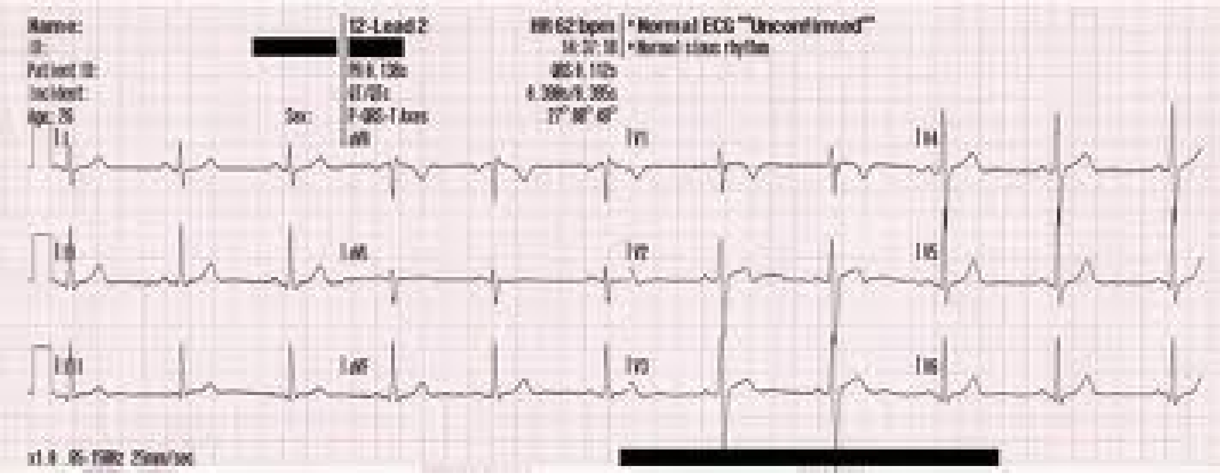
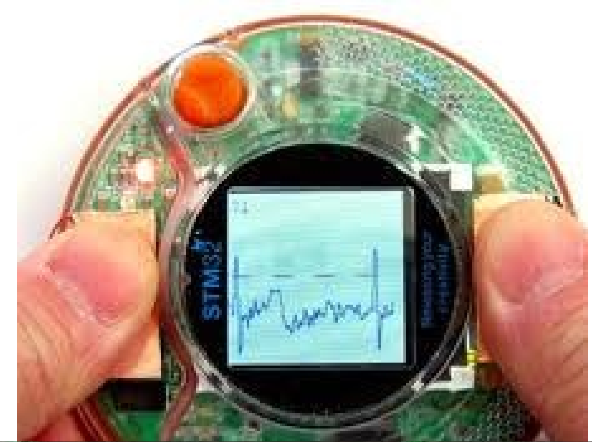


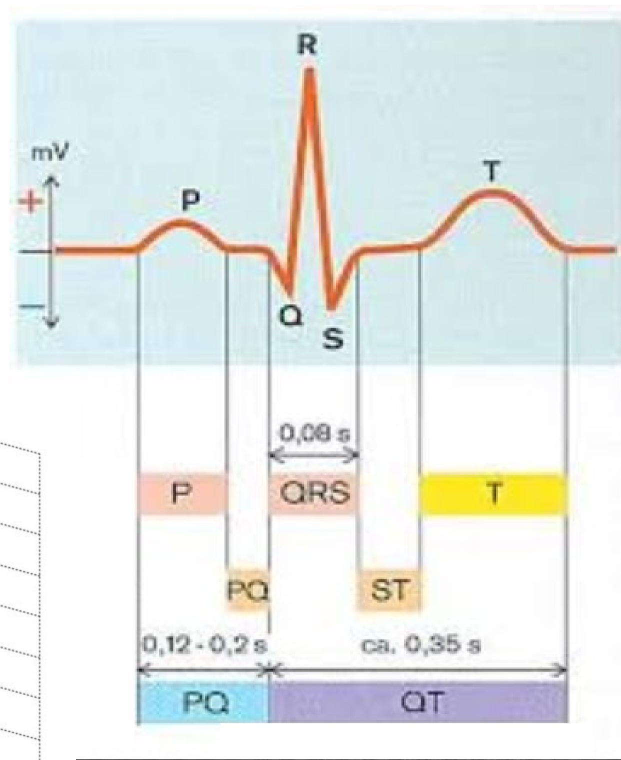




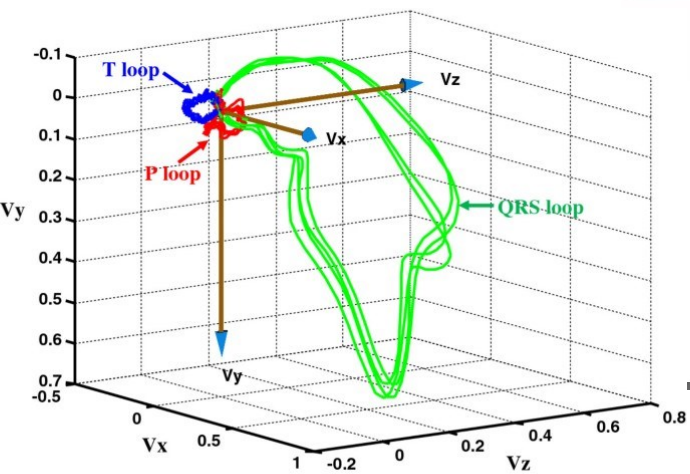
# Electrocardiography, Pacemaker



Schay G.

