1. You are designing a battery pack for a portable electronic device using 12 identical lithium-ion cells. Each cell has the following specifications:

   - Nominal voltage: 3.7 V
   - Capacity: 2 Ah
   - Internal resistance: 50 mΩ

   The cells are arranged in a **3S4P configuration** (3 strings in series and 4 strings in parallel).

   (a) Calculate the total voltage (V_{total}) and total capacity (C_{total}) of the battery pack.

   (b) If one cell in the pack is found to be at 3.0 V while the others are at 3.7 V, calculate the cell imbalance.

   (c) Using Coulomb counting, estimate the State of Charge (SoC) after discharging the pack at a constant current of 1 A for 2 hours by assuming the pack starts fully charged at 100% SoC, which corresponds to 8 Ah.

   (d) Discuss how passive balancing can be implemented to equalize the cell voltages.

2. In order to illustrate how to analyze battery management systems focusing on cell balancing through numerical calculations involving voltage, capacity, heat generation, temperature rise, and cooling requirements, consider a battery pack consisting of 12 lithium-ion cells connected in series. Each cell has the following specifications:

   - **Nominal Voltage**: 3.6 V
   - **Capacity**: 2.5 Ah
   - **Internal Resistance**: $R_i = 0.05\,\Omega$
   - **Initial State of Charge (SoC)**:
     - Cell 1: 100%
     - Cell 2: 95%
     - Cell 3: 90%
     - Cell 4: 85%
     - Cell 5: 80%
     - Cell 6: 75%
     - Cell 7: 70%
     - Cell 8: 65%
     - Cell 9: 60%
     - Cell 10: 55%

  - Cell 11: 50%
  - Cell 12: 45%

3. Calculate the total nominal voltage of the battery pack.

4. Calculate Joule heating heat generation rate for each cell if the total discharge current is $I = I_{\text{load}} = 5$.

5. By assuming that all cells generate heat at same rate, calculate total heat generation for the pack.

6. By ssuming a linear relationship between SoC and voltage, where 100% SoC corresponds to 4.2 V, assess voltage imbalance and by considering that cell voltage for zero SoC is 2.5 V. Caculate the $V_{\text{per\%}}$ and calculate the voltage of each cell based on its SoC as below:

   - - Cell 1: $4.2\,V$
   - - Cell 2: $4.2 - (100 - 95) \times V_{\text{per\%}} = 4.115$ V
   - - Cell 3: $4.2 - (100 - 90) \times V_{\text{per\%}} = 4.03$ V
   - - Cell 4: $4.2 - (100 - 85) \times V_{\text{per\%}} = 3.945$ V
   - and so on.

7. Which cell is the limiting cell? What is its voltage? Note: This cell will limit the overall capacity of the pack.

8. To equalize all cells to match the lowest SoC, we need to bleed down the higher SoC cells. We need to calculate how much energy needs to be dissipated from each cell that has a higher SoC than cell with lowest SoC.

   Calculate the energy difference that needs to be dissipated for each high SOC cell as follows:

   $$E_{\text{cell}} = C_{\text{cell}}(V_{\text{cell}} - V_{\text{min}})$$

9. If we assume that it takes approximately one hour to balance one cell's SoC through passive bleeding, and if we consider that every bleed resistor dissipates 0.50 W per cell and assuming every cell has an energy difference that needs to be bled down, calculation the time needed for balancing all the cells. To find out how long it would take to balance all cells: