Lecture 17 -- Molecular Switches

Molecular Switches/Devices

- Idea: Use a single molecule to as a computing or data storage element.
    - Generally, this means a fairly complex organic molecule, not something simple like water

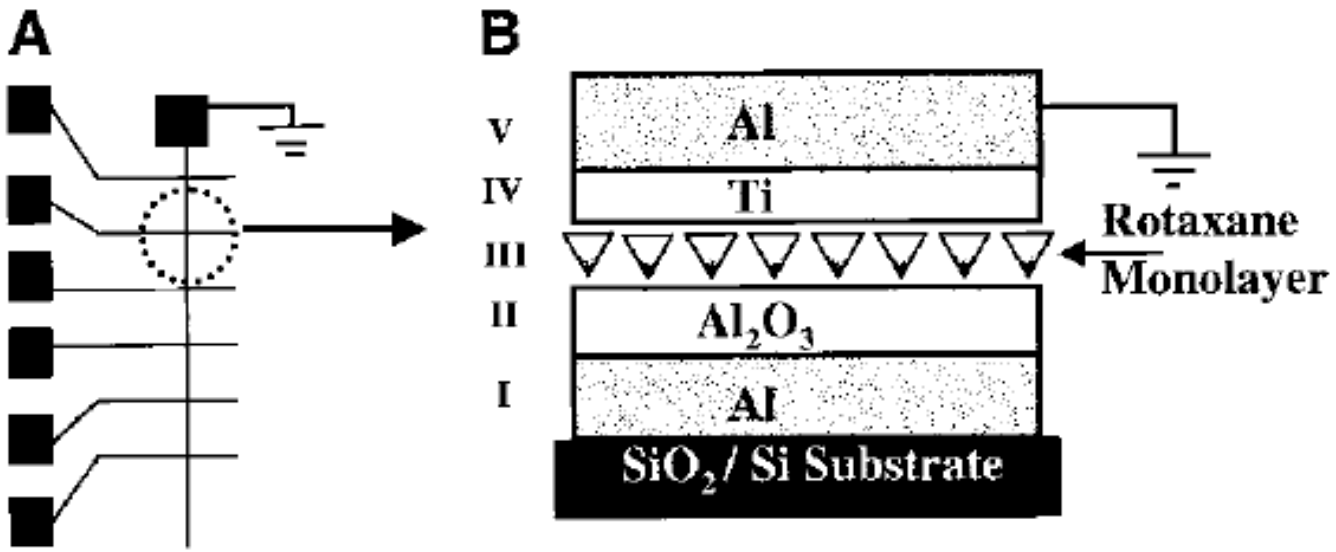
Requirements of Molecular Switches/Circuits

- Need some sort of behavior that we can exploit to do computations or store data
  - State change essential for memory, helpful for logic
- Need input-output compatibility
- Need some way to manufacture in bulk
- Really helps to have a way to integrate with silicon, at least in transition

