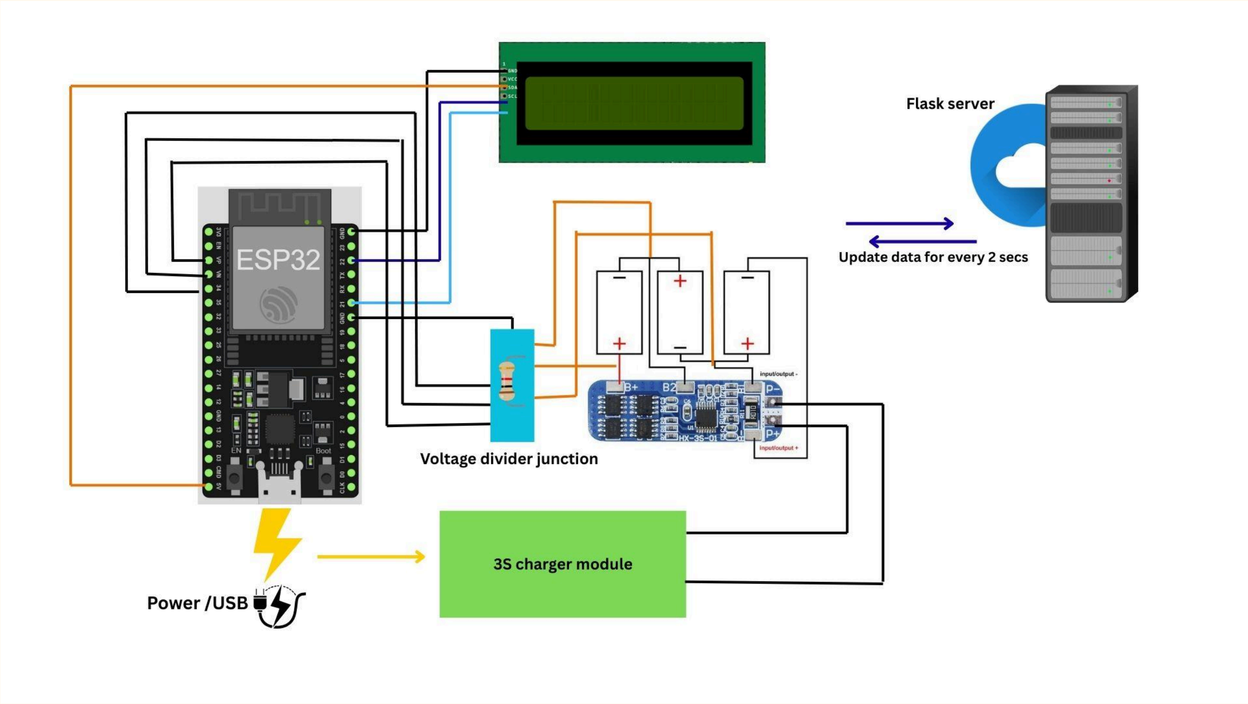
3-CELL
Li-ion monitoring and safe charging System



Explanation :

