Electrical Safety

Electricity in the body

Physiological Effects of Electricity

- Variations among individuals
- Frequency dependence
- Chronaxie

Macroshock / Microshock

Electrical Faults in Equipment

Electrical Protection

Design considerations for this course

Biopotentials

Biopotentials arise from movement of ions in cells and organs. Measurement of biopotentials yeilds clinically and diagnostically significant information.

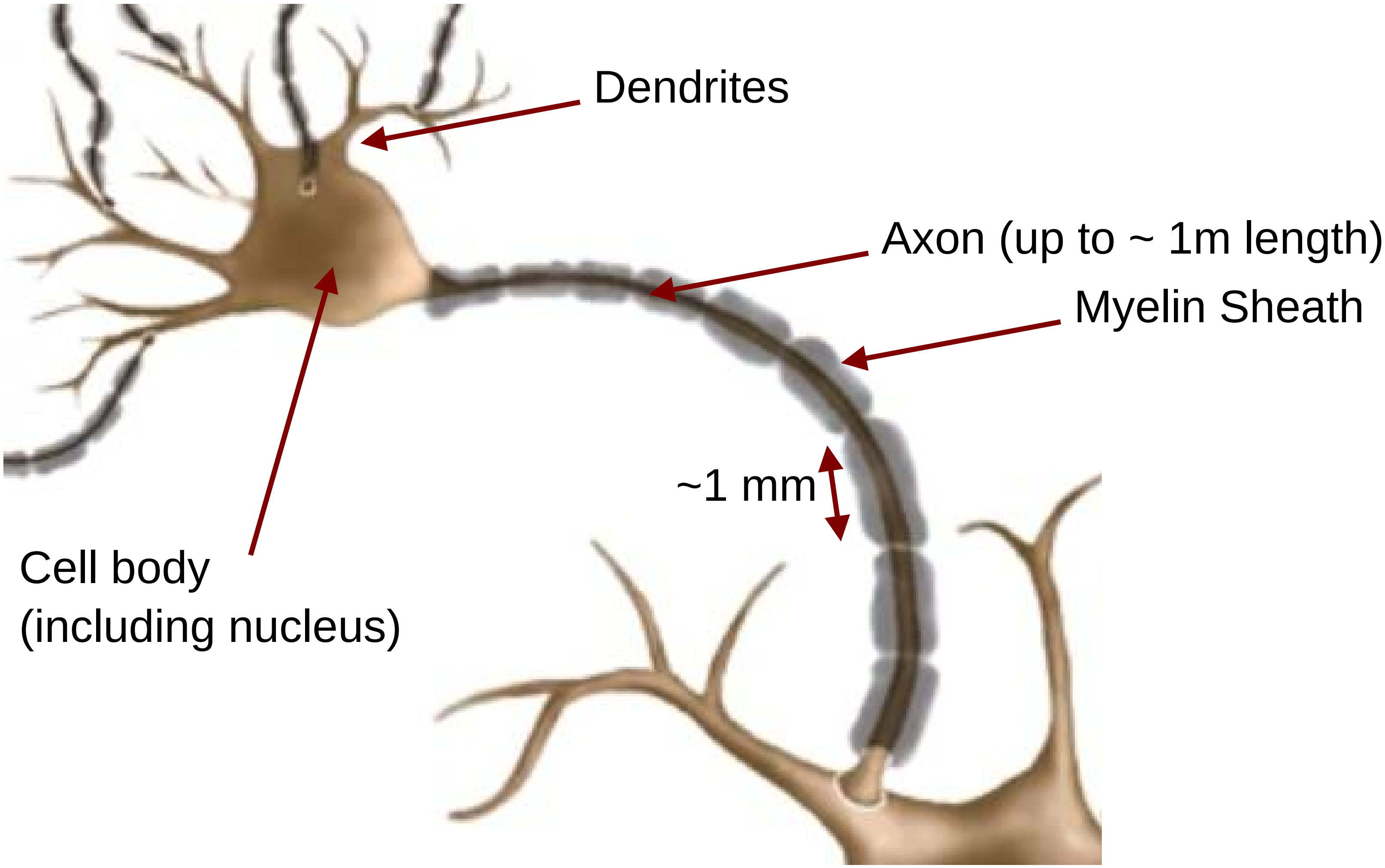
Important biopotentials

From Nerves

- Brain (EEG – electroencephalogram)

- From Muscles
  - Heart (ECG – electrocardiogram)
  - Muscles (EMG – electromyogram)
- From Retina
  - Transepithelial potential (EOG – electrooculogram)

Anatomy of a nerve cell



Source: www.youtube.com/watch?v=G9rHAM0gIn8

Questions

- Do nerves conduct only in one direction?
- What stops an AP from turning around and propagating in both directions?
- Signalling in nerves can be compared to a Pulse Rate Modulation Communications scheme. Compare and contrast.
- Would you modify the video, to better explain the electrical activity? www.youtube.com/watch?v=G9rHAM0gIn8

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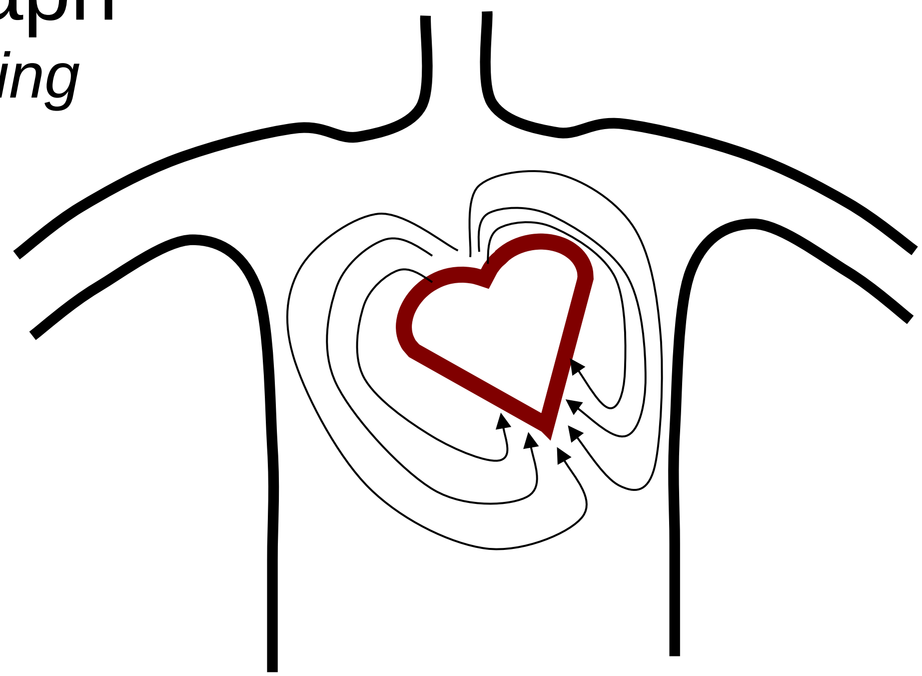
Electro-Cardiogram (ECG)

- Electro - Cardio - Graph
  Electrical *Heart* *Writing*
- Measurements depend where on the body surface measurements are performed



- Therefore, we need standard placements for ECG leads
  - 3 leads RA, LA, LL
  - 12 leads