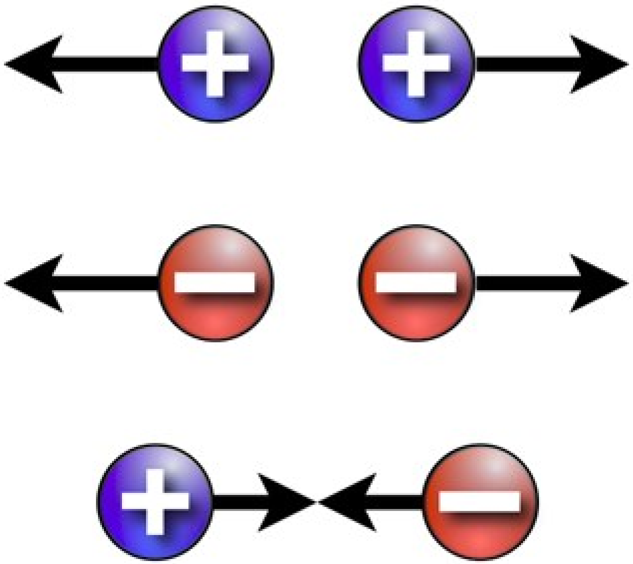


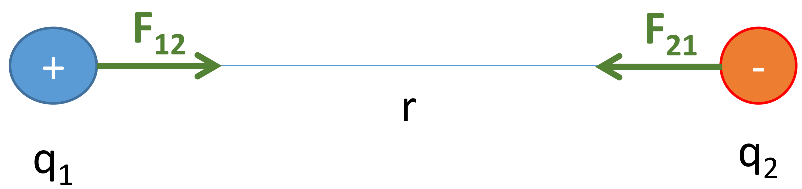


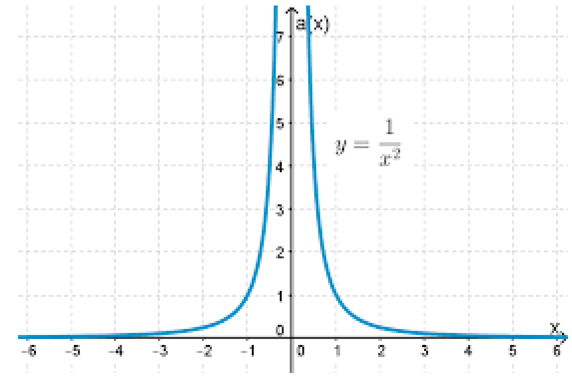




electro - cardiography






magnitude: $F_{12}=F_{21}$ $$F = k\frac{q_1 q_2}{r^2}$$

just like gravity, we have **1/squared relationship**

there exists a minimal, elementary charge: $e = 1{,}6 \cdot 10^{-19}\mathrm{C}$

charge only appears bound to material

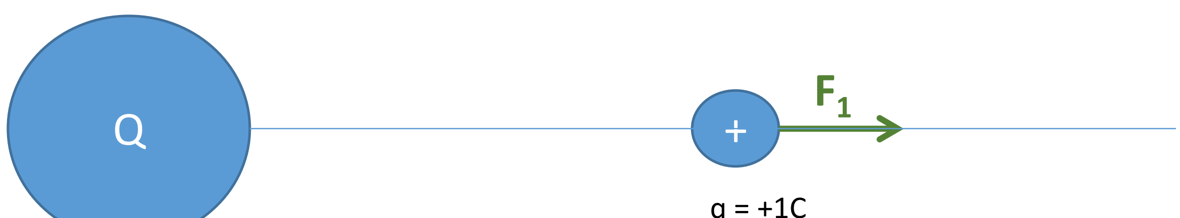
$$k_e = \frac{1}{4\pi\varepsilon_0} = \frac{c_0^2\mu_0}{4\pi} = c_0^2 \times 10^{-7}\ \mathrm{H \cdot m^{-1}}$$
$$= 8.987\,551\,787\,368\,176\,4 \times 10^9\ \mathrm{N \cdot m^2 \cdot C^{-2}}$$

what “conveys” the force?

electric **FIELD**

the **electric field strength** is the force acting on a +1C probe.

