# Lecture 14: Electrical Safety

(Quiz)

0. Review

1. Physiological Effects of Electricity

2. Macroshock Hazards

3. Microshock Hazards

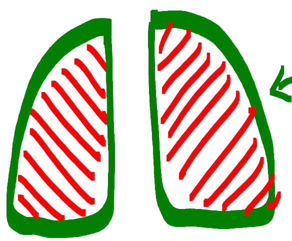
- PreLab 6 due in lab session
- Thu: HW6 due
- Fri: Lab 5 report due
- Exam #2 next Thu (Mar 5)
  - → Lectures 9-14 material
  - → Labs 4-6 material
  - → see course website for 2019 exam.

☆ Presentations: Mar 10 + 12

☆ Ellis Tour (Mar 10)

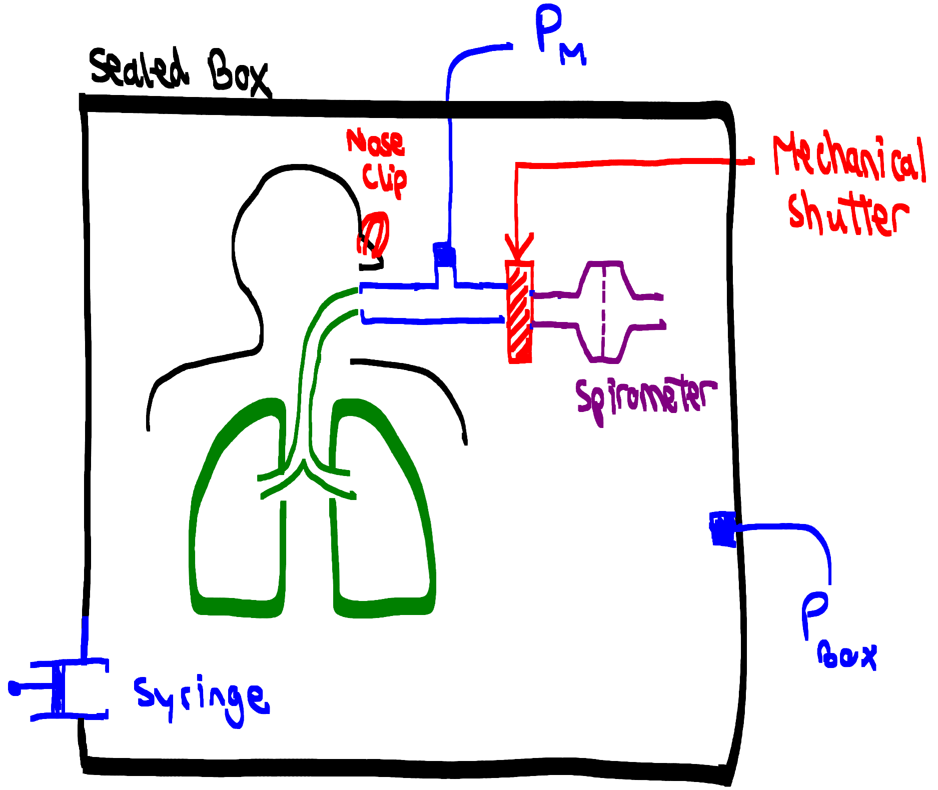
# 0. Review

- **Absolute Lung Volume:** FRC is lung volume at rest
  Functional Residual Capacity



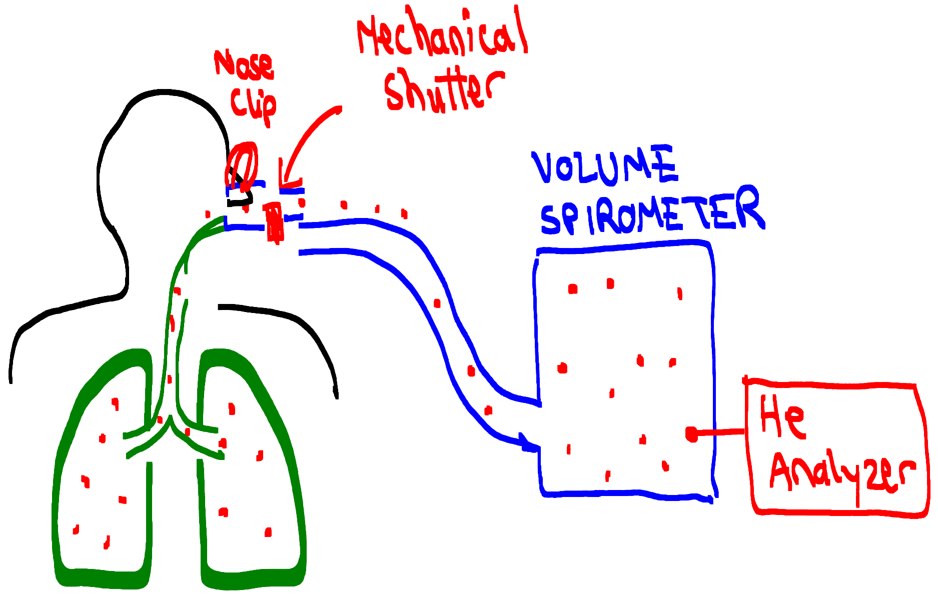

## ① Whole Body Plethysmography

$$\boxed{FRC = \frac{P_M - \Delta P_M}{\Delta P_M} \cdot (\Delta V_{Box})}$$



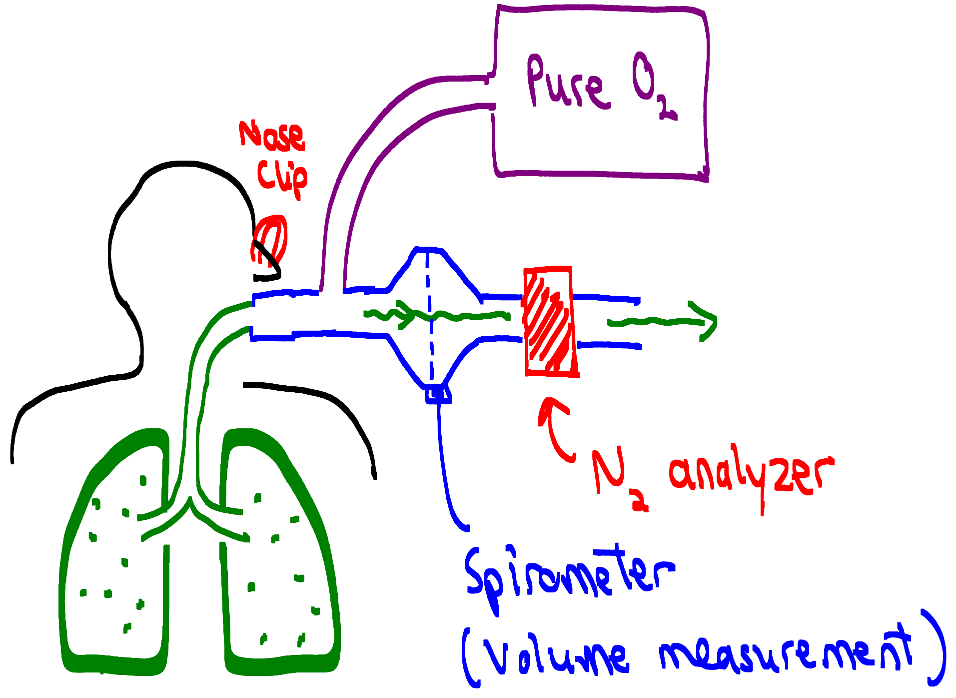

## ② Helium Dilution ← "Closed Circuit"

$$\boxed{FRC = V_L = \frac{(C_s - C_{Ls})}{C_{Ls}} \cdot V_s}$$




## ③ Nitrogen Wash-out ← "open circuit"

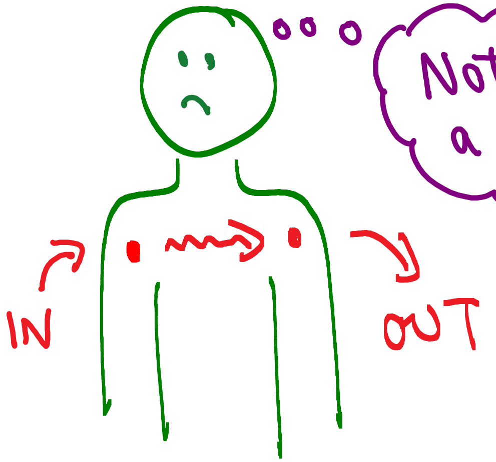
$$\boxed{FRC = V_L = \frac{\sum_b C_b \Delta V_b}{C_L}}$$



# 1. Physiological Effects of Electricity

- Intro

(Current enters the body at one point and leaves at some other point.)