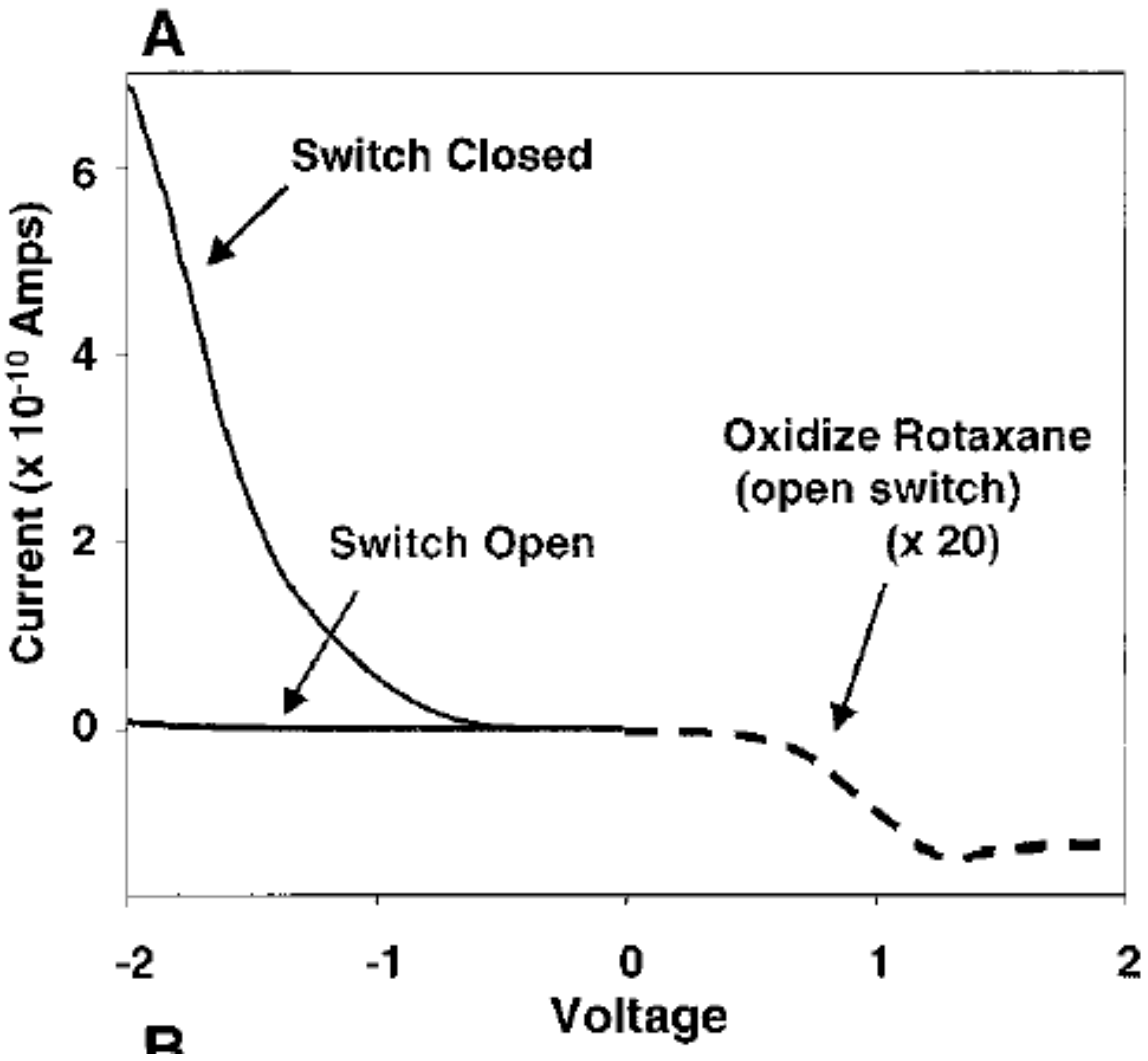
Electronically Configurable Molecular-Based Logic Gates

- Idea: Thin (one-molecule) layer of rotaxane changes resistance significantly based on oxidation state, letting it be used as a switch.
  - "Closed" switch state has non-linear I-V curve, making it more effective than classical resistance for this
- Can "program" individual switches by applying voltage to oxidize