**E**

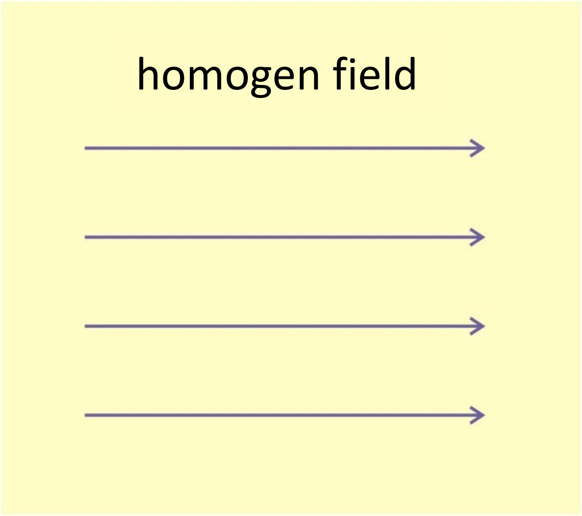


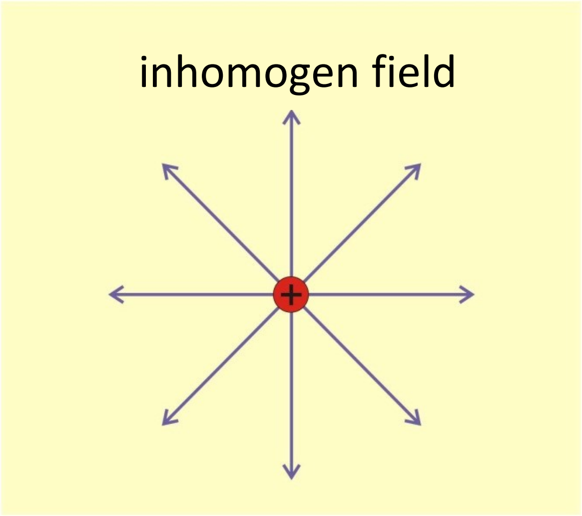

F=q*E

and E=k*Q/r$^2$

unit: [F]/[q] = N/C

**FIELD LINES are always parallel to the direction of the coulomb's force**.




magnitude of the force is proportional to the field-line DENSITY (Flux)

## work in electric field:

$W=\vec{F}*\vec{s}$, but is a scalar product

but $F=q*E$

so

$W=q*E*s$

**ELECTRIC POTENTIAL**: $W=q*\Delta\phi$

( just like in gravity field: $E_{pot}=mgh$)

so $\phi = E*s$, we need a 0 point.

**Legyen $\phi$ =0 at infinitely far away**

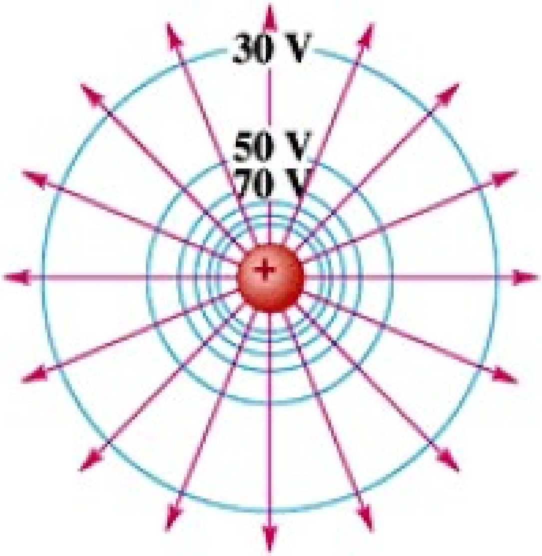
on a closed loop the work is zero, the E is a conservative field.