Not having a good day

This is what matters!

Current = Voltage / ( [skin resistance] + [Internal body impedance] )

Voltage: Not as important

★ skin resistance

- Biological Phenomena

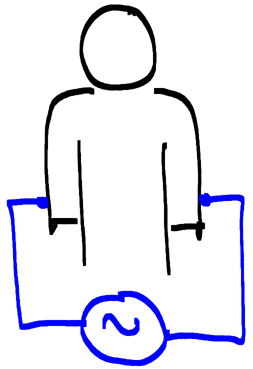
① Electrical Stimulation of excitable tissue

② Resistive heating of tissue (thermal burn)

③ Electrochemical burns

(current causes formation of $HCl$, $NaOH$, ...)

- Current Thresholds



60 Hz
1 to 3 sec

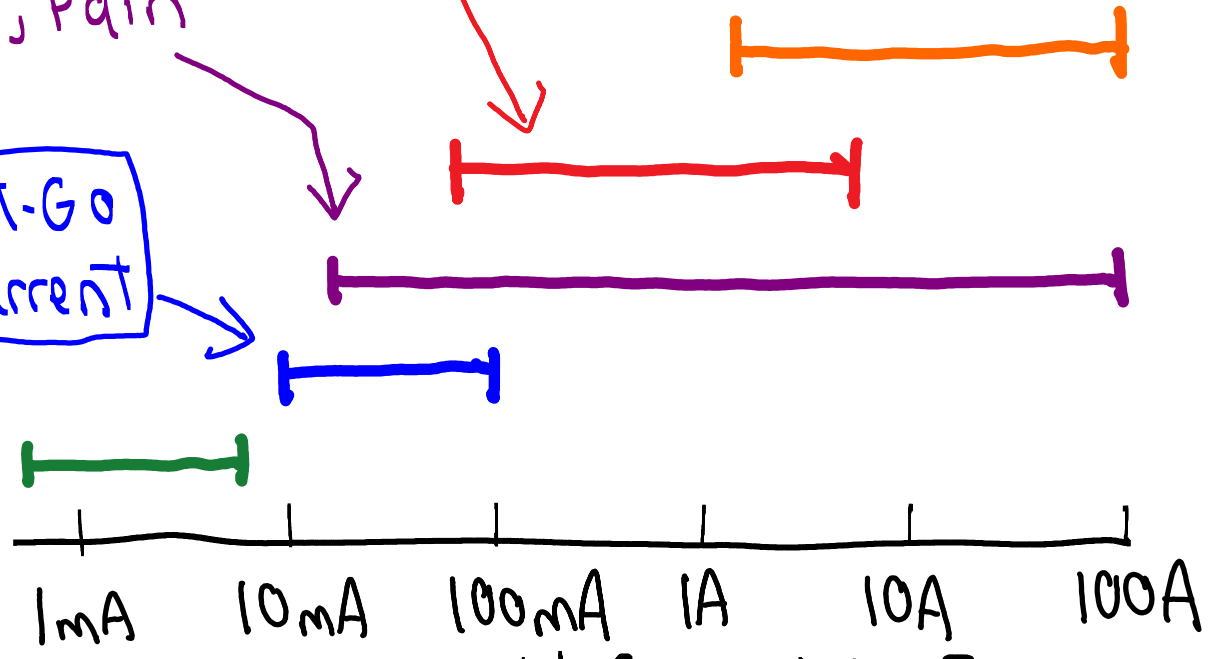
★ Major cause of death due to electric shock → Ventricular Fibrillation