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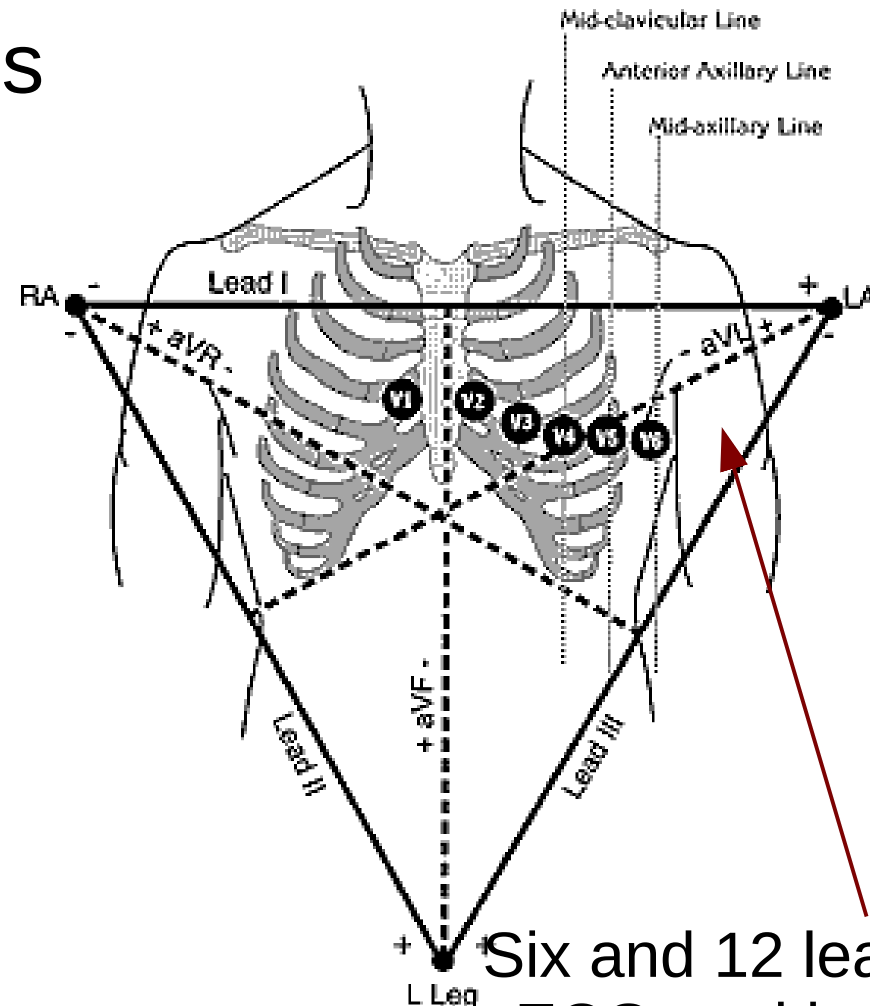
Standard ECG Leads

The Einthoven limb leads (standard leads) are:

$$V_I = \phi_{LA} - \phi_{RA}$$
$$V_{II} = \phi_{LL} - \phi_{RA}$$
$$V_{III} = \phi_{LL} - \phi_{LA}$$

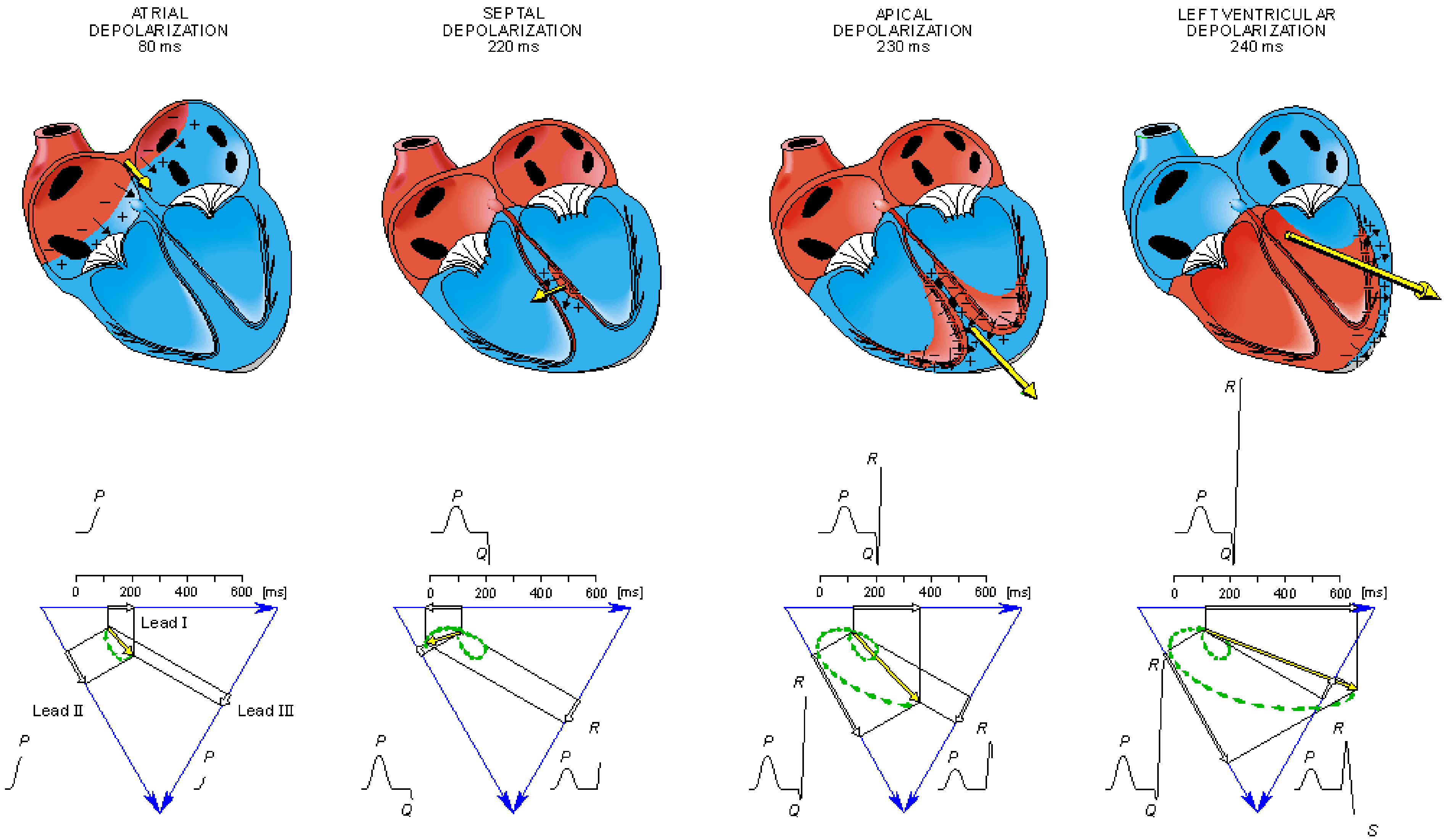
LA = Left Arm
RA = Right Arm
LL = Left Leg

$$V_I + V_{III} = V_{II}$$



Six and 12 lead ECG positions are also defined

ECG Vector Potential



Source: http://www.bem.fi/book/15/15x/animati/000.htm

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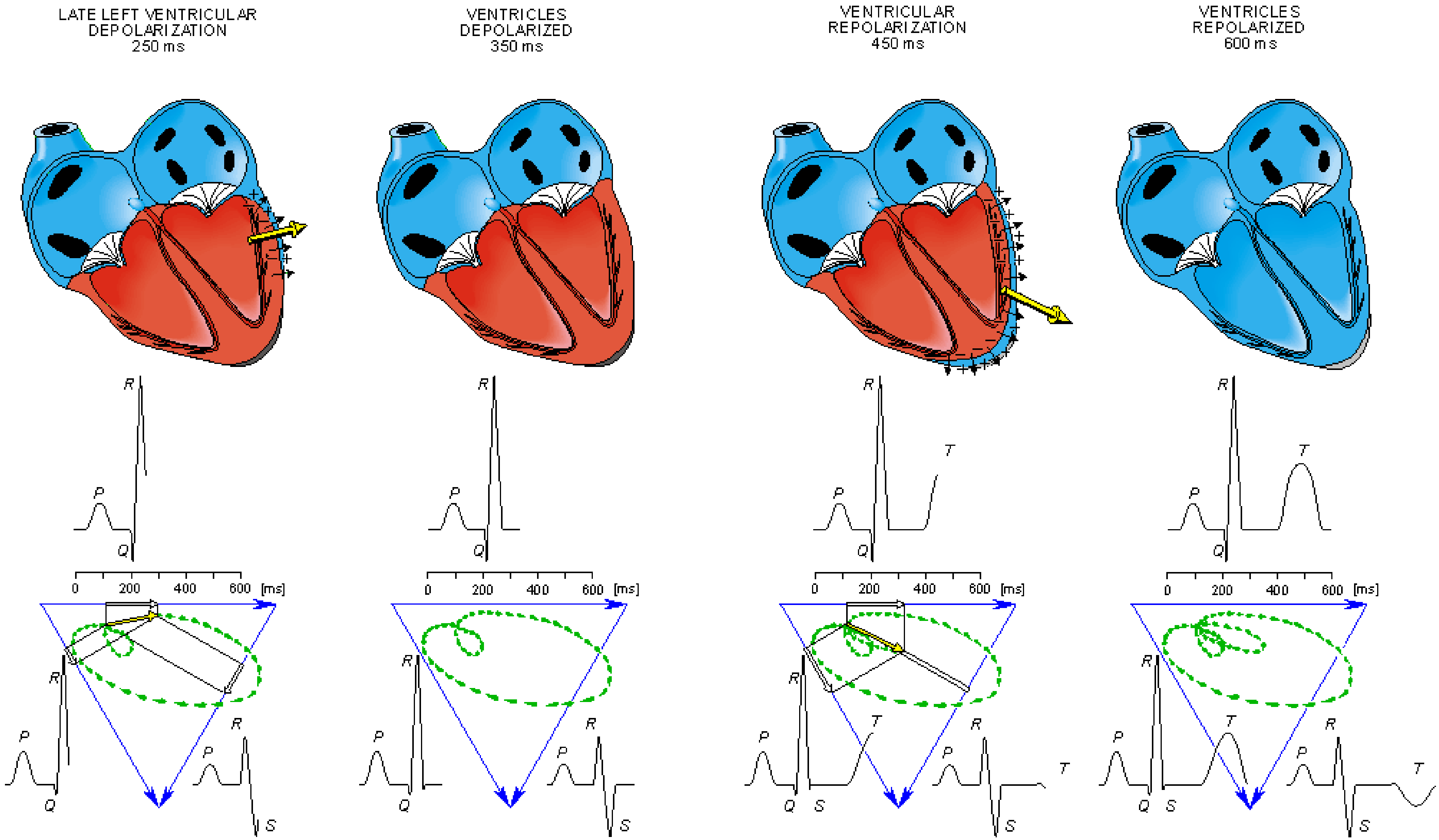
ECG Vector Potential