**$U= \Delta\phi$, ELECTRIC VOLTAGE, unit: [W]/[q] = J/C = Volt [V].**

thus **$W=q*U$**

Field lines

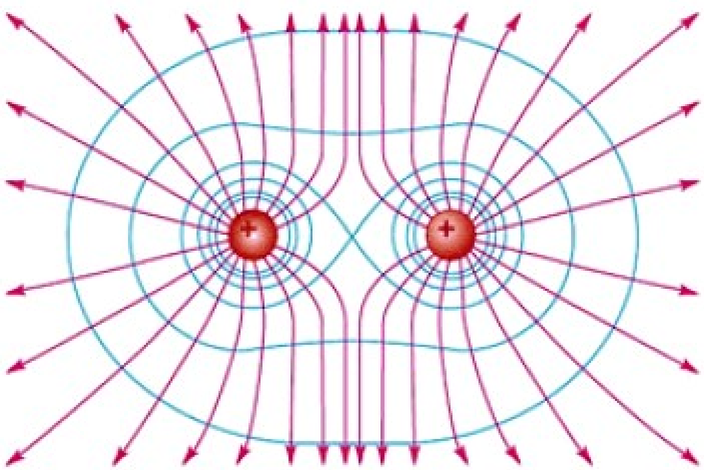
equipotential lines

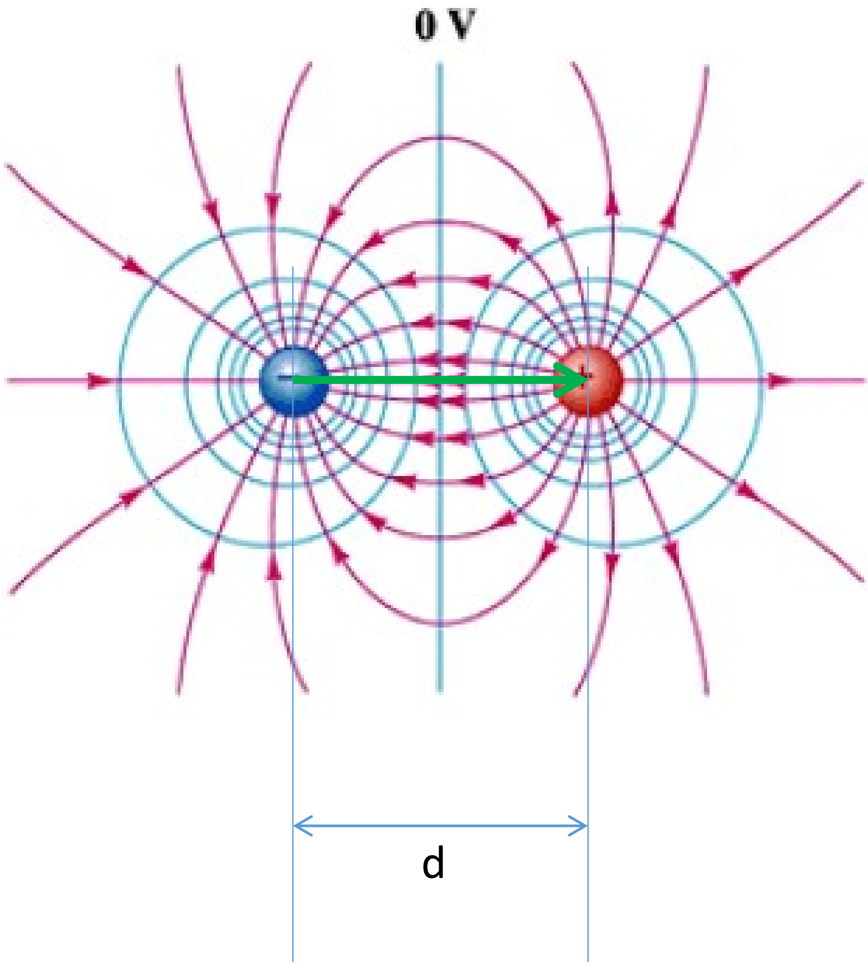



MONOPOLE: 1 charge

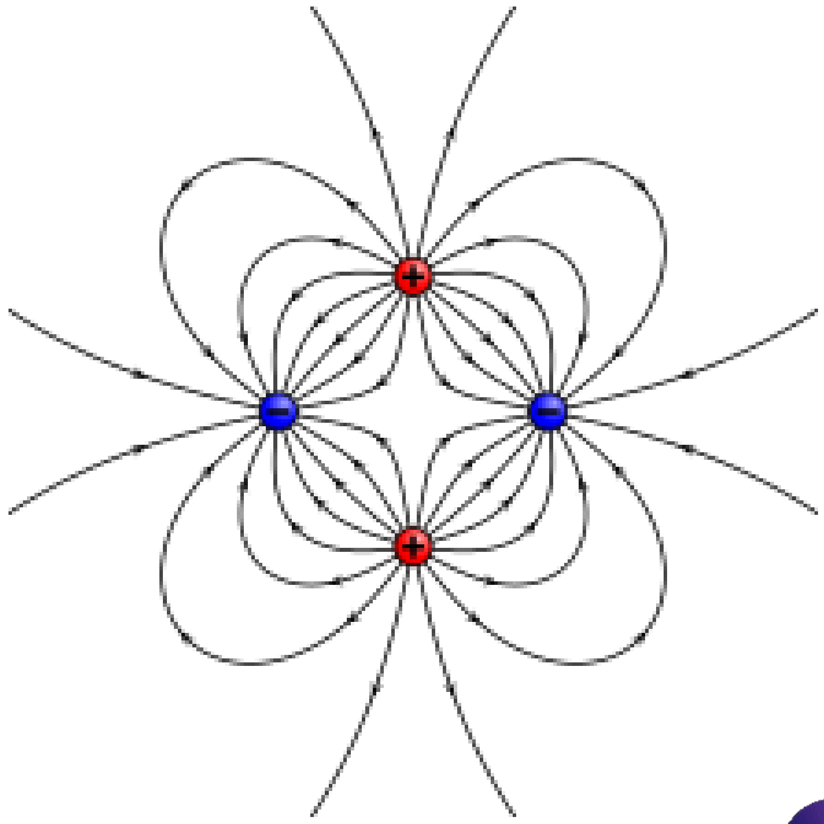
DIPOLE

dipole vectorm: **p**=q***d**
(**vector**)