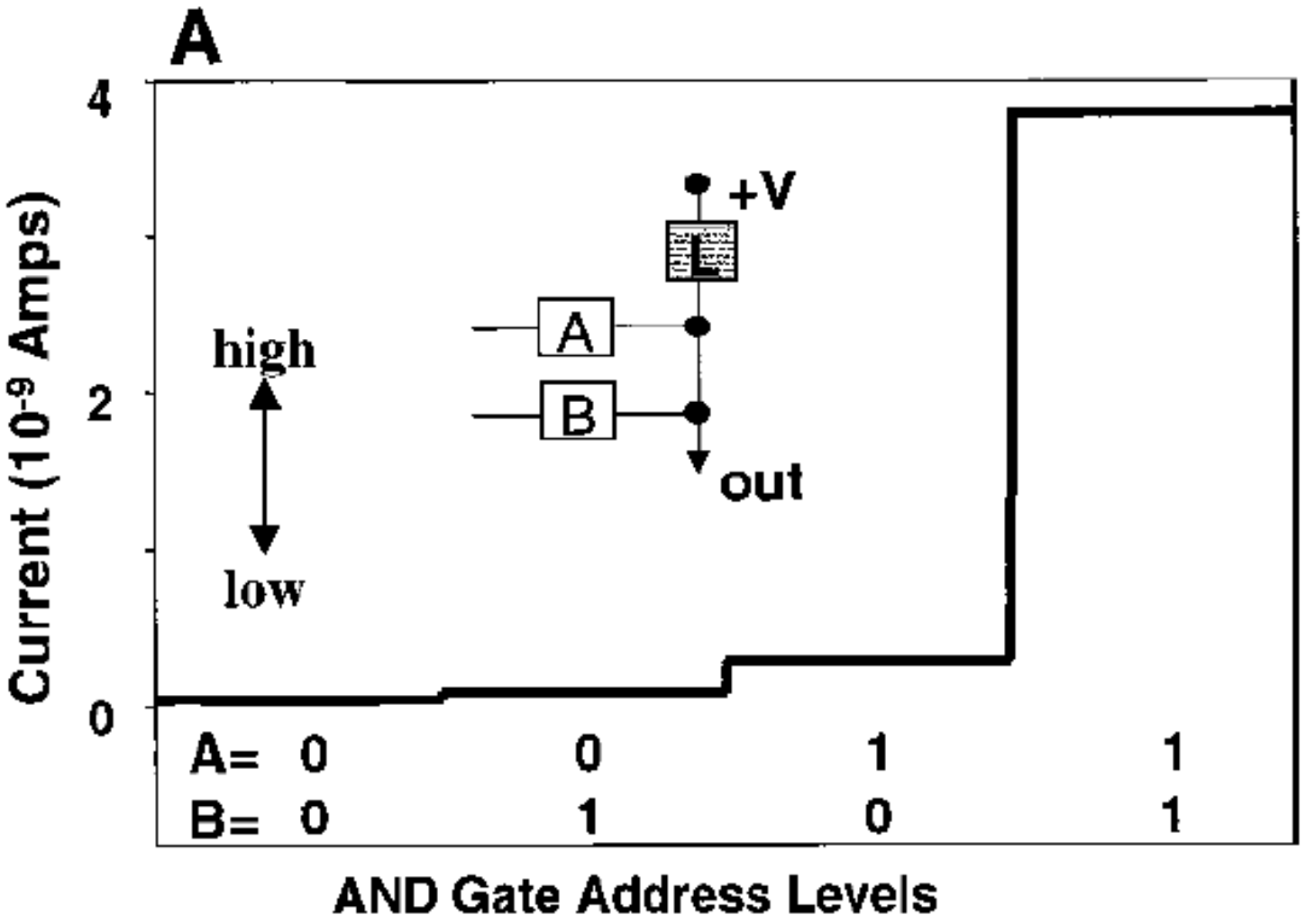
Proposed Gate



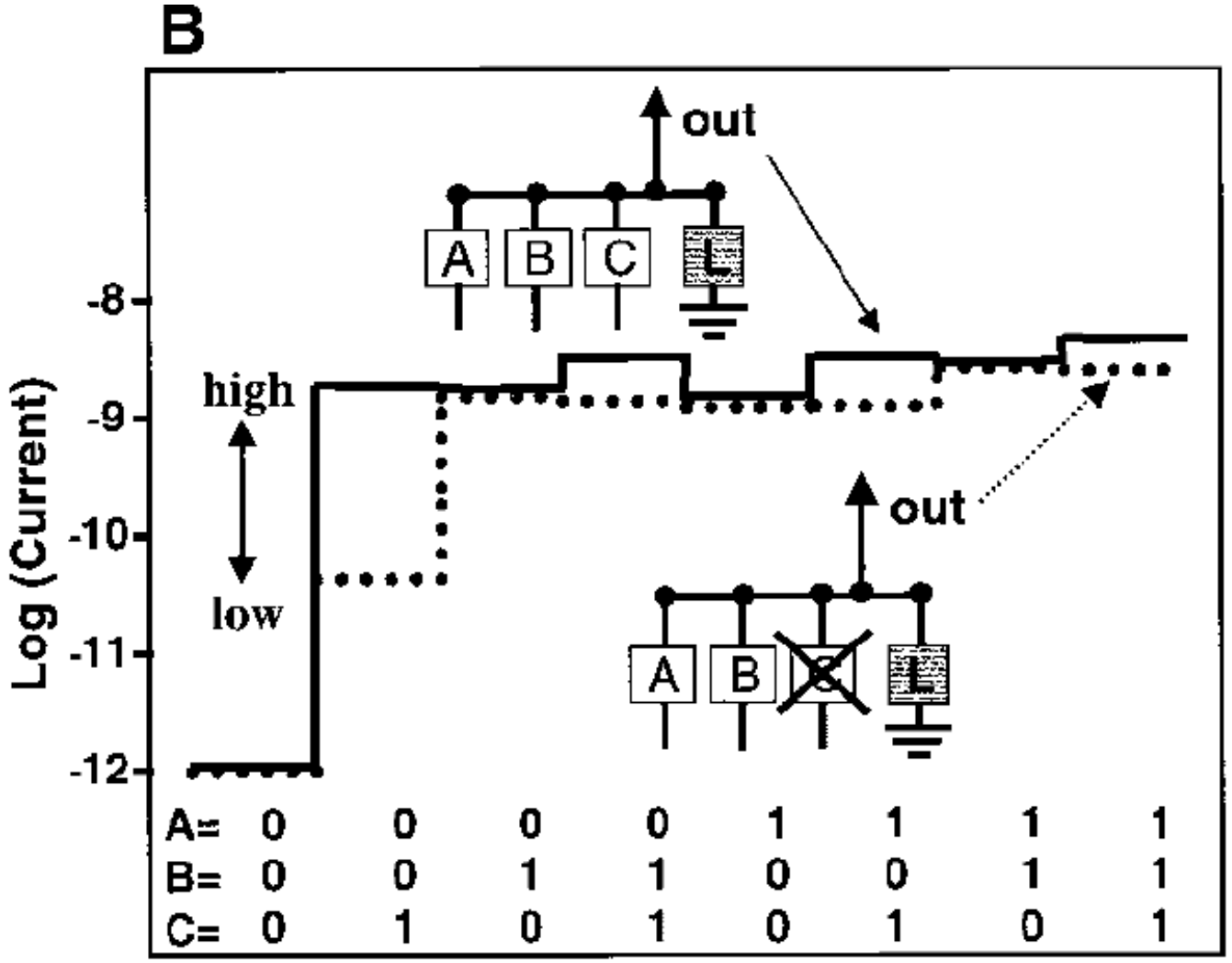
I-V Curve


A
Switch Closed
Switch Open
Oxidize Rotaxane
(open switch)
(x 20)
Current (x 10-10 Amps)
6
4
2
0
-2
-1
0
1
2
Voltage
B

AND Gate


A
4
2
0
Current (10^{-9} Amps)
high
low
+V
A
B
out
A= 0 0 1 1
B= 0 1 0 1
AND Gate Address Levels