Source: http://www.bem.fi/book/15/15x/animati/000.htm

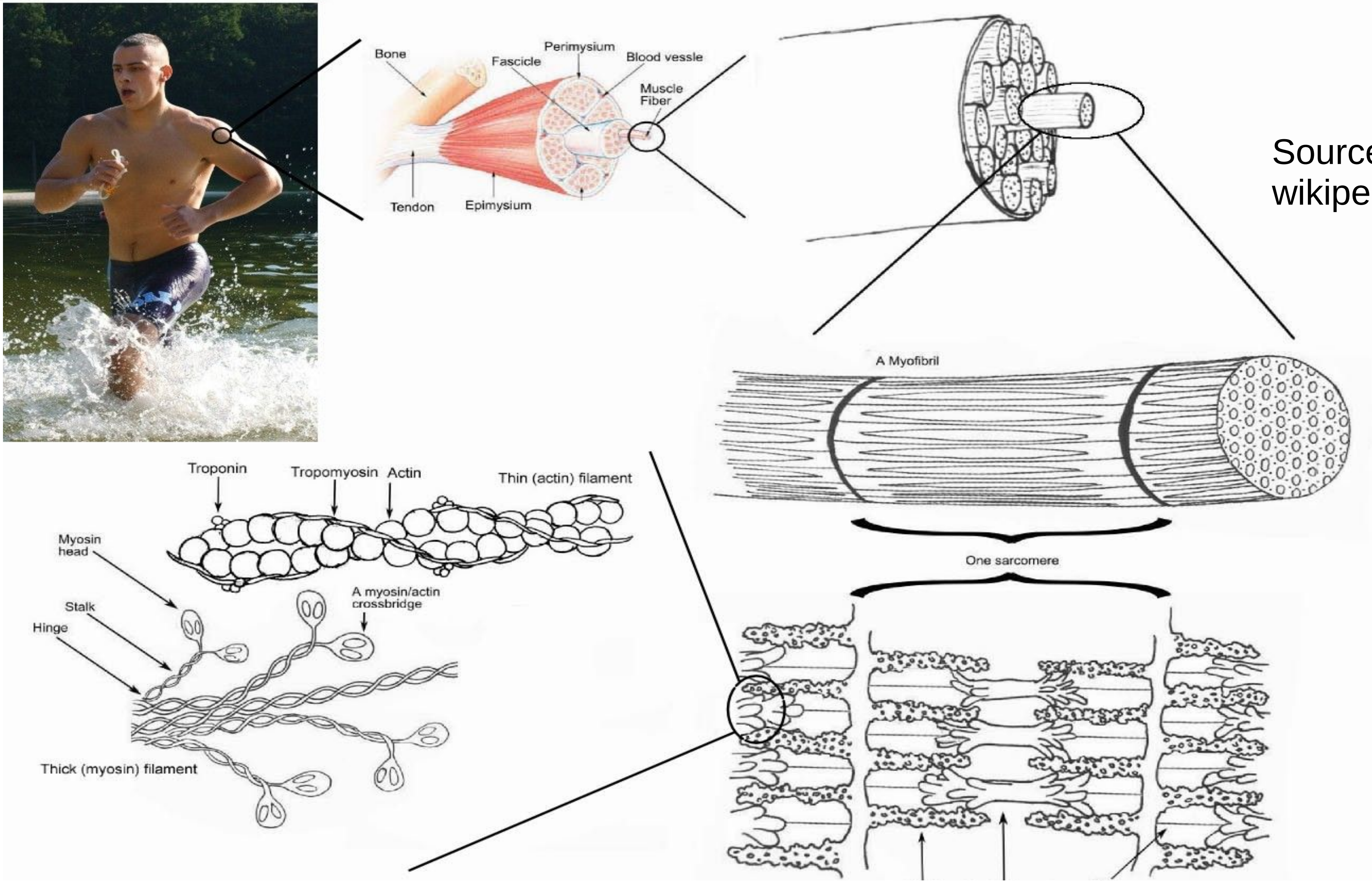
Questions

- Draw a heart, and label the important electrical and mechanical structures (nodes, chambers, arteries ...).
- What is the function of the SA-node?
- What is the function of the AV-node?
- In what way is the ECG a vector field?
- Indicate the electrode locations for the three lead ECG.
- Draw the electrode configuration on Einthoven's Triangle and explain the mathematical relationship between the electrodes.

Electro-Myogram (EMG)

- *Skeletal* (voluntary muscle) is anchored by tendons to bones. Fast response. Fatigues with load.
- *Smooth* (involuntary muscle) is found within the walls of organs and structures (e.g.: esophagus, stomach, intestines, bronchi, uterus, urethra, bladder, blood vessels, and skin). Slow response. Can maintain continuous force.
- *Cardiac muscle* is found in heart. An involuntary muscle but is similar to skeletal muscle. Fast response, but does not fatigue easily.
- Myoelectric (Myo = muscle) signals are the signals captured in the EMG (electromyogram). A voluntary (or induced contraction) creates an electrical signal composed of the action potentials travelling across the muscle fibers