- Burns, injury
- Sustained myocardial contraction

Respiratory paralysis, Fatigue, Pain

Max current to let go voluntarily → Let-Go Current

Threshold of perception

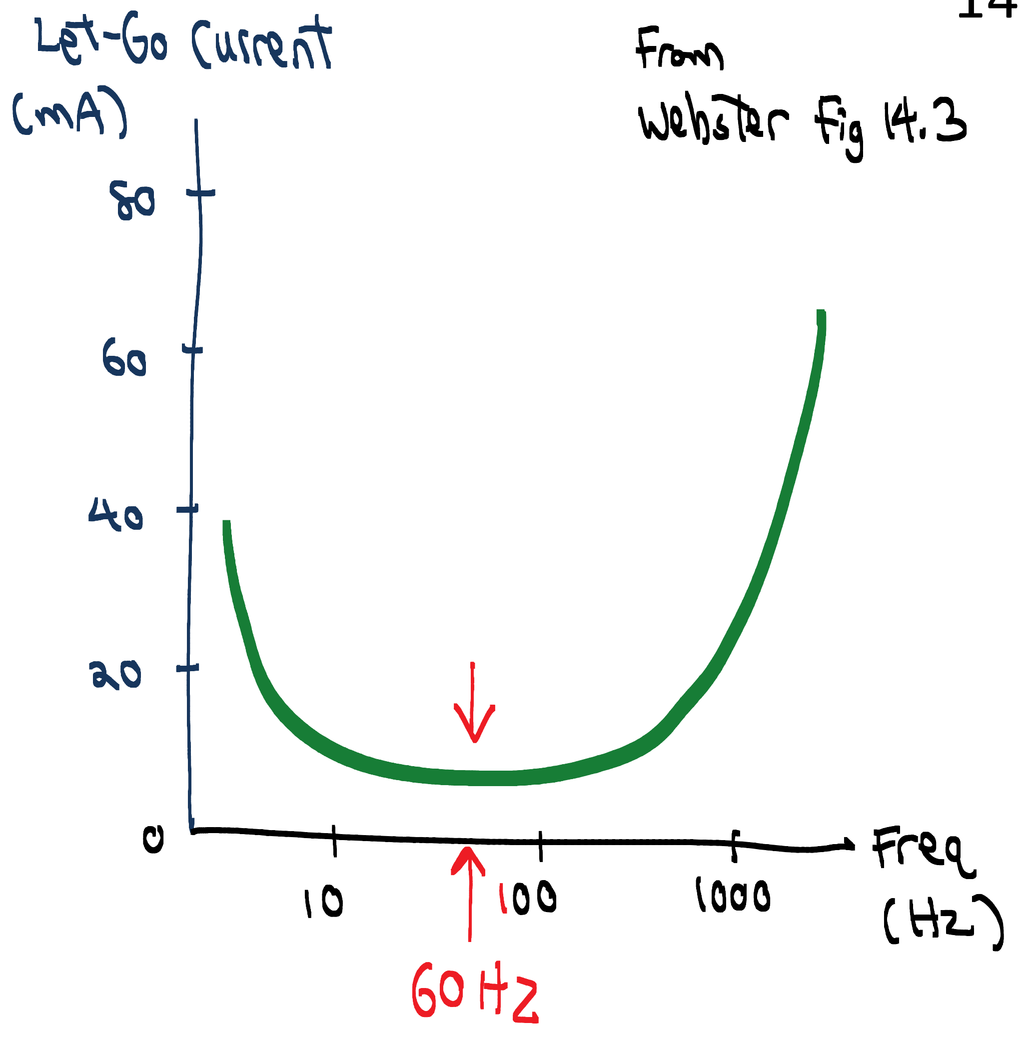



Adapted from Webster Fig 14.1

- Threshold of perception

  Varies considerably between individuals

  60 Hz → ~ 0.5 mA
  DC → few mA
  ] Frequency dependence!




- Let-Go current

  Varies considerably between individuals

  60 Hz → ~10 mA

- Respiratory Paralysis, Pain, and Fatigue

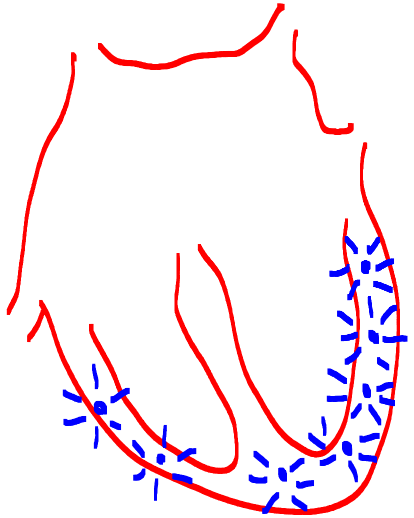
  Involuntary contraction of respiratory muscles → can lead to asphyxiation

  60 Hz → > 20 mA

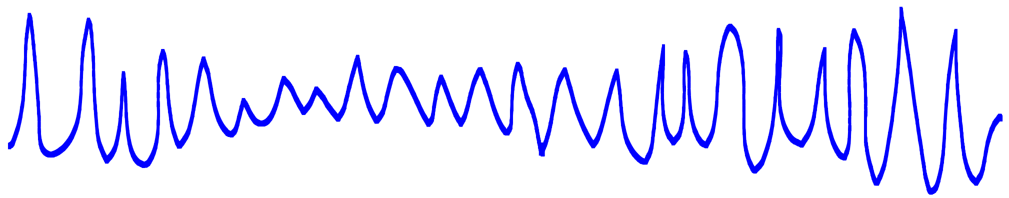
- Ventricular Fibrillation (V-Fib)

75-400 mA

Electrical shock can disrupt the normal cardiac cycle



webster Fig 4.20 (b)



ECG waveform

wavefronts of depolarization randomly sweep over the ventricles ⇒ ventricles twitch in a feeble, uncoordinated manner ⇒ Heart rate can rise to 300 beats/min!

No blood is pumped from the heart ⇒ Lose consciousness within few sec ⇒ Brain damage or death within few min

☆ V-Fib continues after the electric shock is over!

Defibrillator

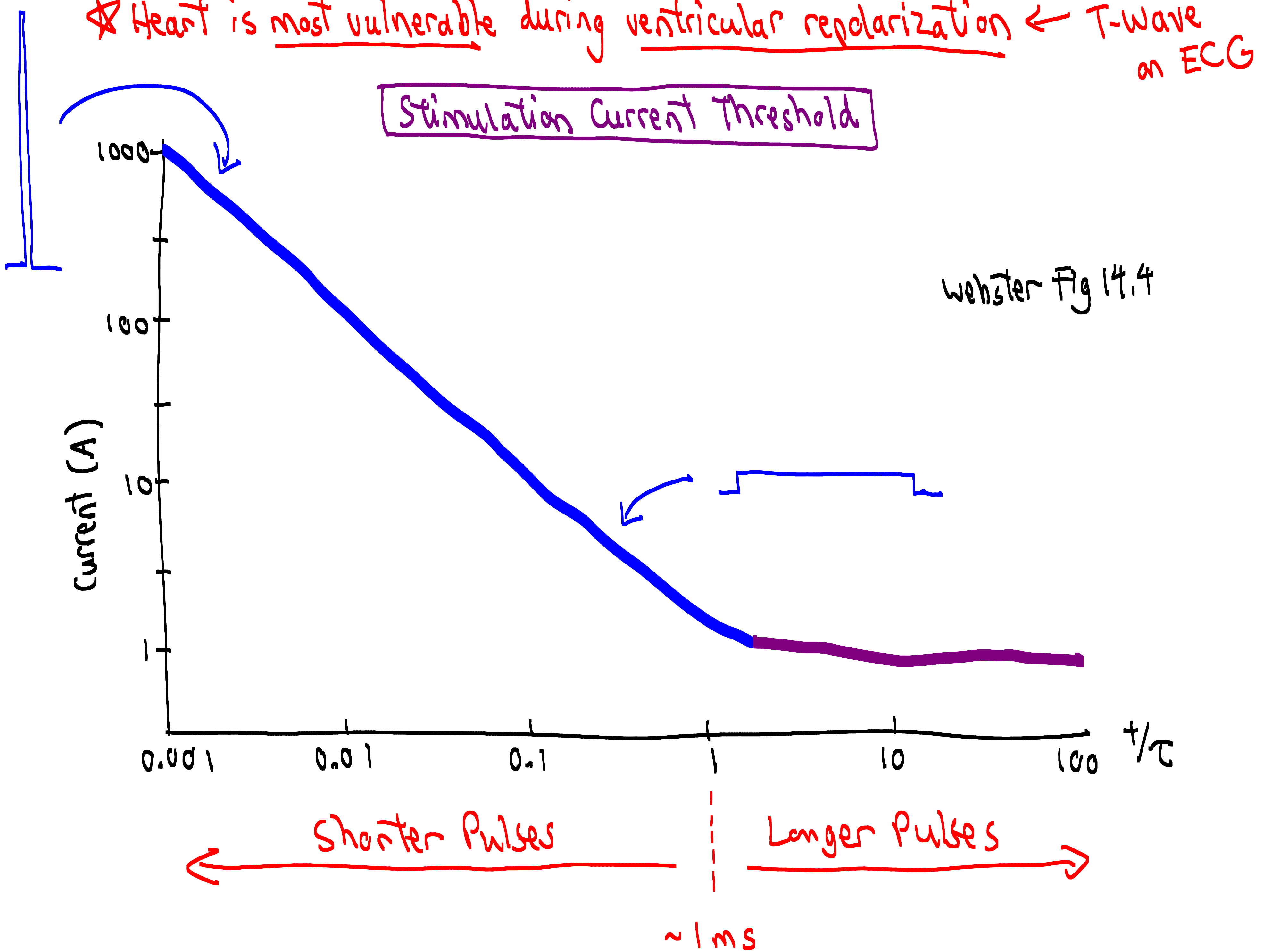
- Applies a short, high current pulse to heart
- Depolarizes entire heart muscle
- After the cells relax together, normal rhythm returns.

☺

- Shock Duration

★ Shocks must last long enough during the T-wave in each cardiac cycle.