Configurable OR Gate



2- and 3-Terminal OR Gate Address Levels

Limitations

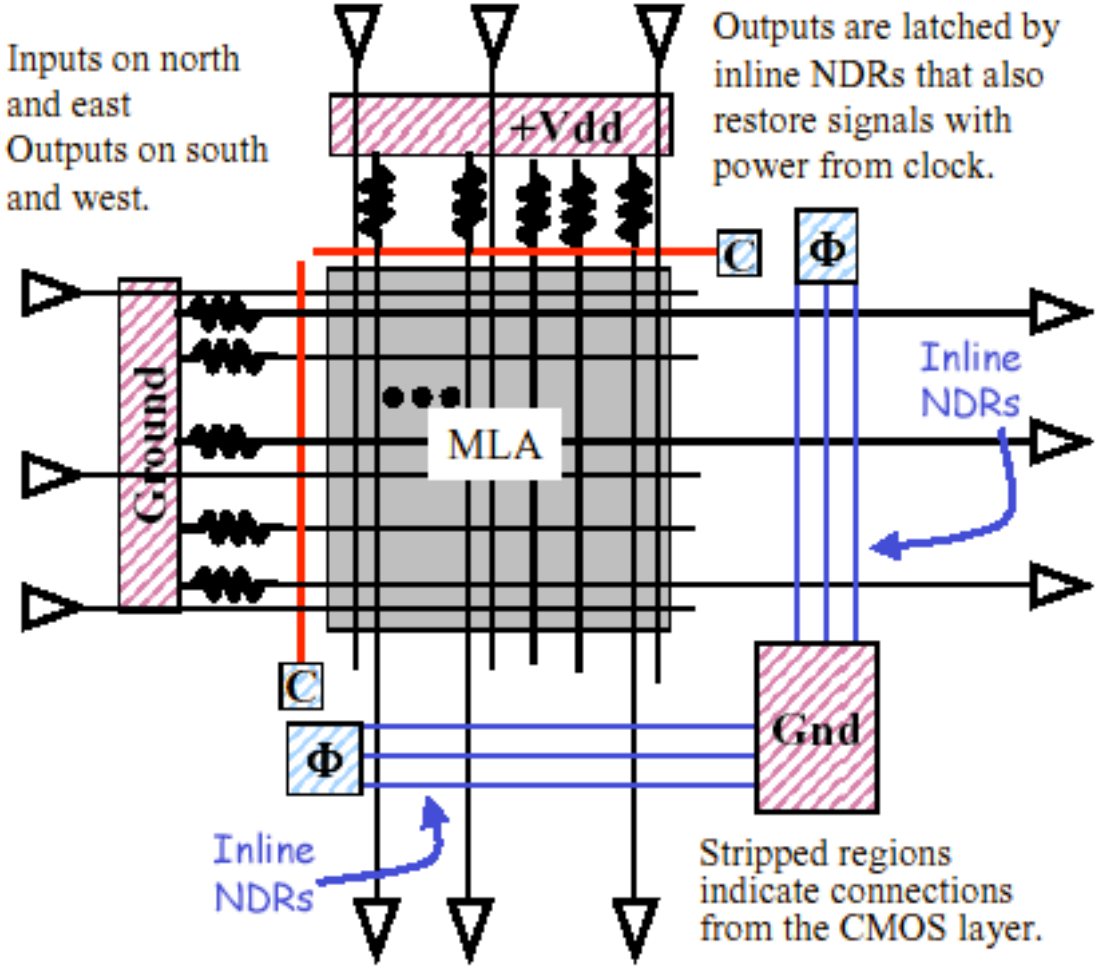
- One-time programmable -- oxidation is irreversible
- Static (though small per device) current
- Only inherently molecule-sized in one dimension
  - Need fabrication technology to reduce area as well
  - Issue with how we connect configuration current in devices that small.