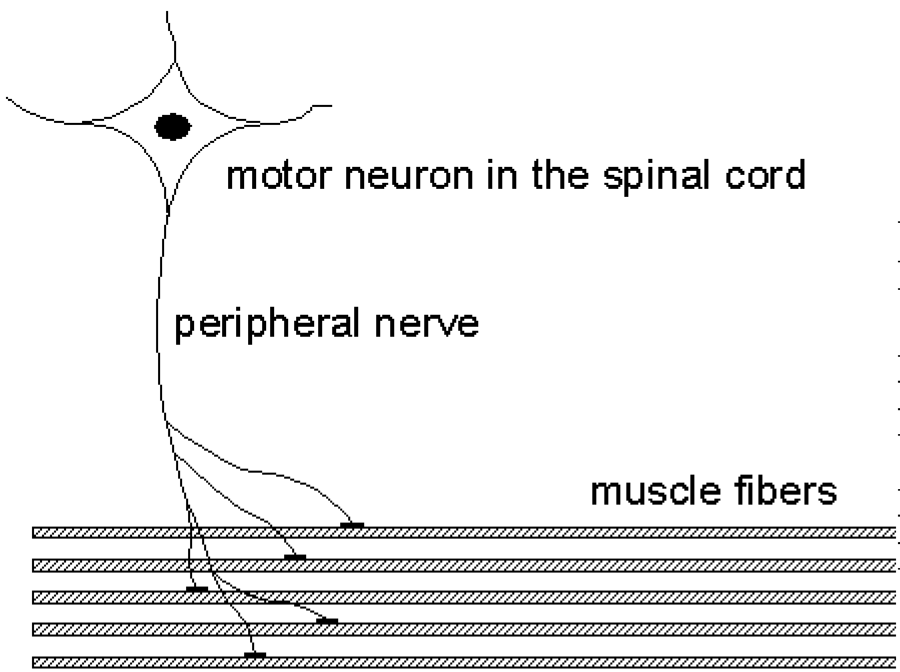
Anatomy of Muscles



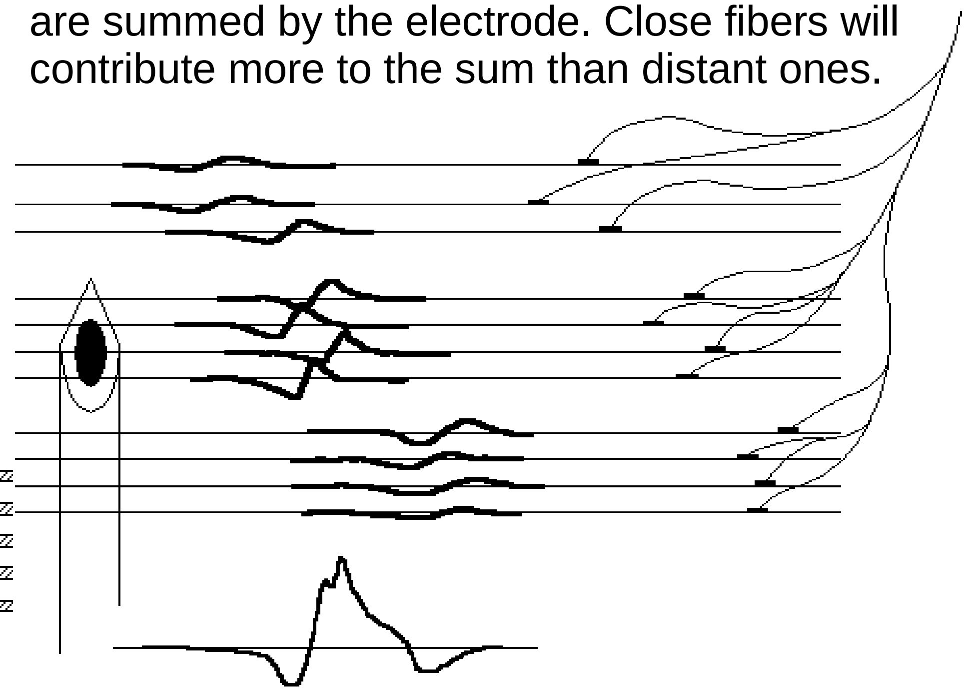
Source: wikipedia

Activation of Muscles

- Each somatic (voluntary) neuron activates a group of muscle fibres.
- *Motor Unit*: one somatic neuron and the group of fibres it activates
- Every action potential initiated by a particular somatic neuron creates a motor unit action potential (MUAP), and for the same somatic neuron, all its MUAPs will look the same.



The SFAPs propagate along the muscle fibers and are summed by the electrode. Close fibers will contribute more to the sum than distant ones.



Source: signal.uu.se

Muscle Recruitment

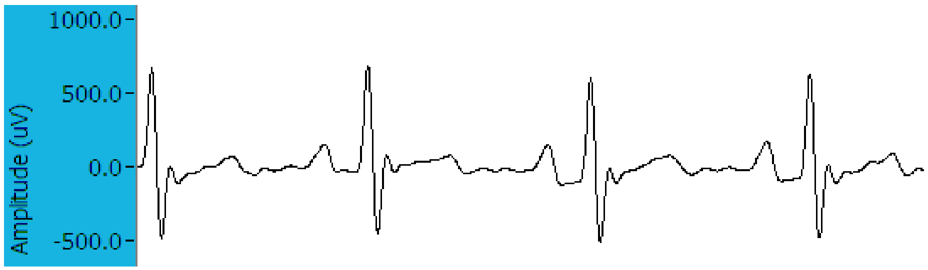
To increase the contraction strength:

1. Increase the firing rate of MUs (temporal recruiting)
2. Activate more MUs (spatial recruiting)

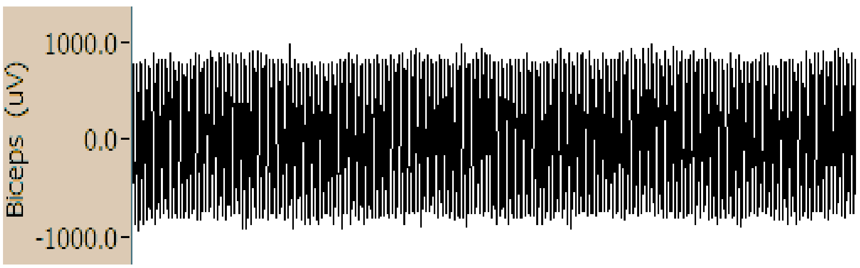
- Large muscle: 100s of fibres/nerve
- Small muscle: 10s of fibres/nerve (fine motor control comes from here)
- at max rate, MUAPs fuse together to form tetanus.

Questions

- What is a motor unit? What is a muscle fibre?
- Explain the difference between spatial and temporal recruitment
- The normal ECG 'always' has the same structured shape and is easily recognizable, why is this not true of the EMG?