★ Heart is most vulnerable during ventricular repolarization ← T-wave on ECG



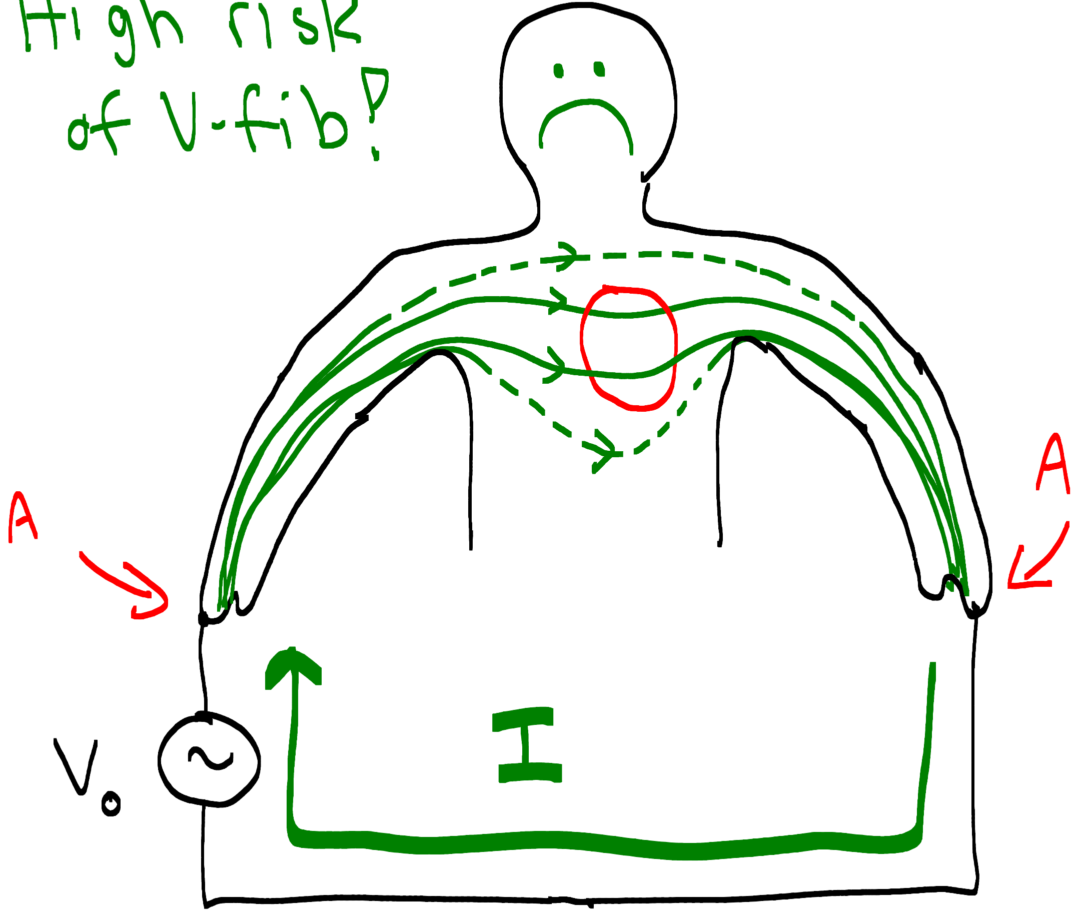

- Electric fences and Tasers use very short (<100μs) pulses ← do not cause V-Fib

- **Points of Entry:** Where current enters/exits the body matters!

Ⓐ Points on opposite sides of heart

→ Large % of $I$ goes through heart

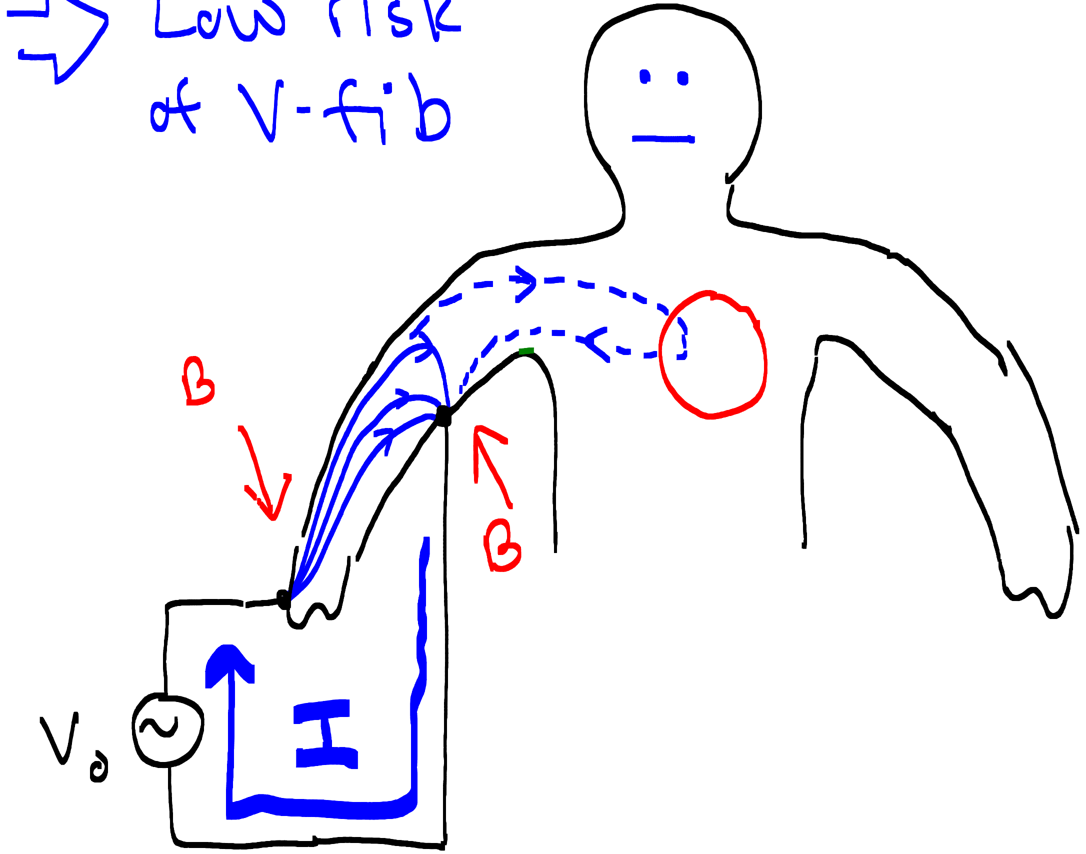
⇒ High risk of V-fib?