Digital Logic Using Molecular Electronics

- Proposal for larger-scale system design using molecular switches
- Construct "functionalized" wires that have appropriate molecular layer
- Arrange wires in grid via fluid flow
- Creates programmable switch at each intersection

- Each grid assembled through nanoscale-friendly processes. Grid placement and inter-grid connections done lithographically
- Grids act like programmable logic arrays
- Signals restored to full swing at edges of grid by latching structures

NanoBlock Design



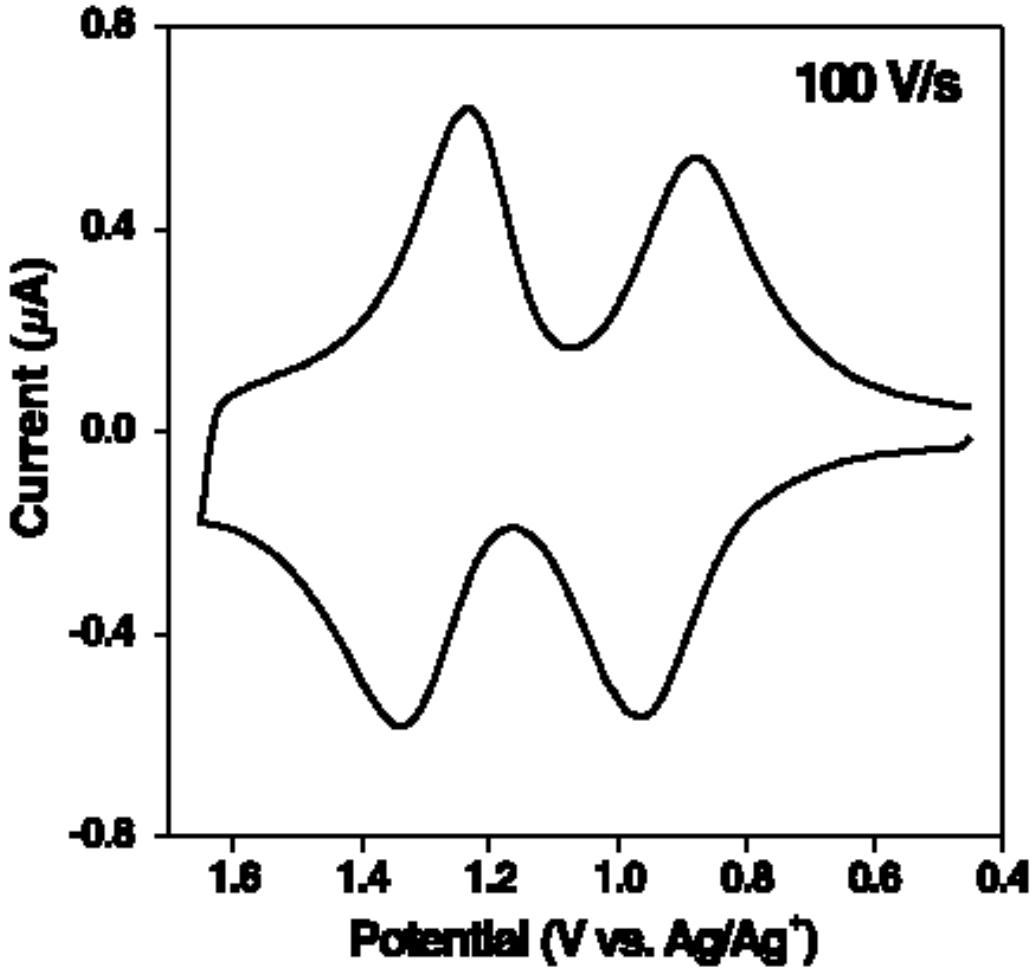
Molecular Memories That Survive Silicon Device Processing and Real-World Operation

- Memories need:
  - Reversible (many, many times), detectable, state change
- For moderate-term practicality:
  - Must be integratable with CMOS
  - Must tolerate CMOS fabrication processes

Proposed Molecules

- Belong to the porphyrin class of molecules that have the same ring structure
- Attach well to silicon, and the attachment remains stable at wide temperature ranges
- Have very different conduction characteristics based on whether the molecule is oxidized
    - Conduction characteristics remain stable over many oxidations, retain oxidation state for minutes.