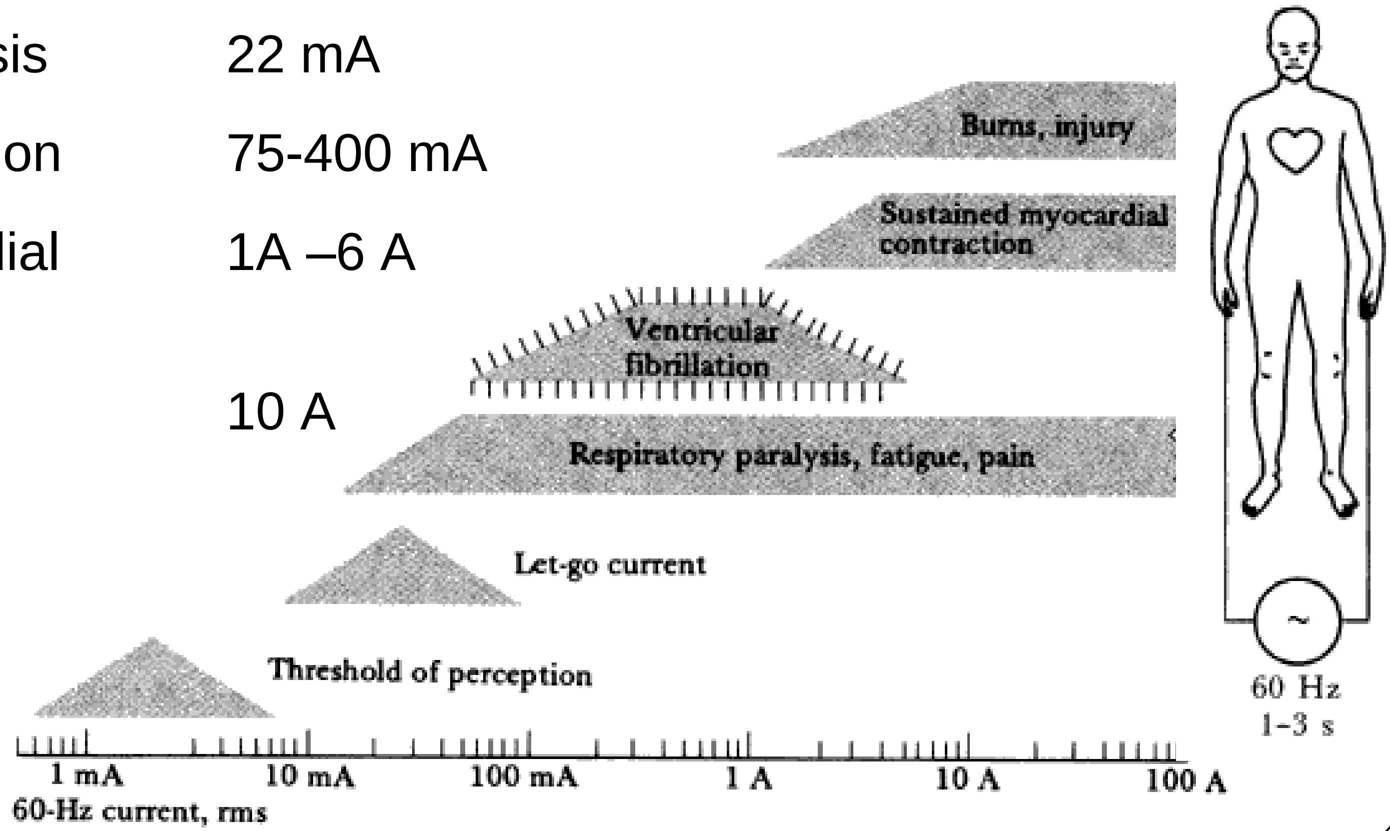
Vs



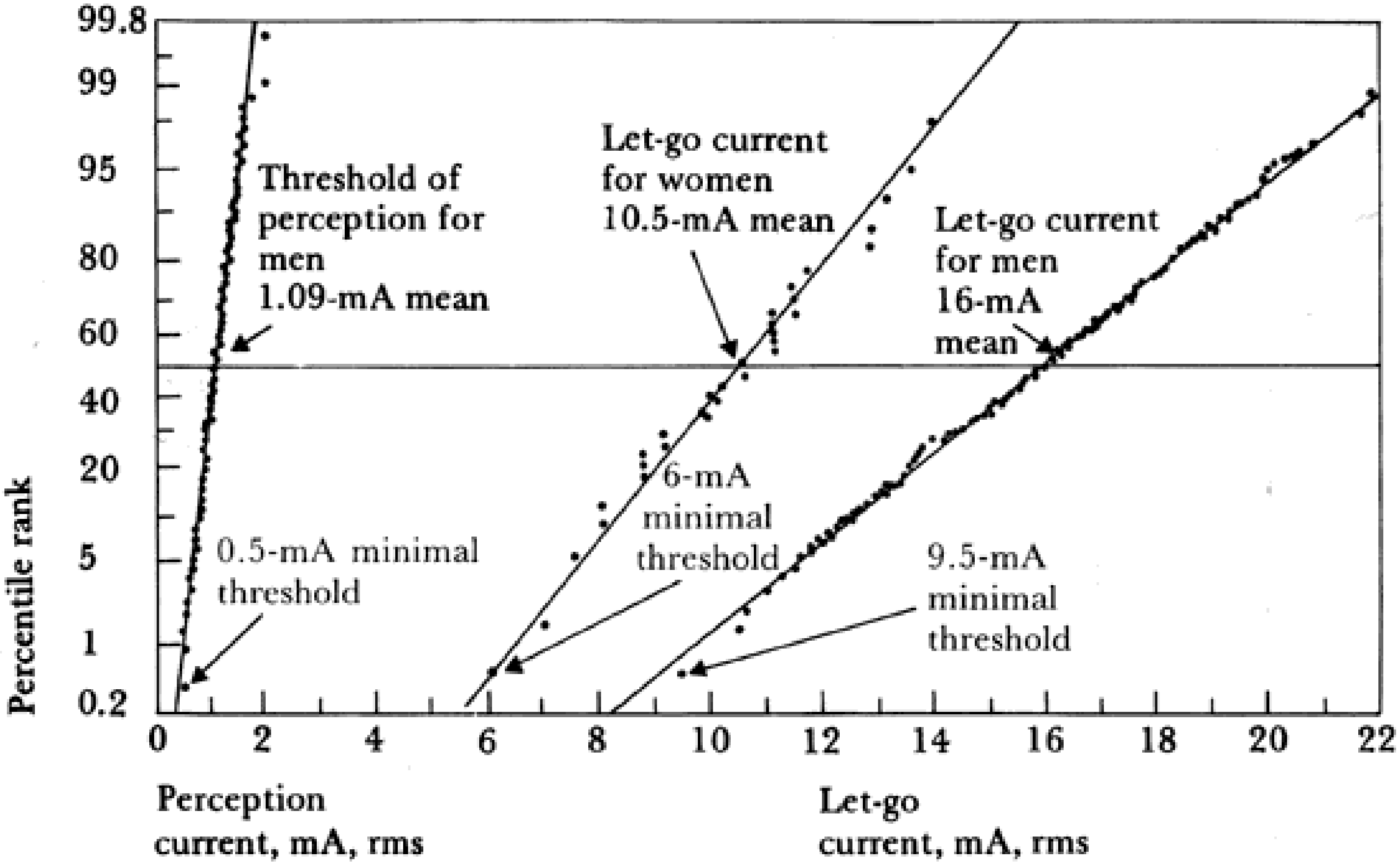
Physiological Effects of Electricity

- Threshold of perception 1 mA
- Let go current 6 mA
  - Maximum current allowing voluntary release
- Respiratory paralysis 22 mA
- Ventricular Fibrillation 75-400 mA
- Sustained Myocardial contraction 1A –6 A
- Burns 10 A
  - Usually on skin (from high skin resistance)

Threshold or estimated mean values are given for each effect in a 70 kg human for a 1 to 3 s exposure to 60 Hz current applied via copper wires grasped by the hands.



Variation among individuals

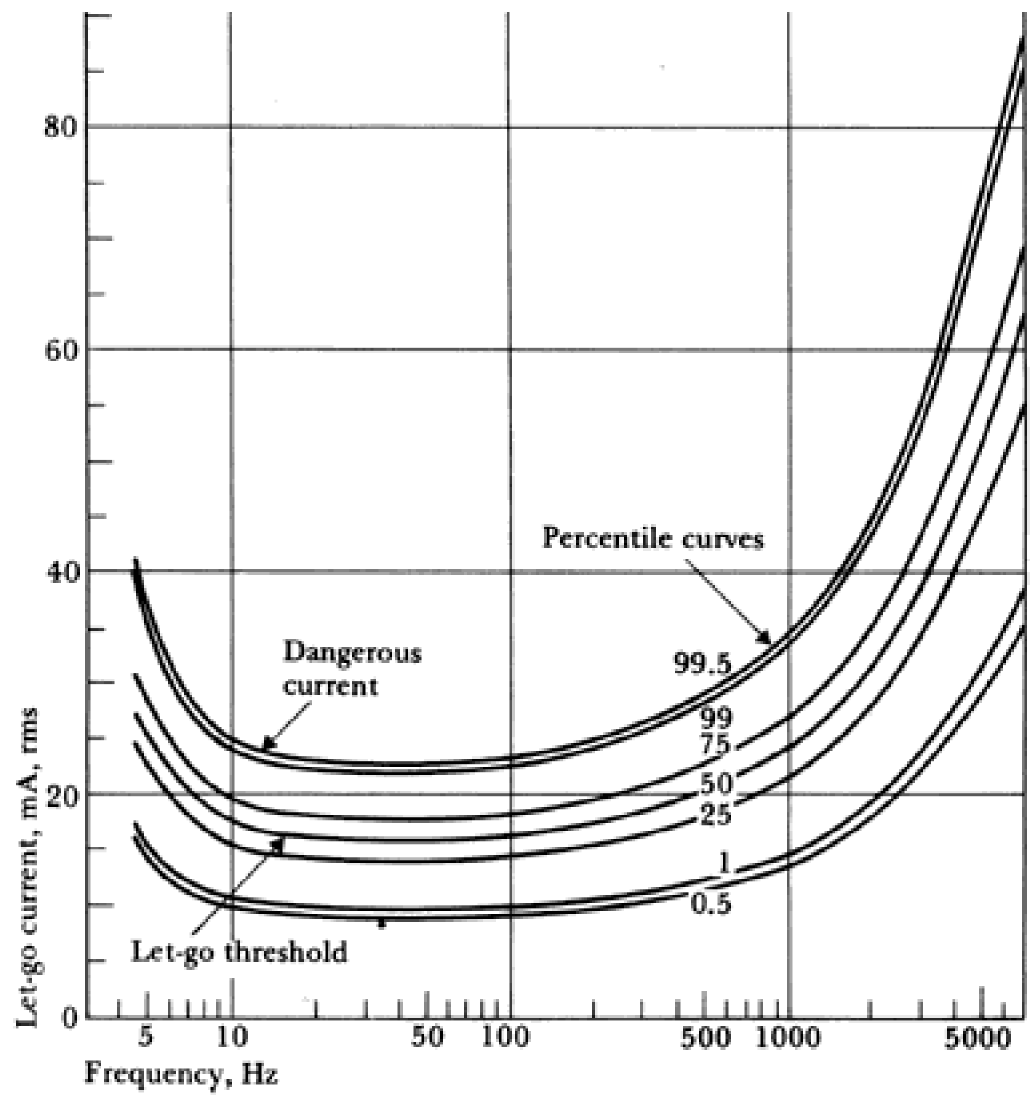


- Body Weight – thresholds are roughly proportional
- Points of entry – affected by the current path (and amount of I going through heart)

