of $5 \times 20\,\text{Ah} = 100\,\text{Ah}$
- A nominal energy capacity of $5 \times 3\,\text{V} \times 20\,\text{Ah} = 300\,\text{Wh}$







## Summary

- A cell is the smallest electrochemical storage unit
- Primary cells are not rechargeable; secondary cells are rechargeable
- Cells have nominal (i.e., typical) voltage and charge-storage capacities
- The C rate is a way of normalizing electrical current to cell nominal capacity
- Cells store energy that can be released to do work: rate of energy release is power
- Batteries are made by connecting cells in series and/or parallel
- We can compute battery nominal voltage, nominal capacity, and nominal energy ratings by knowing how the cells are connected

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