Oxidation Behavior



Long-Term Stability

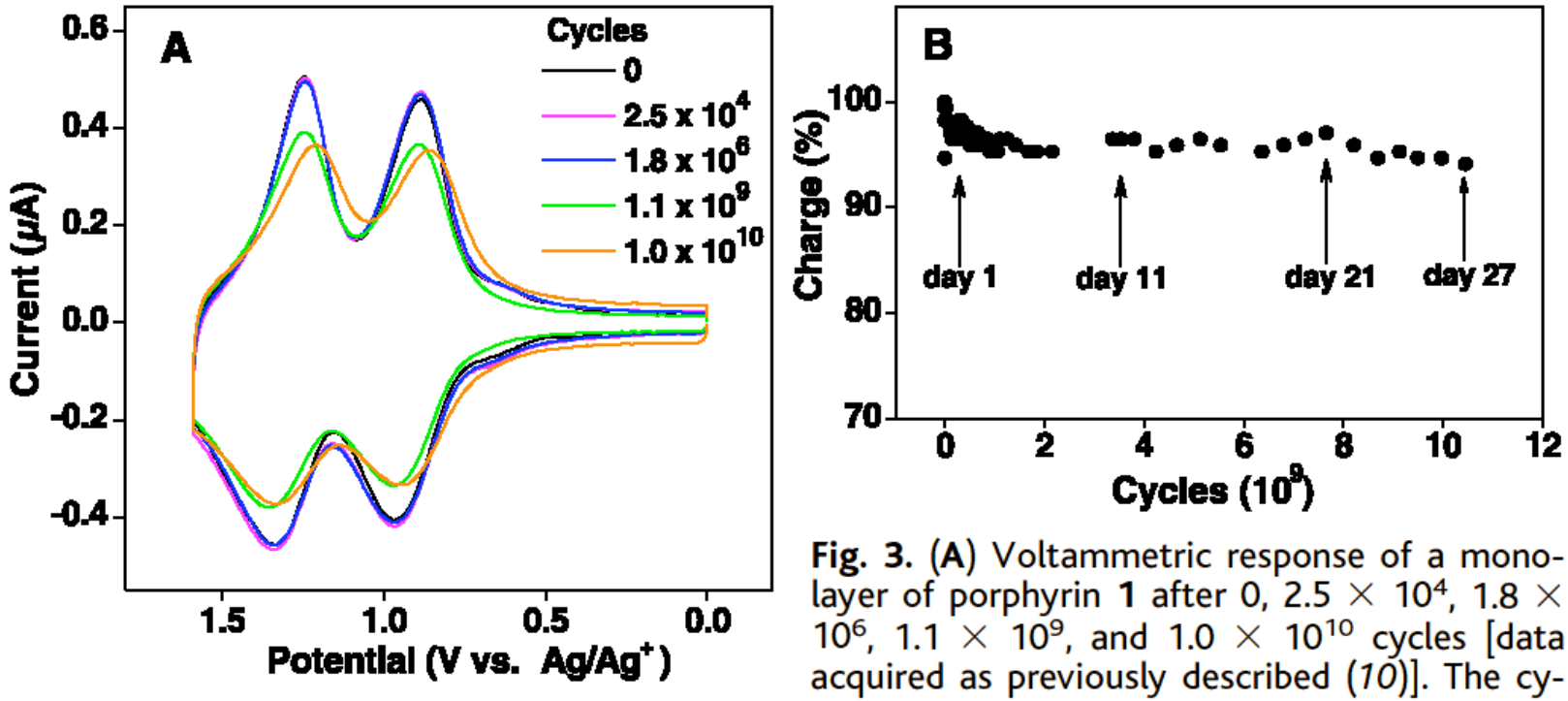


Fig. 3. (**A**) Voltammetric response of a monolayer of porphyrin **1** after 0, 2.5 × 10^4, 1.8 × 10^6, 1.1 × 10^9, and 1.0 × 10^{10} cycles [data acquired as previously described (*10*)]. The cy-