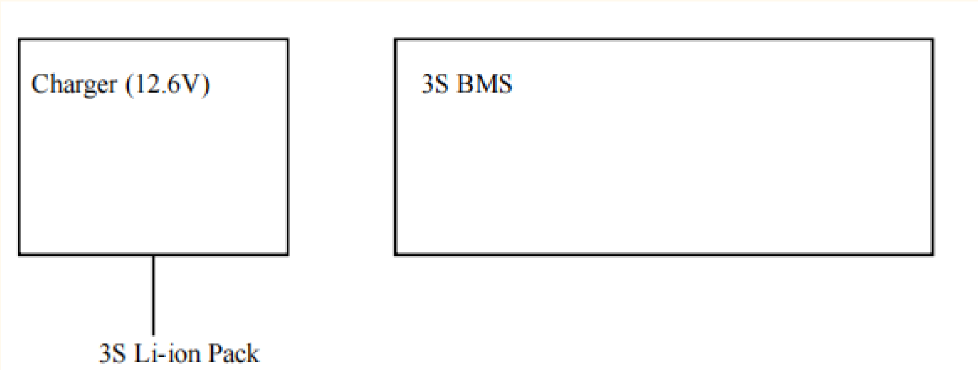
The project assigned to our team is to design a Battery Monitoring System using the ESP32 microcontroller, a Battery Management System (BMS), TP4056 charging modules, and three 18650 Li-ion cells. The system is expected to charge the three Li-ion cells connected in series (3S configuration) and also provide monitoring of each battery's voltage, state-of-charge, and overall status. The ESP32 should interface with the batteries, and data should be visualized on a Flask web server, with graphs and status indicators available to the user. The main challenge arises from the charging requirement. While TP4056 modules were provided, they are designed for charging only a single Li-ion cell and cannot directly charge a series pack. This creates a technical difficulty: how to implement safe and efficient charging for the 3S battery pack while still making use of the materials provided and additional hardware if necessary. Therefore, identifying the problem clearly and proposing a safe solution is an essential first step.

2. Why TP4056 Cannot Be Used for Series Charging

The TP4056 is a linear charger designed specifically for single Li-ion cells. It regulates the charging current and voltage based on the negative terminal of the cell it charges. In a series configuration, the ground potential of each cell is different, which means that one TP4056 cannot be directly referenced to the pack ground to charge individual cells. Attempting to connect TP4056 modules directly across each cell in a series pack introduces several critical risks: - Electrical conflicts: Each TP4056 assumes its ground is at 0V, but in a series configuration, cell grounds are stacked at higher voltages. - Overcharge/undercharge: Without independent balancing, one cell may charge to above 4.2V while another remains below 4.0V, creating imbalance. - Safety hazards: Overcharging cells can cause heat buildup, electrolyte breakdown, swelling, or fire. - Module damage: Current may backflow between modules, damaging the TP4056 boards themselves. For these reasons, TP4056 cannot be used directly to charge a 3S pack. The only theoretical workarounds would be to either disconnect the cells from the series string and charge them individually, or to use isolated power supplies for each TP4056 module. Both approaches are impractical for our application.

3. Correct Charging Solution for a 3S Pack

The safe and standard method of charging three Li-ion cells connected in series is to use a dedicated 3S charger that outputs 12.6V (3 × 4.2V) with a constant-current/constant-voltage (CC/CV) profile. In addition, a 3S BMS is used to monitor each individual cell's voltage. The BMS ensures that no cell is overcharged or undercharged by balancing the voltages between cells during charging. The BMS also provides critical protection features including over-voltage protection, under-voltage protection, short-circuit protection, and over-current protection. In practice, the circuit works as follows: the charger applies 12.6V across the pack, the BMS connects to each cell tap, and the balancing resistors within the BMS bleed small amounts of current from higher-voltage cells to equalize them with lower-voltage ones. This ensures that all cells reach full charge simultaneously. Compared to using TP4056, this method is reliable, widely accepted, and ensures long-term safety of the pack.



4. Battery Monitoring Process

Monitoring the individual cells is essential for understanding pack health and performance. The ESP32 is connected to the balance leads of the BMS. Voltage dividers scale down each cell's voltage so that it does not exceed the 3.3V ADC limit of the ESP32. For example, using a resistor divider ratio of 2:1, a 4.2V cell voltage is reduced to approximately 2.1V, which is safe for ADC measurement. The ESP32 reads the voltage periodically and calculates the state-of-charge (SoC) of each cell using a voltage-to-SoC mapping table. For improved accuracy, additional methods such as coulomb counting with a current sensor (e.g., INA219) can be added. Temperature sensors (e.g., NTC thermistors or DS18B20) are also recommended to detect overheating conditions. All collected data is transmitted to the Flask server, which visualizes the status of each cell in real-time charts. The graphs allow quick identification of imbalances, degraded cells, or abnormal behavior.