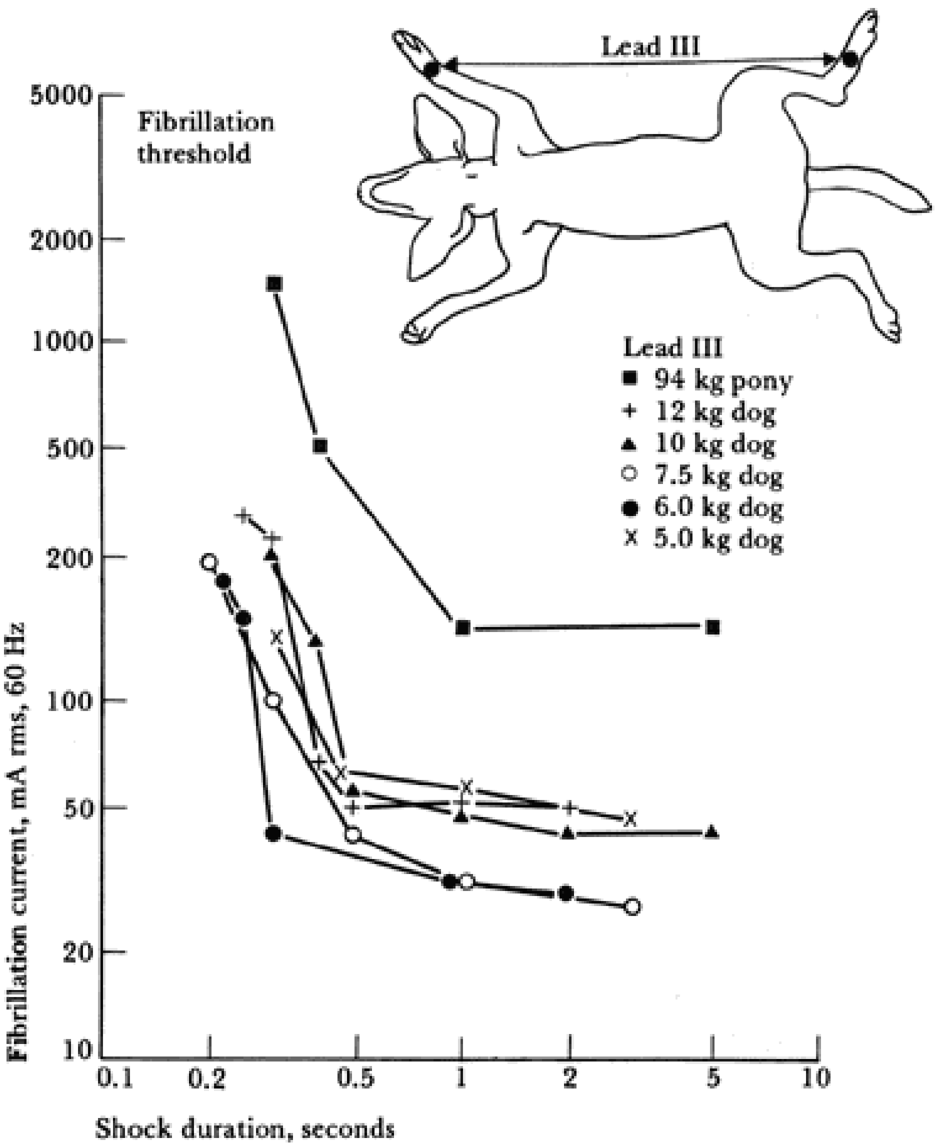
Variation with frequency

Let-go current versus frequency. Percentile values indicate variability of let-go current among individuals. Let-go currents for women are about two-thirds the values for men. (Dalziel (1973) "Electric Shock")

Maximum is around 50-60Hz



Strength vs. Duration



A smaller current for a longer time can have the same effect as a larger, shorter one

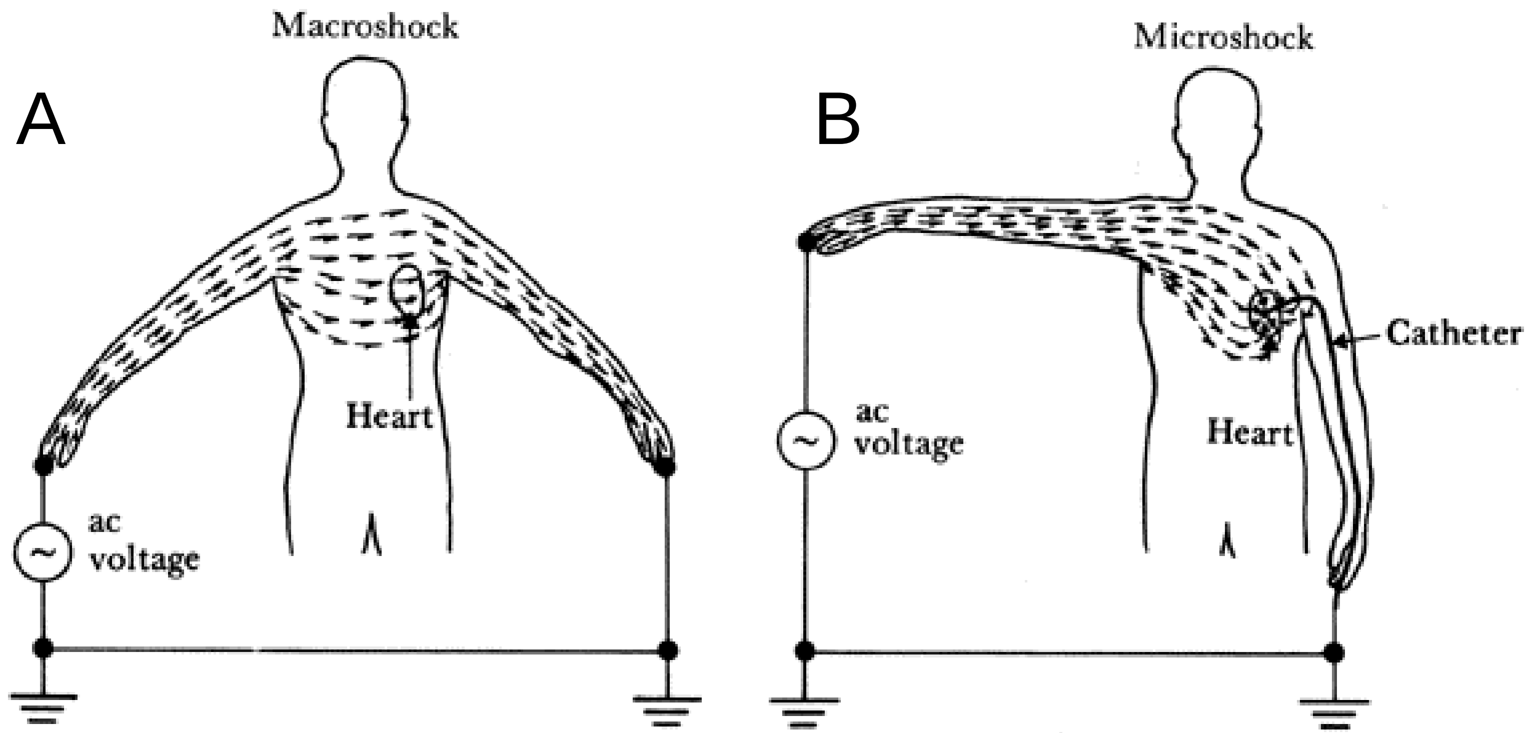
(above a threshol)

Fibrillation current versus shock duration. Thresholds for ventricular fibrillation in animals for 60 Hz AC current. Duration of current (0.2 to 5 s) and weight of animal body were varied. (Geddes, 1973)

Questions

- What happens at the threshold of perception?
- Why is threshold for ventricular fibrillation so much lower than for sustained myocardial contraction?
- The Let-go current for men is larger than for women. What does this say about men and women☺?
- Why is threshold higher for larger people?
- What is the threshold of pain?