Ⓑ Points on same extremity

→ Small % of $I$ goes through heart

⇒ Low risk of V-fib



- **Macroshock vs. Microshock**

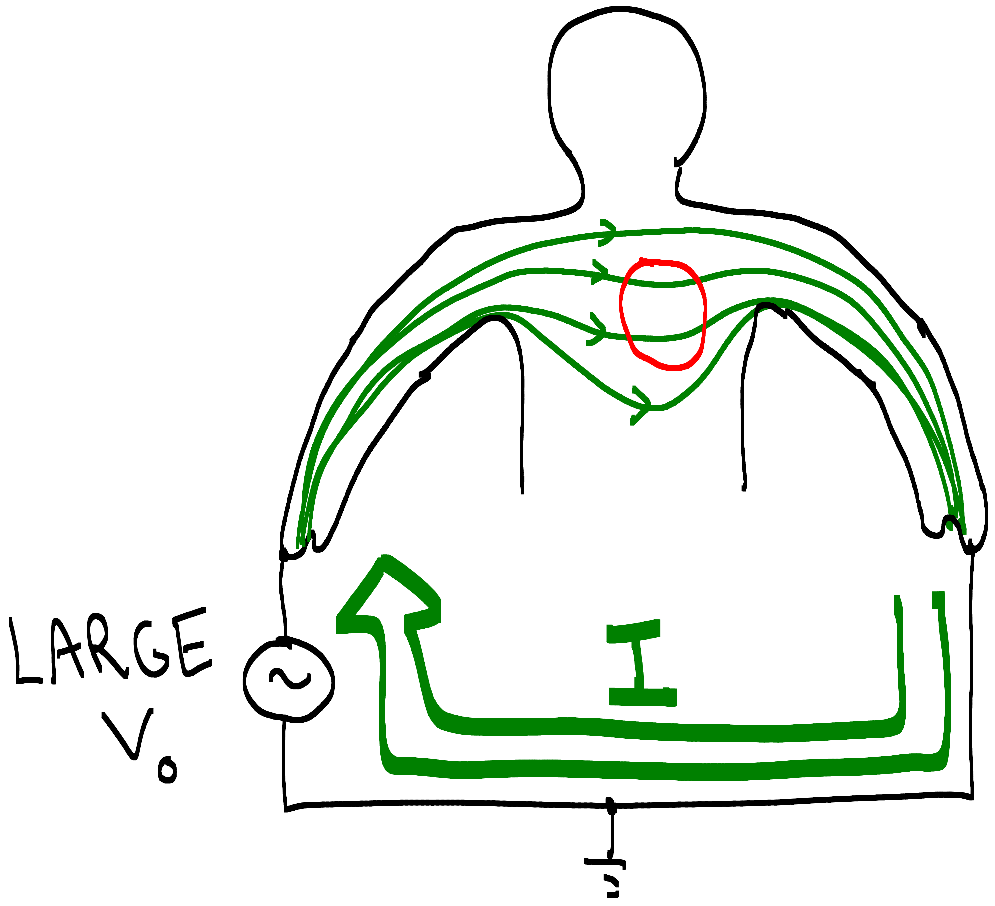
$\boxed{\text{MACROSHOCK}}$

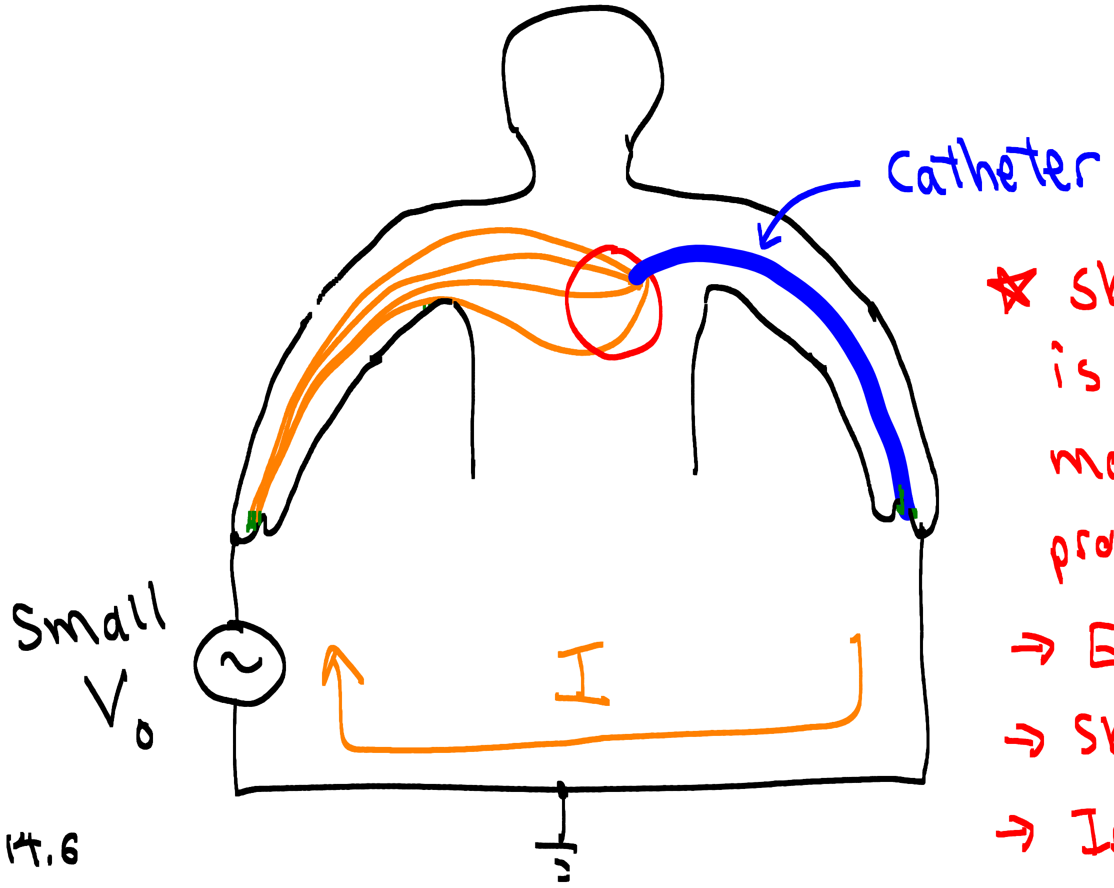
- High voltage on skin
- Large I spreads out

→ Small % causes V-fib

$\boxed{\text{microshock}}$ ← Does not mean less dangerous!

- Medical device provides conductive path to heart
- Small I is concentrated
  ↳ causes V-fib




Webster fig 14.6

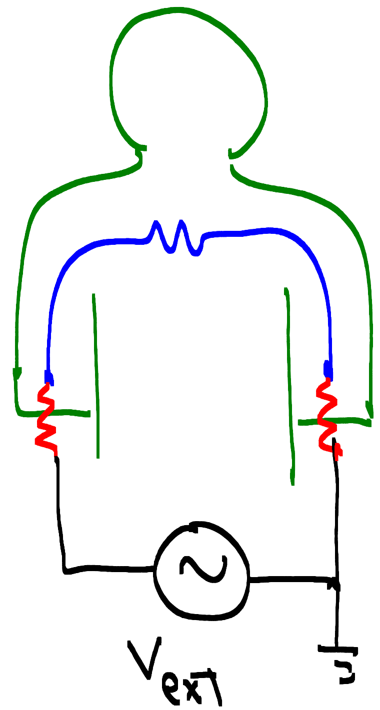
★ skin resistance is bypassed in many medical procedures!

→ ECG gel
→ skin incision
→ Invasive device

## 2. Macroshock Hazards ← Large currents due to contact with AC power line

### A. Reduced Skin Resistance

$$\text{Current} = \frac{\text{Applied Voltage}}{[\text{Skin resistance}] + [\text{Internal body resistance}]}$$