5. Flask Server for Visualization

The Flask server serves as the central dashboard for the battery monitoring system. Running either directly on the ESP32 (with MicroPython and Flask-like frameworks) or on a connected computer, Flask provides a web interface accessible via any browser. Data from the ESP32 is sent to Flask endpoints, which are then rendered using HTML templates and JavaScript charting libraries such as Chart.js. The web interface displays: - Real-time voltage of each cell. - Graphs of state-of-charge over time. - Warnings if any cell voltage exceeds safe limits. - Indicators for temperature and current draw. This visualization makes the system not only functional but also user-friendly, allowing users to track battery health remotely and in detail.

6. Materials Provided

ESP32 Development Board

3S Battery Management System (BMS)

TP4056 Charging Module (single cell)

Three 18650 Li-ion Batteries

Resistors (for voltage dividers)

Wires and connectors

7. Additional Materials Needed

3S-compatible 12.6V charger with CC/CV output

Optional external ADC (ADS1115) for high-accuracy measurements

Current sensor module (INA219)

Protection fuses for added safety

Recommended modules and justification (for 3S Li-ion monitoring and safe charging)

Request for hardware to complete 3S battery project:
Please provide the following components to complete the charging and monitoring practical:

1. One 3S Li-ion CC/CV charger module (12.6 V output) suitable for charging a 3-cell series pack. Specifications: 12.6 V CC/CV output, adjustable current or fixed 0.5–2.0 A (preferred 1.0 A), and standard P+/P− output terminals. A balance-capable charger that exposes balance leads (B1, B2) is preferred.
2. One INA219 (or INA226) current/voltage sensor breakout (I^2C), including an appropriate low-ohm shunt (e.g., 0.1 Ω), to measure pack charging/discharging current and bus voltage.
3. Optional but recommended: ADS1115 ADC breakout (16-bit) or INA3221 multi-channel monitor for higher-resolution or per-channel monitoring if available.
 These components are necessary to safely evaluate charging, balancing, and current behavior of the 3S pack and to complete the data-logging and dashboard experiments.

Explanation :

1) 3S Li-ion CC/CV charger (required)

Specification (required):

- Output voltage: 12.6 V DC (CC/CV) (exactly 12.6 V for 3 × 4.2 V cells).

- Output current: adjustable or fixed in the range 0.5 A – 2.0 A (recommend ~1.0 A for typical 18650 cells; charge rate should not exceed 1C for safety unless cells rated higher).
- Input: DC adapter compatible with the module (often 15 V DC input) OR an integrated wall adapter.
- Output terminals: P+ and P– (or charger + / –) intended to be connected to the BMS P+ / P– on your pack.
- Optional but preferred: explicit balance-charging capability (module exposes balance leads or works with balance connector). If the module does not have balance lead connections, the BMS should still perform passive balancing during charge.

Why this is required: TP4056 modules are single-cell chargers and cannot safely charge a 3S pack. A dedicated 3S CC/CV charger provides the correct overall pack voltage and current-limited charging required for series-connected cells. The charger connects to P+ / P– of the BMS; the BMS handles protection and balancing.

How it integrates (high level):

- Charger + → P+ on BMS
- Charger − → P– on BMS
- BMS remains connected to individual cells (B–, B1, B2, B+)
- Charger outputs raise pack voltage; BMS balances cells (passive balancing) or the charger performs balancing if it has balance leads.

2) Pack current sensor (recommended: INA219 or INA226 breakout)

Specification and role:

- A current+voltage sensor breakout (e.g., INA219 or INA226) to measure charging/discharging current and pack voltage.
- Typical INA219 modules include a small low-ohm shunt (often 0.1 Ω) or require an external shunt. INA226 provides higher accuracy and wider voltage range; either is acceptable.

Why use one: Current measurement is necessary to show charging current on the LCD and web dashboard, to log charge/discharge profiles, and to detect abnormal currents (shorts or BMS trip events). These modules communicate over I²C and are easy to read from ESP32.