Macroshock / Microshock



Effect of entry points on current distribution (a) *Macroshock*, externally applied current spreads throughout the body. (b) *Microshock*, all the current applied through an intracardiac catheter flows through the heart. (From Weibell, 1974 "Electrical Safety in the Hospital")

Macroshock

Macroshock

- Shock from electrical connections on the skin.
- Worrisome current levels are > 1mA (depending on frequency).
- Typically due to an electrical fault, circuit flaw
- Any effect/device that reduces resistance of skin is a potential hazard (Skin resistance is 15kΩ - 1MΩ, internal resistance is lower ≈100 Ω)
- Skin resistance varies with
  - Injury
  - Water (wet)
  - Oil

Microshock

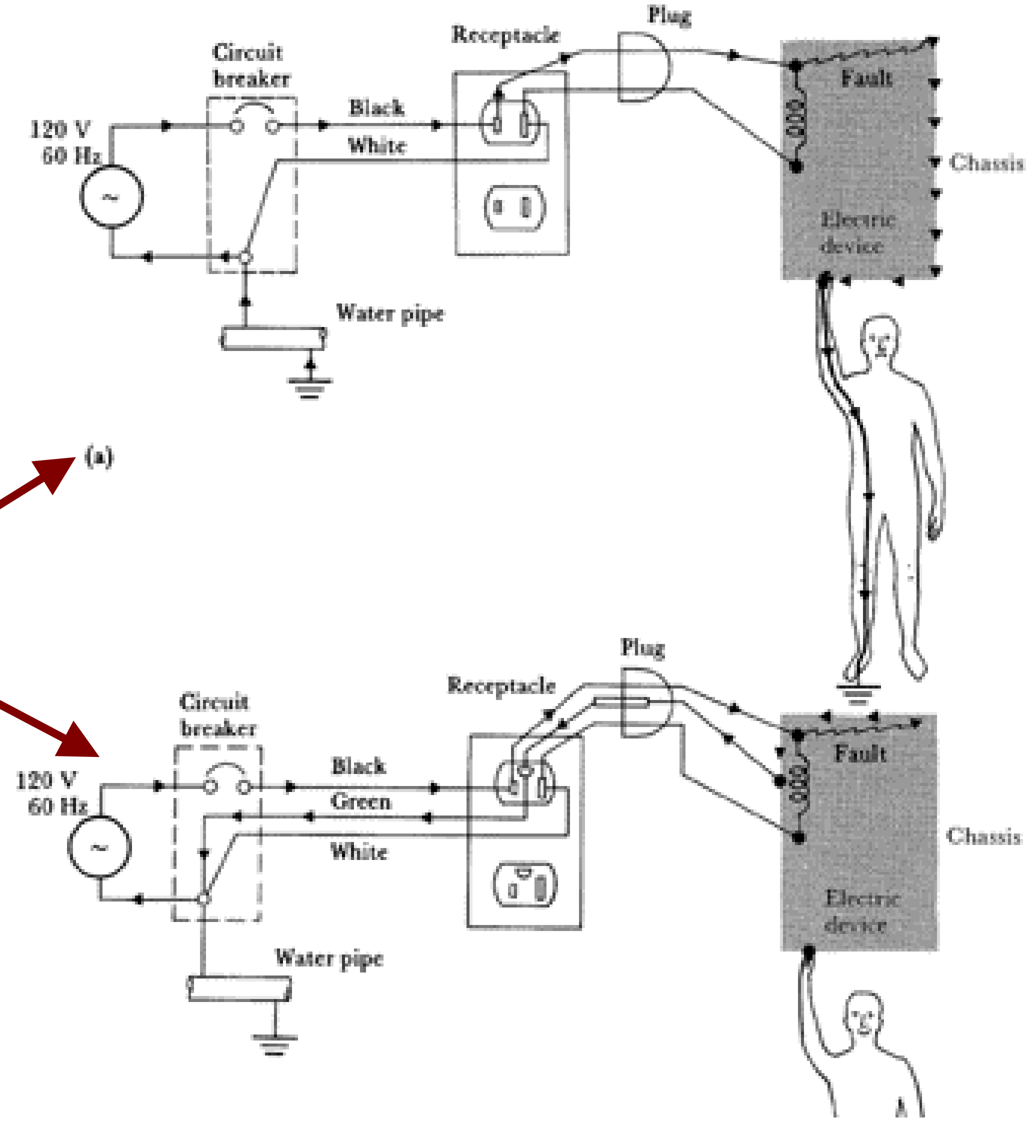
Microshock

- Shock from connections on / near the heart
- Much smaller currents are dangerous. Even a few μA directly to heart is dangerous
- Microshock hazard is due to leakage current in designs
- Hazard from
  - Cardiac catheter
  - IV lines with instruments
  - Cardiac electrodes
  - Pacemakers

Macroshock & Protection

Macroshock due to a ground fault from hot line to equipment cases for

- ungrounded cases
- grounded chassis.



Shock prevention

Protection strategies for shock

- Reliable grounding
- Double-insulated equipment
- Isolation in design
  - Isolation transformers
  - Isolation amplifiers
    - Optoisolators, Capacitive/Transformer isolation
  - Low voltage design/operation
  - Low leakage current design

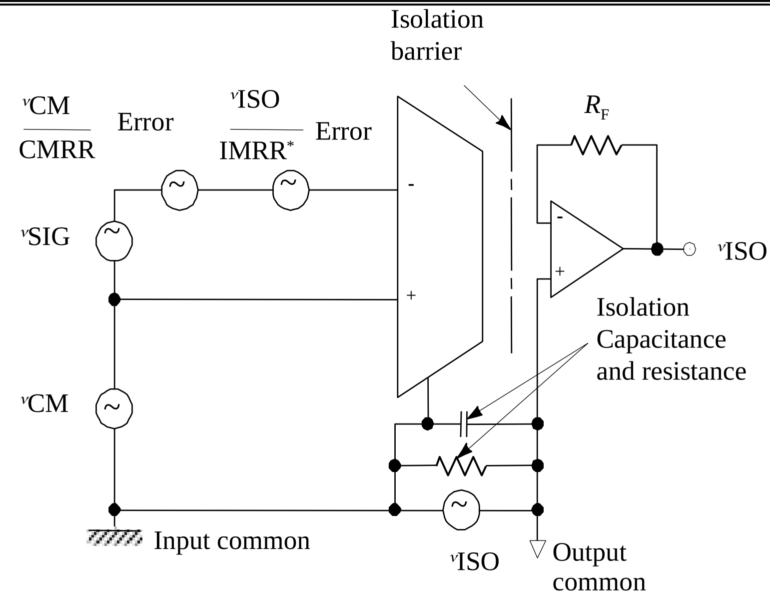
Isolation

- Isolation amplifiers:
  - break ground loops,
  - eliminate source ground connections,
  - isolation protection to patient and equipment
- Isolation amplifiers technologies:
  - transformer isolation,
  - capacitor isolation
  - opto-isolation.

Nagel, J. H. “Biopotential Amplifiers.”
The Biomedical Engineering Handbook: Second Edition

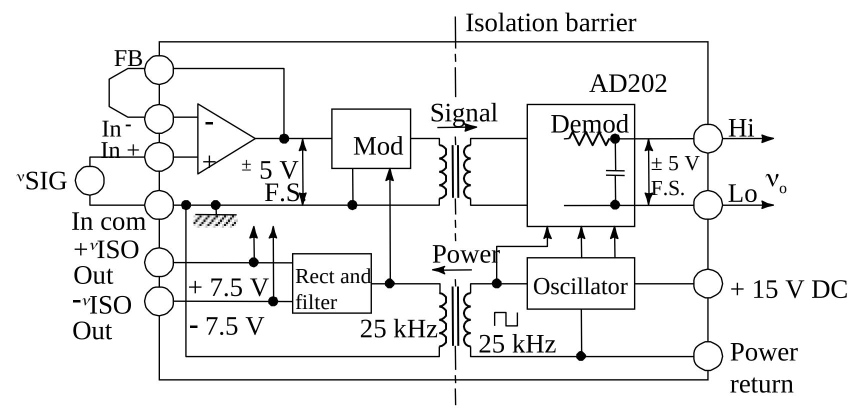
Electrical Isolation Isolation amplifiers

General model for an isolation amplifier



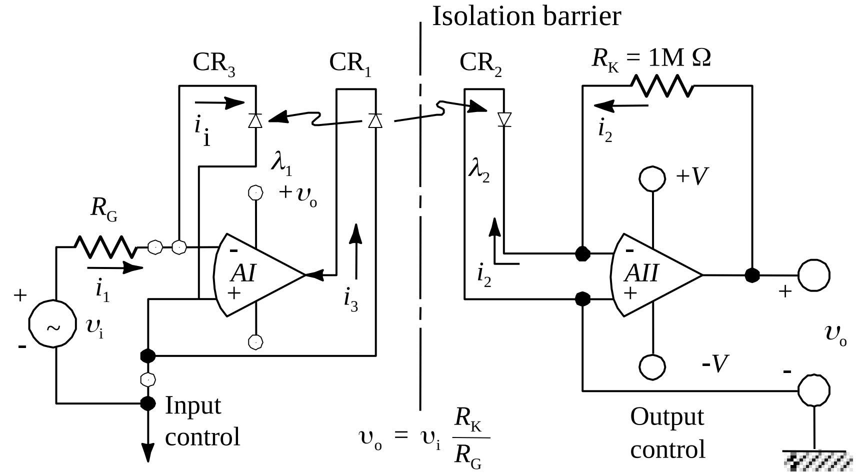
(a)

Transformer isolation amplifier (Analog Devices, Inc., AD202).