Dry skin: 15 k to 1 MΩ

Wet skin: ~100Ω

ECG: ~10Ω

Skin Treatment + Gel

Each limb ~200Ω

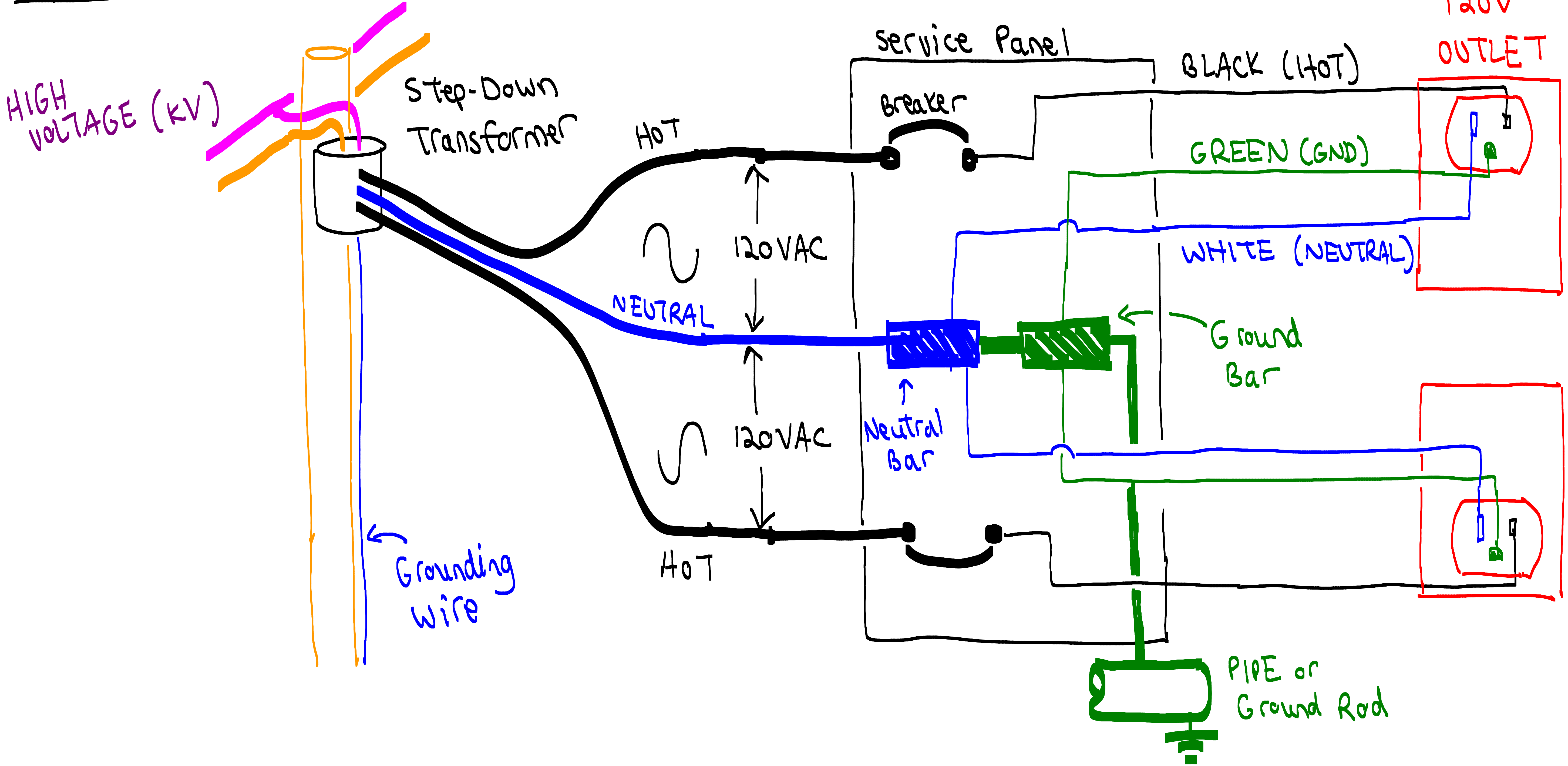
\+ Trunk ~ 100 Ω

~500Ω between 2 limbs

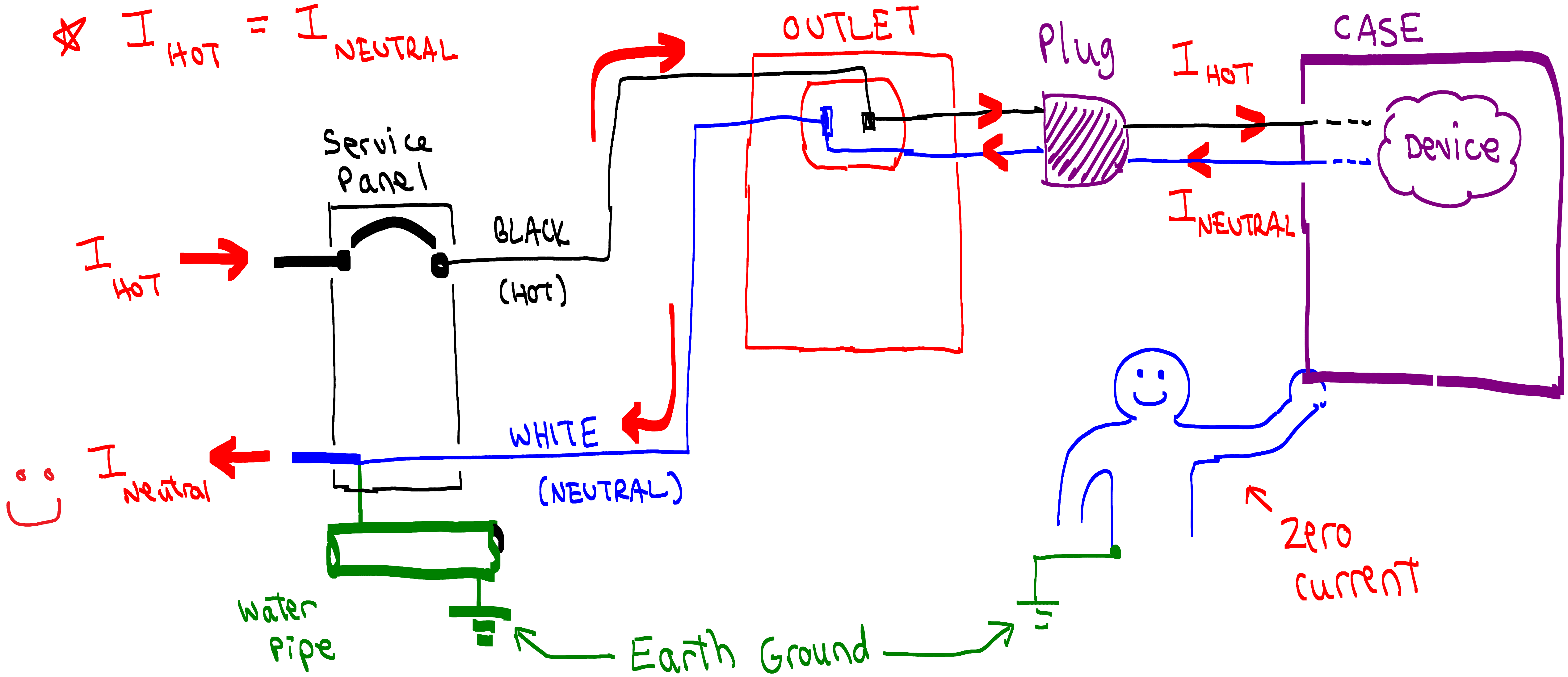
Example: $V_0 = 12V$

- Dry skin $I \sim \frac{12V}{100K} = .12mA$ :-)
- Wet skin $I \sim \frac{12V}{.6K} = \underline{\underline{20\ mA}}$! :-O

## B. Typical Power Line Wiring

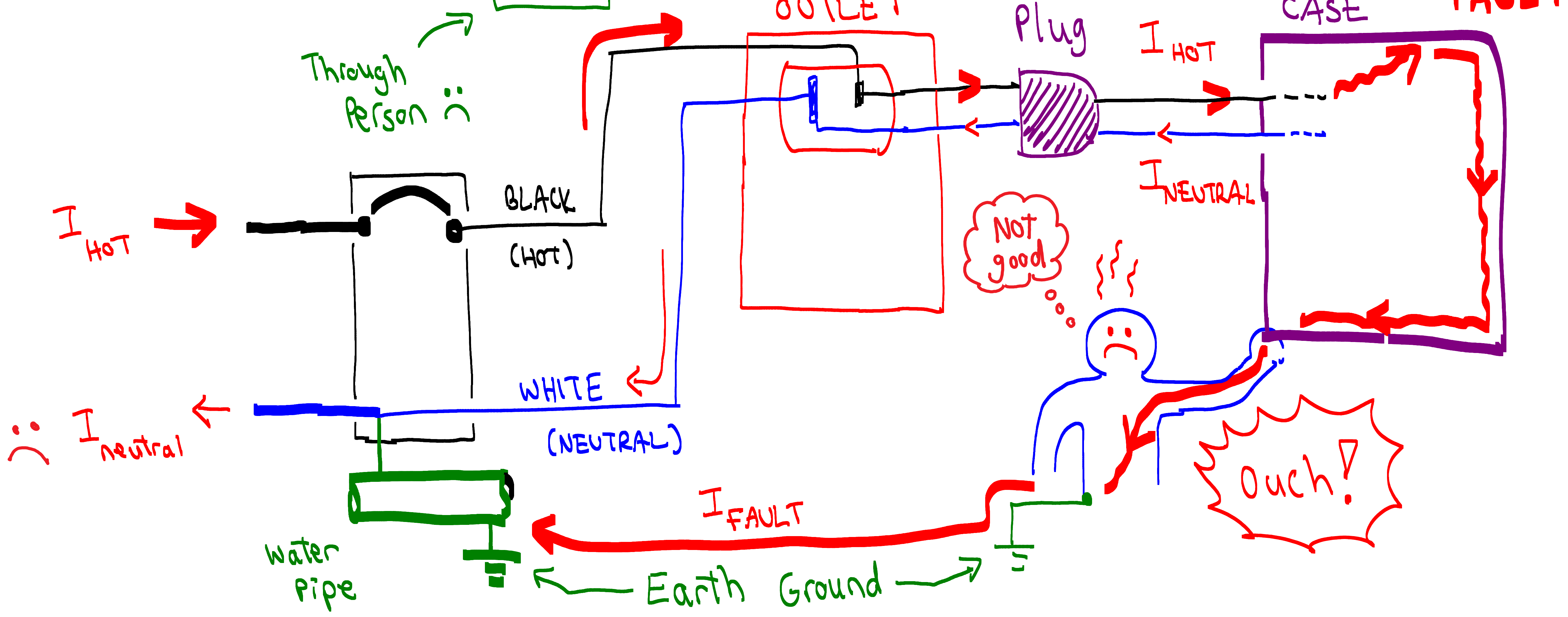


• **2-wire:** under normal conditions, neutral carries all return current.