Wiring (typical, safe):

- VIN+ (sensor) → charger/load positive (external side)
- VIN– (sensor) → P+ (pack positive terminal on BMS)
- VCC → ESP32 3.3 V
- GND → ESP32 GND (and B– common)

- SDA → ESP32 SDA (GPIO21)
- SCL → ESP32 SCL (GPIO22)

This places the sensor on the high side (between charger/load and pack) and measures both charge and discharge current direction and magnitude. Confirm the breakout supports the pack voltage (most INA219 breakout boards support up to 26 V).

3) Multi-channel voltage/current monitor (optional but powerful: INA3221 or ADS1115)

INA3221 (three-channel shunt monitor):

- Can measure three independent shunt voltages and corresponding bus voltages on I^2C.
- Use case: if you want higher-resolution, multi-channel current sensing or to monitor three separated shunts (advanced). This is more complex because per-cell current sensing requires shunts installed in series with each cell path.

ADS1115 (16-bit ADC):

- Use ADS1115 when you want higher resolution ADC for cell voltage measurements instead of ESP32 internal ADC. Connect the divider outputs for B1, B2, B+ to ADS1115 inputs and read via I^2C.

Recommendation: For the project scope (per-cell voltages + pack current), use the ESP32 ADC with properly chosen resistive dividers for voltage and use INA219/INA226 for pack current. If you later require higher precision, add ADS1115.

More details :

For reliable charging and monitoring of a 3-series (3S) lithium-ion battery pack, it is essential to use a dedicated charging and protection module rather than individual single-cell charging boards. Attempting to charge a 3S pack with two TP4056 modules is not recommended because it does not provide proper balancing or coordinated charge control across all cells. Instead, the following modules and arrangements are recommended:

1. **3S BMS with Integrated Charger and Balancing:**
   A single 3S Li-ion Battery Management System (BMS) module with charging capability is the most suitable option. This module provides coordinated charging of all three cells up to 12.6 V (4.2 V per cell), includes over-charge and over-discharge protection, and ensures that the cells are balanced to avoid voltage imbalance. The BMS has connections labeled B+, B1, B2, and B− for the three cells, and P+ and P− for the combined pack's input/output (to charger and load). This eliminates the need for multiple TP4056 boards.
2. **Alternative 3S Charging Module:**
   If a combined BMS and charger is not available, a dedicated 3S Li-ion charging module that accepts a DC supply (typically 15 V input) and outputs regulated 12.6 V constant-current/constant-voltage charging may be used. In this case, a separate 3S protection board (BMS) is still required for safe operation.
3. **Current and Voltage Monitoring Modules:**
   For accurate measurement and data logging, modules such as the INA219 (single-channel) or INA3221 (three-channel) are recommended. The INA219 allows the ESP32 to measure both pack voltage and charging/discharging current over the I^2C interface. The INA3221 provides three channels, enabling monitoring of individual cell voltages and currents, which makes it particularly well-suited to multi-cell systems.
4. **Integration with ESP32 and Display:**
   The ESP32 can read the voltage data (from resistor dividers or monitoring modules) and current data (from INA219/INA3221), process the information, and display results on the LCD. In addition, the ESP32 can transmit the measurements to a Flask server for web-based visualization and logging.

Summary:
The most practical and reliable solution for this project is to use a **3S BMS module with balancing and charging capability** to safely manage the pack, together with an **INA219 or INA3221 module** for accurate monitoring. This approach ensures safe charging, prevents imbalance, and enables real-time monitoring of individual cells and the full battery pack using the ESP32 and Flask dashboard.

Safety and Conclusion

Handling and charging Li-ion cells requires strict adherence to safety protocols. The project should never attempt to charge series cells using TP4056 directly, as this poses severe risks. Instead, a 3S charger with a BMS provides the correct solution. The ESP32, combined with a Flask web server, adds real-time monitoring and visualization, allowing users to observe cell voltages, state-of-charge, and battery health indicators. Resistors and wires provided will be used to build the voltage dividers and connections to the ESP32. Additional modules such as current and temperature sensors improve accuracy and enhance system safety. In conclusion, by addressing the limitations of TP4056 and adopting the correct charging and monitoring strategies, this project delivers a safe, functional, and educational demonstration of a modern battery monitoring system.