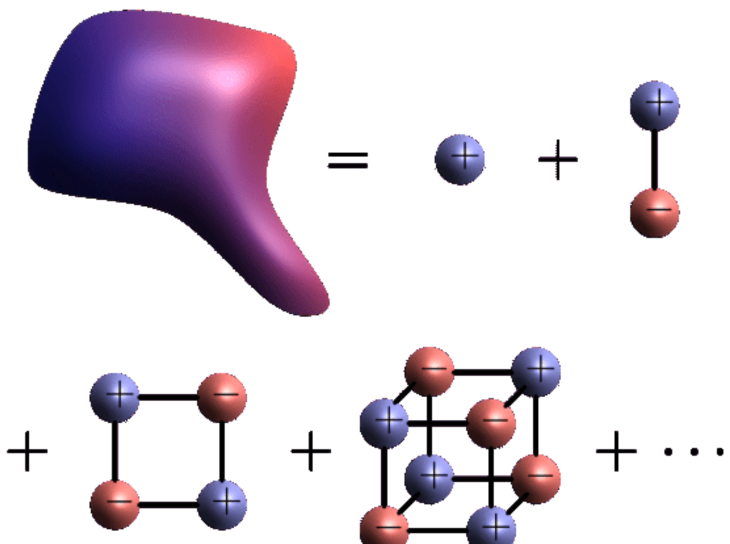




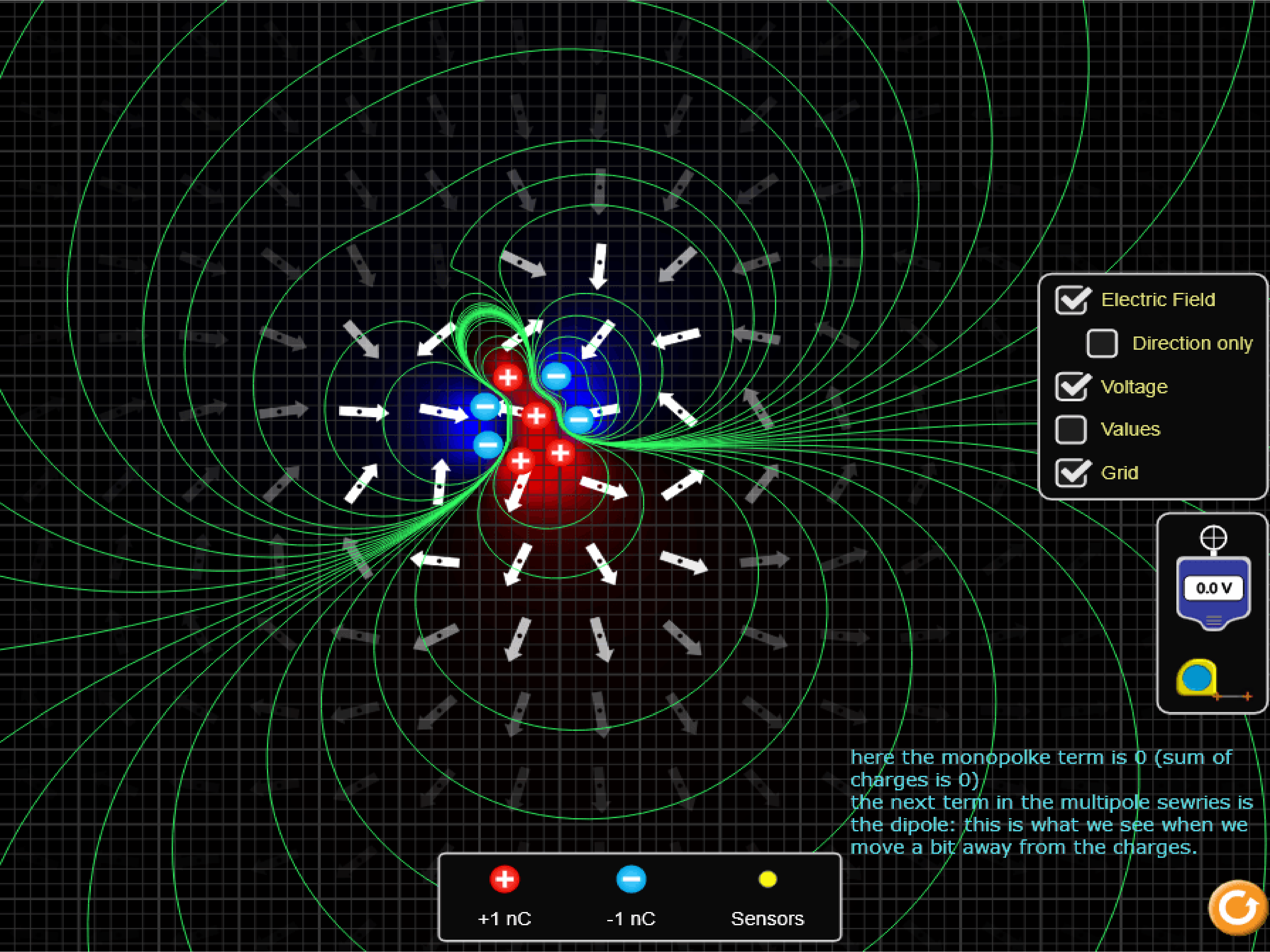
Quadrupole…

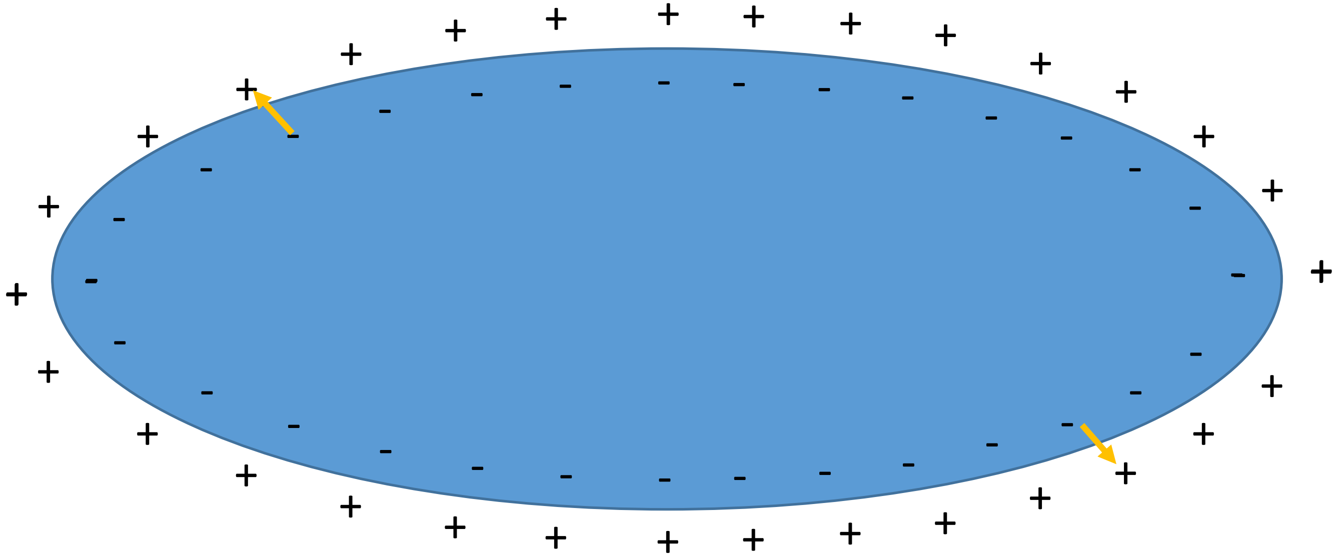


Multipole series expansion

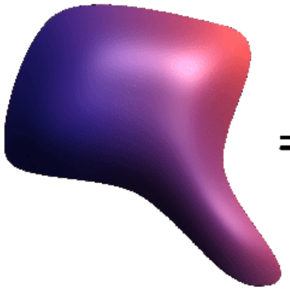


https://www.physics.uoguelph.ca/chapter-3-legendre-polynomials