Ground Fault ← HOT wire is shorted to case.

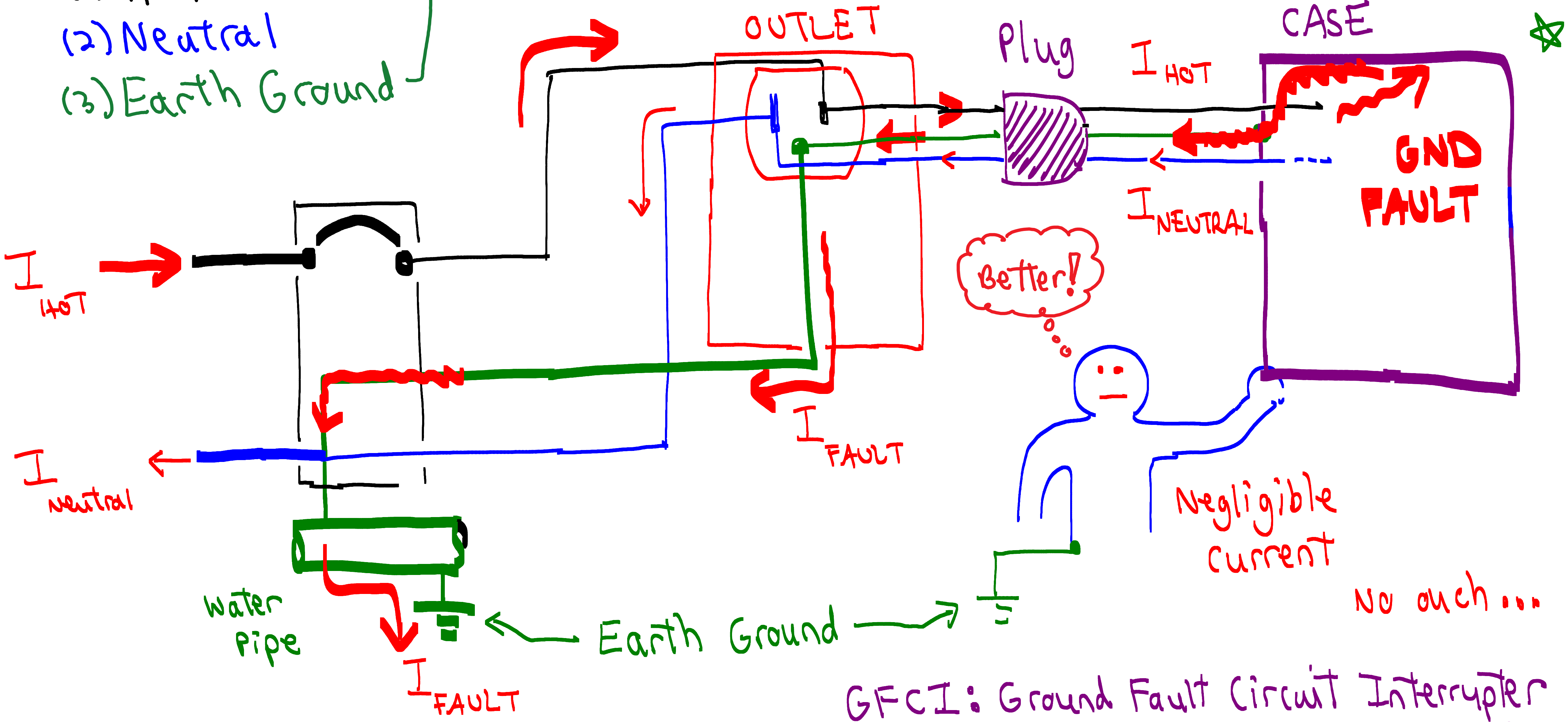
$$\rightarrow I_{HOT} = I_{NEUTRAL} + \boxed{I_{FAULT}}$$



- **3-wire:**

(1) HOT
(2) Neutral
(3) Earth Ground

★ $I_{FAULT}$ goes through ground conductor, not the person!




★ Proper grounding of equipment enclosure is important!

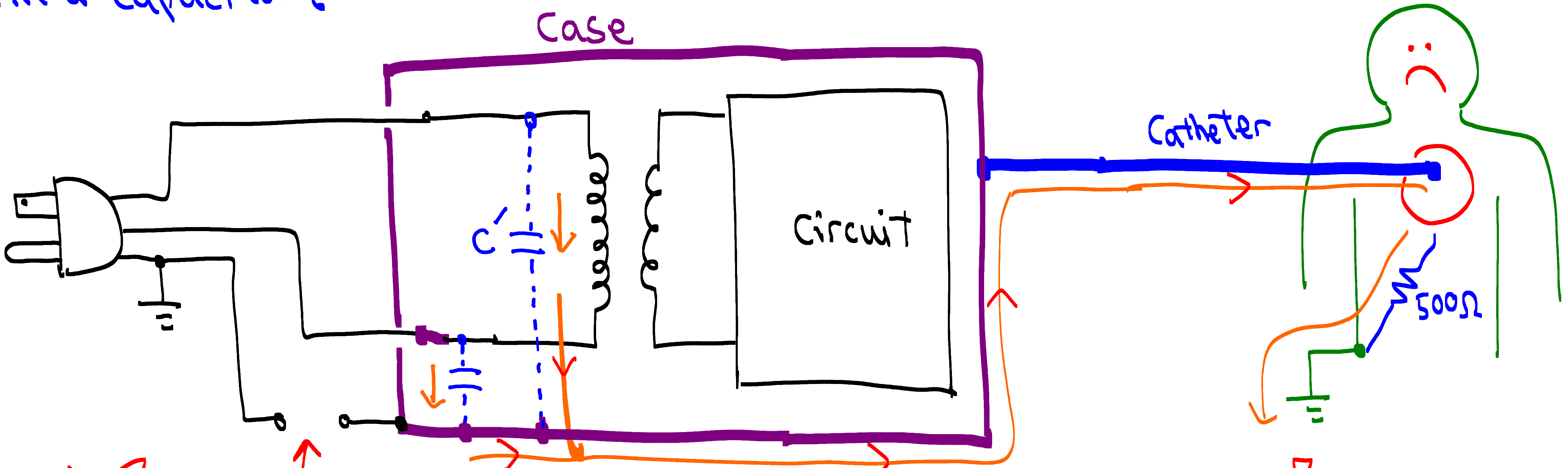
GFCI: Ground Fault Circuit Interrupter
(trips when $I_H - I_N \gtrsim 5\,mA$)

## 3. Microshock Hazards

Due to a device that is directly connected to the heart!

Leakage Currents: Tiny currents (few μA) flow between adjacent insulated $\underbrace{\text{conductors at different}}_{\text{stray capacitance } C'}$ potentials — Possibly dangerous if earth gnd is broken

Any 2 objects form a capacitor!