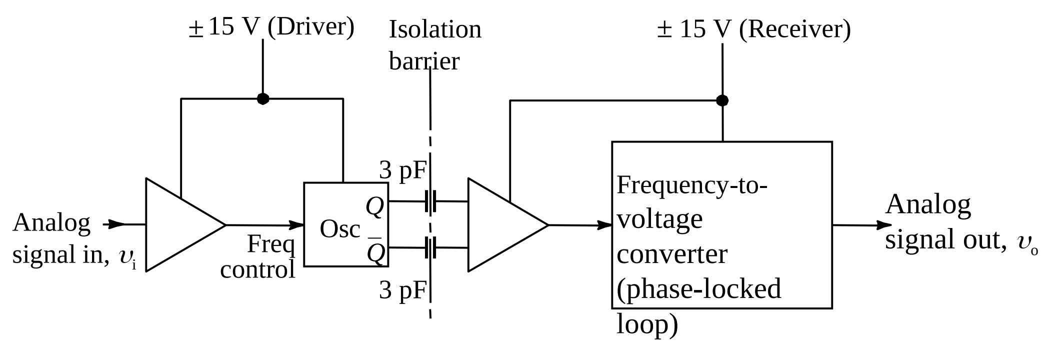


Electrical Isolation

- Simplified equivalent circuit for an optical isolator



- Capacitively coupled isolation amplifier

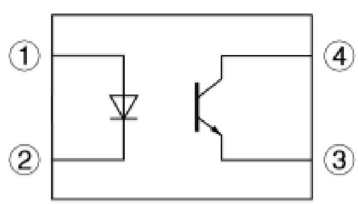


Optocoupler

- Optocoupler
- www.sharp-world.com/products/device/lineup/data/pdf/datasheet/PC1231xNSZ1B_e.pdf

SHARP **PC1231xNSZ0F Series**

■ **Internal Connection Diagram**



① Anode
② Cathode
③ Emitter
④ Collector

This course

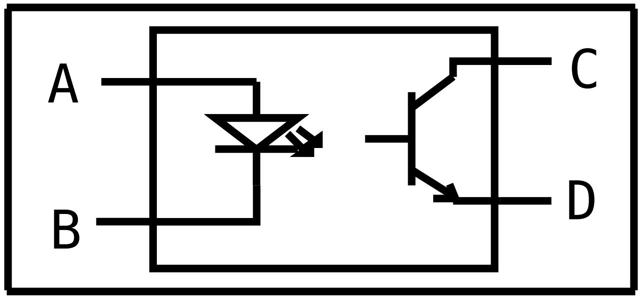
- Practically, we need guidelines for projects
- I want to say “I told you so” if I have to visit you in hospital ☺ .
- Rules
  - In IV instruments for projects
  - For student’s research building own circuits
    - Use batteries instead of plugging in.

Questions

- Why are isolation amplifiers required for biomedical designs?
- Name some isolation techniques used to design isolation amplifiers?
- What is the difference between *macro*shock and *micro*shock?
- Imagine you're listening to a radio in the bath and you drop it in. How does the third ground wire help protect you? Draw the current pathways.

Q1 from 2015 Midterm

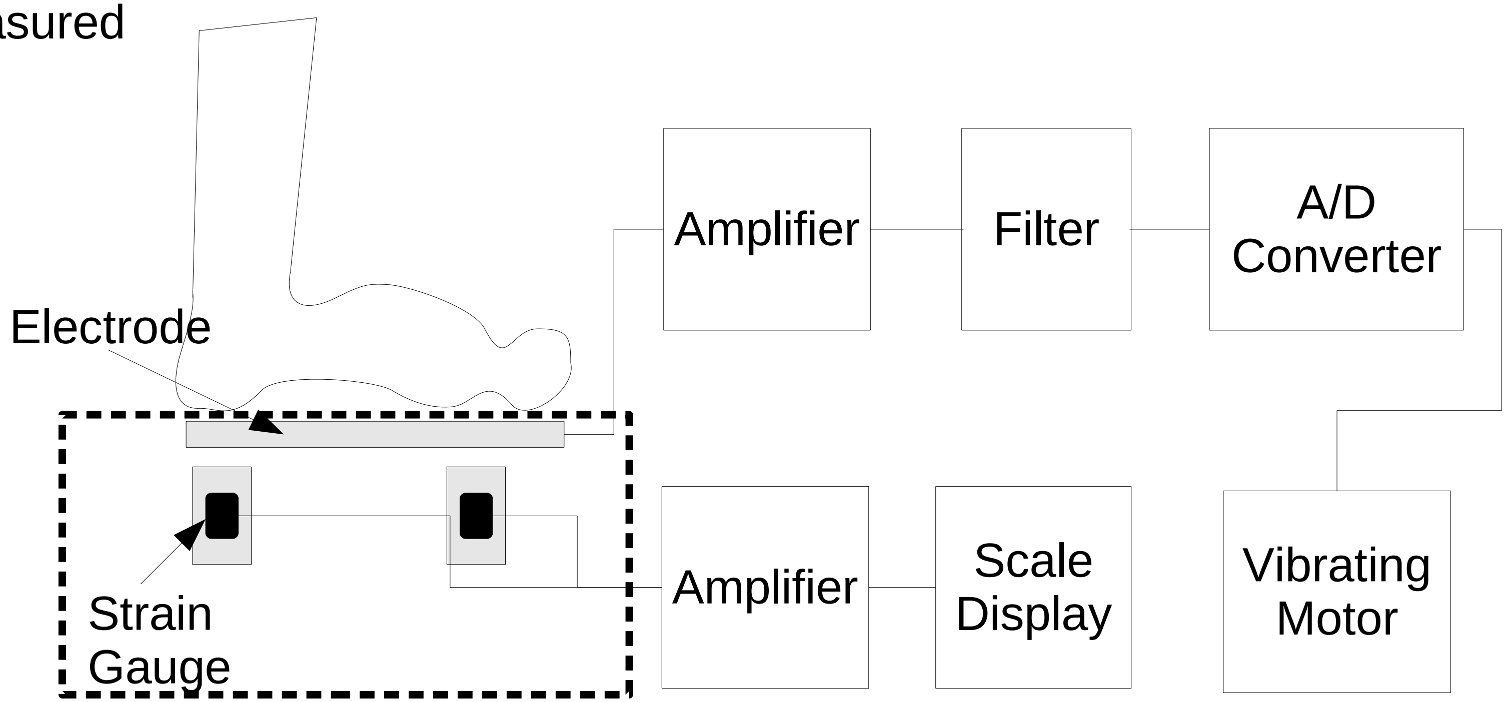
(Electrical Safety) Electrical safety is obviously an important factor in biomedical electronics. In class we studied the optoisolator



- (a) Define the terms “let-go current” and “threshold of perception”, and explain the difference between them.
- (b) The optoisolator above has an isolation voltage of 6.2 kV. Unfortunately, lightening strikes the circuit, applying 500 kV to terminal C, while terminal D is at ground. The terminals A and B are connected to a circuit which is connected to the patient. Where does (and doesn’t) the current flow?
- (c) In the previous question, explain whether the patient is protected

Q1 from 2015 final

- Background: As you know, health and weight loss products sell!
- After graduation, your first job asks you to design a bathroom scale which also measures heart rate, and gives feedback via a vibrating motor.
- As shown in the diagram below, the customer will stand on the scale. Their weight will deform strain gauges attached to two internal posts; this signal drives a dial. At the same time, stainless steel electrodes touch their feet from which their ECG is measured



Q1 from 2015 final

1. (30 points) Electrodes and Electrical Safety

- (a) ...
- (b) What kind of shock risk is possible in this design? Sketch current pathways in the body and indicate if they can travel through the heart.
- (c) In a bathroom, there is an obvious risk: the electronics can get wet. What risk does this pose for the user? Describe one electrical isolation technology that can protect against this risk.