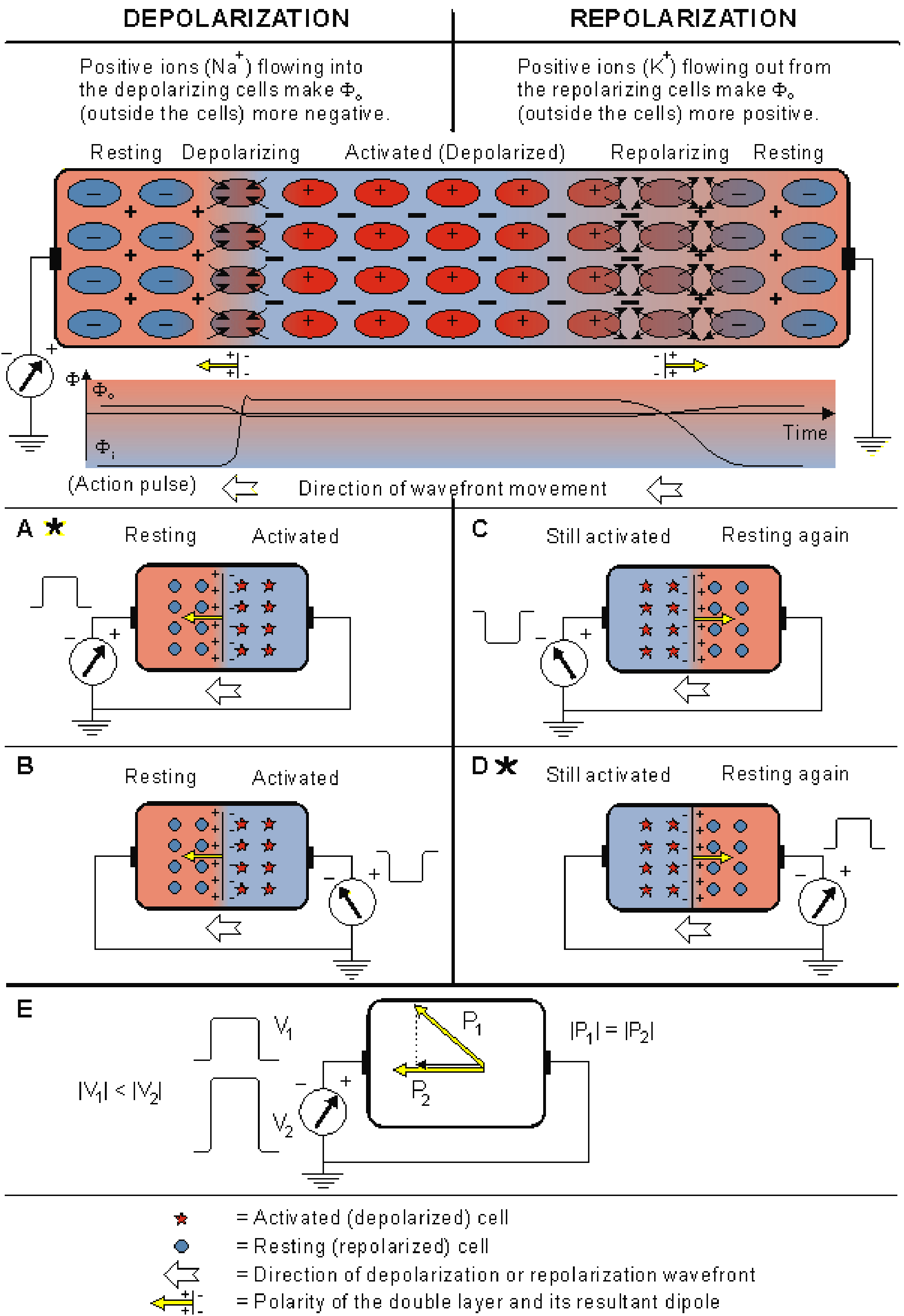

Electric Field
Direction only
Voltage
Values
Grid
0.0 V
here the monopolke term is 0 (sum of charges is 0)
the next term in the multipole sewries is the dipole: this is what we see when we move a bit away from the charges.
+1 nC
-1 nC
Sensors