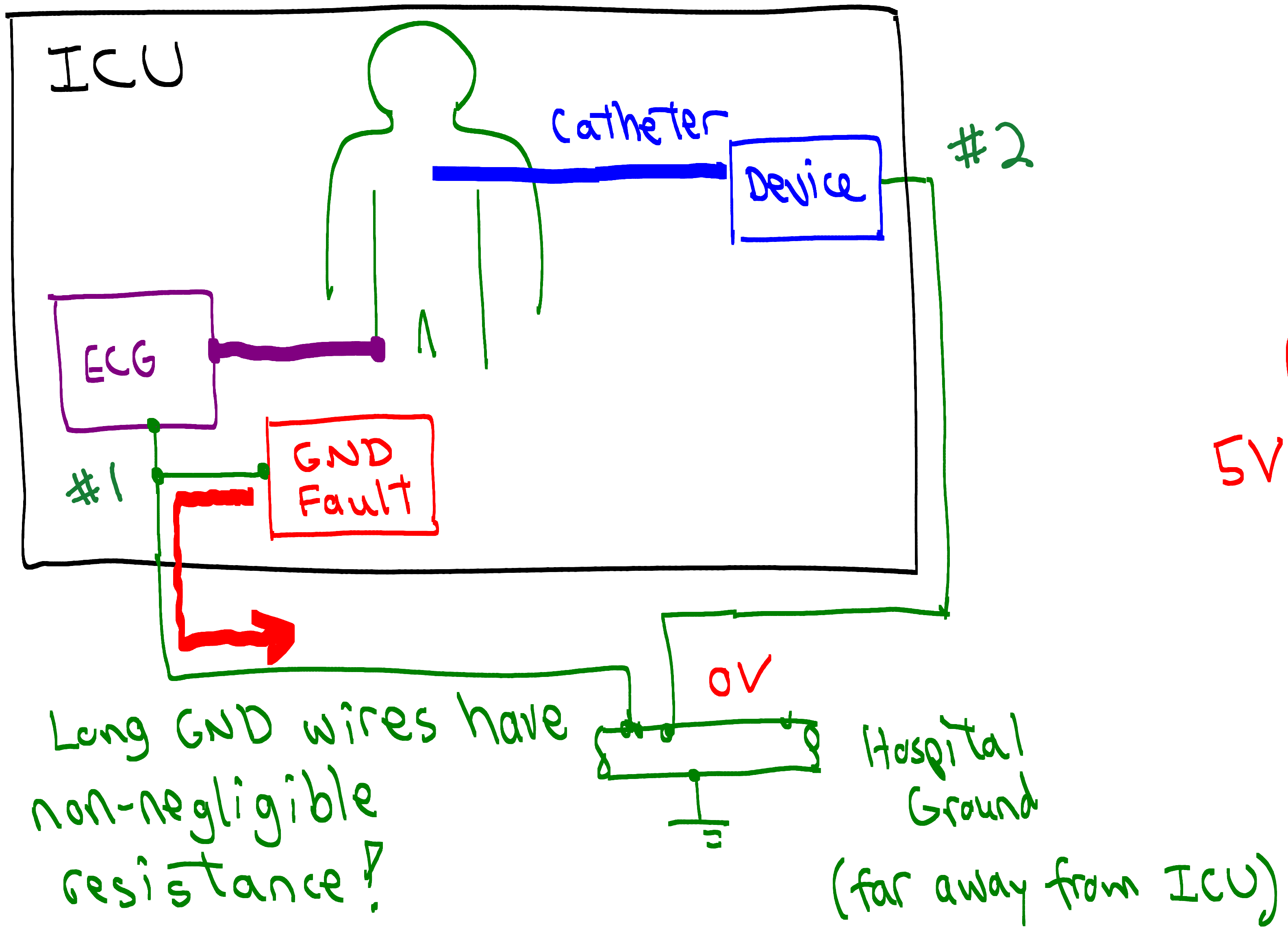



Broken ground causes Leakage Current to enter patient!

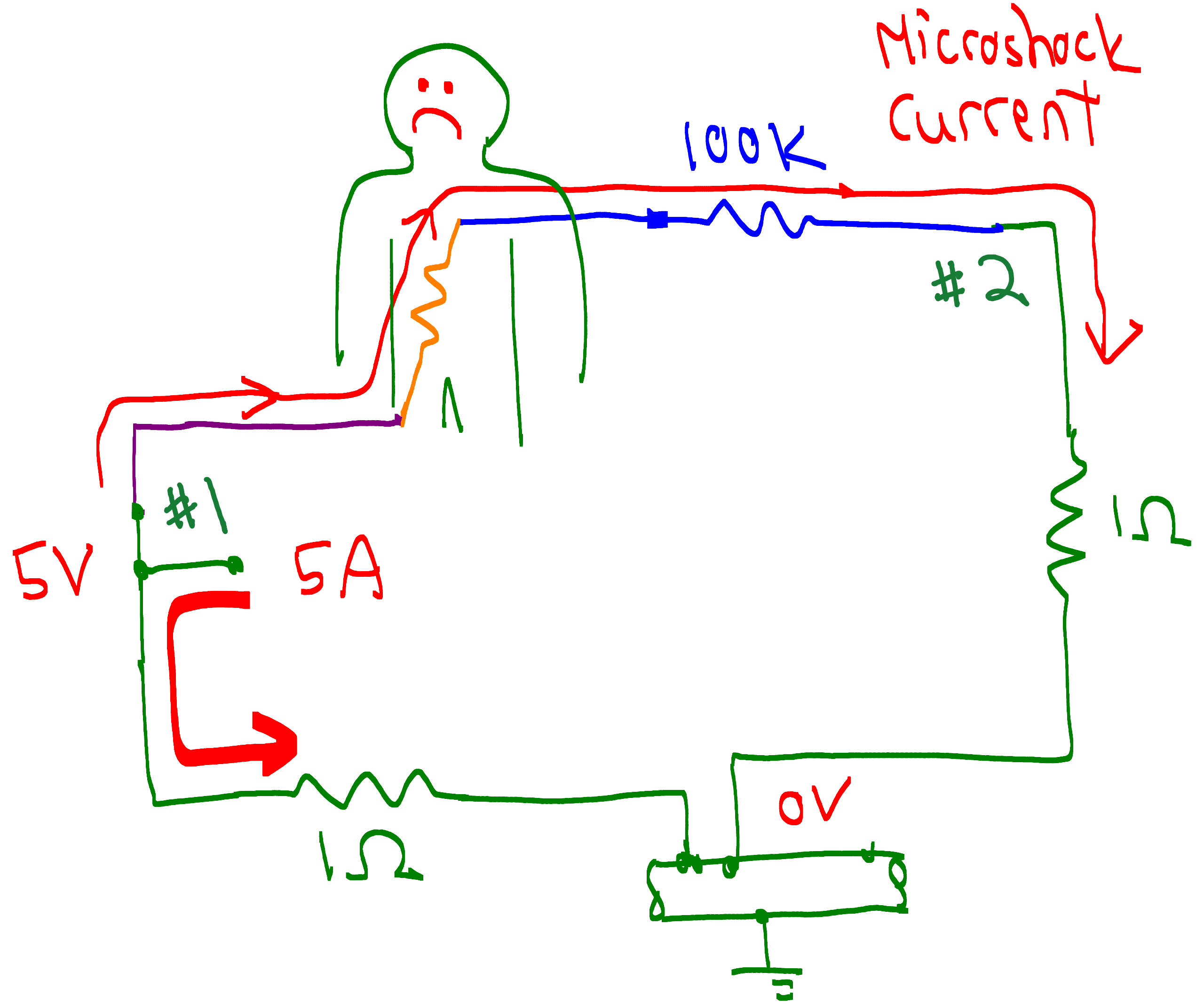
B. Ground Potential Differences

- critical care areas (e.g. ICU) need a single patient-grounding point.

why? Consider two GND points:




$I \sim \frac{5V}{100K} = .05mA$



☆ single ground point can minimize microshocks!