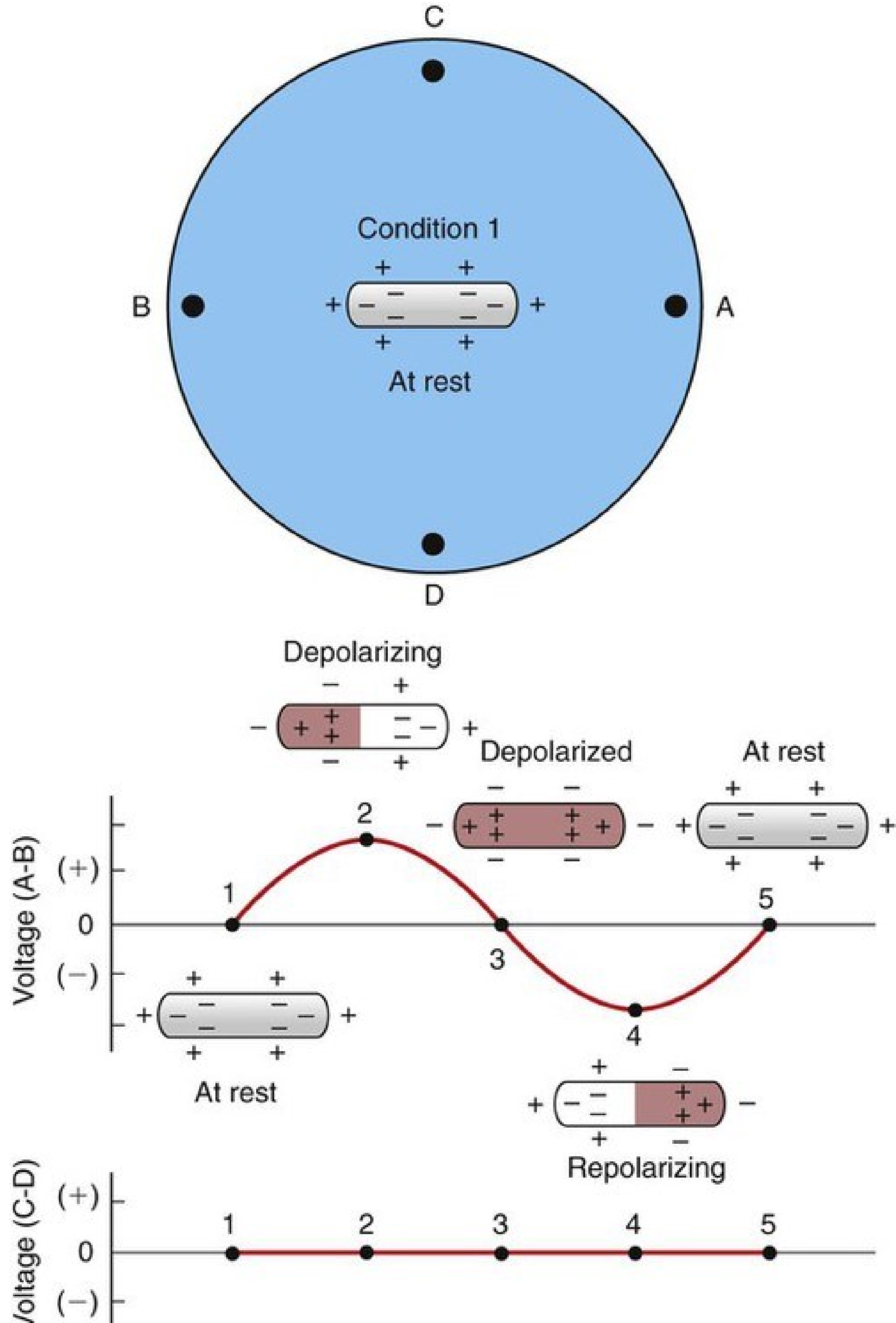


resting state or fully depolarized cells have 0 dipole.



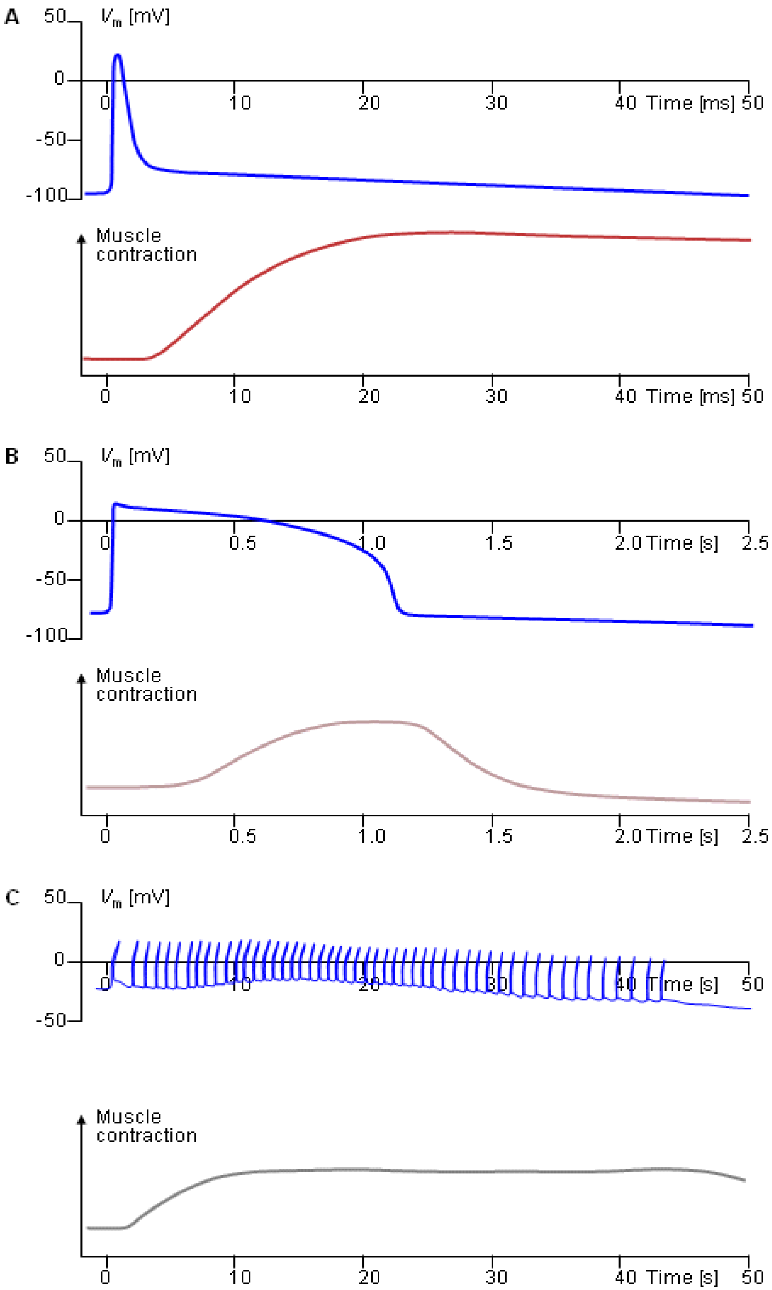
the monopole term is 0

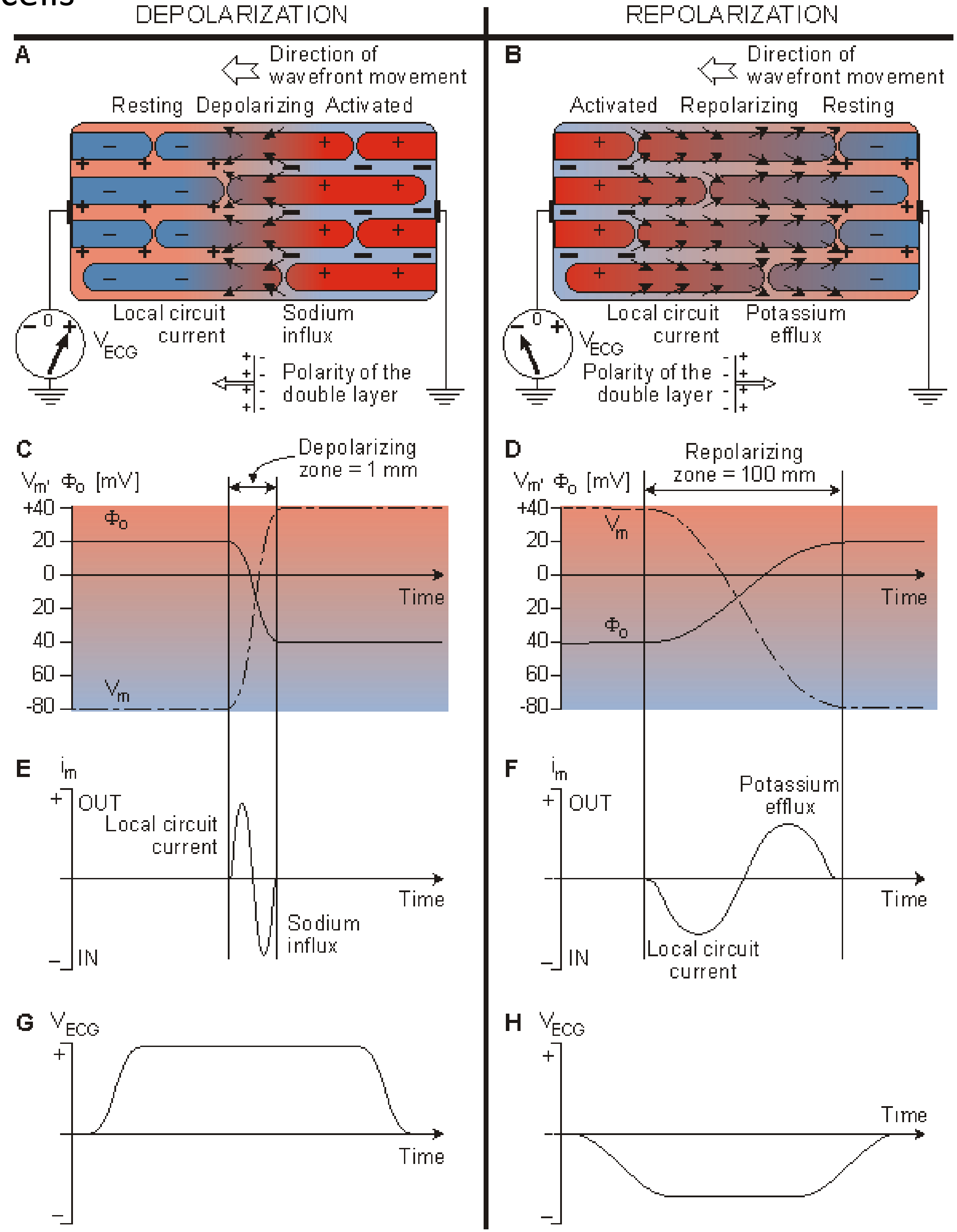

DEPOLARIZATION
REPOLARIZATION
Positive ions (Na+) flowing into the depolarizing cells make Φo (outside the cells) more negative.
Positive ions (K+) flowing out from the repolarizing cells make Φo (outside the cells) more positive.
Resting
Depolarizing
Activated (Depolarized)
Repolarizing
Resting
Φ
Φo
Φi
Time
(Action pulse)
Direction of wavefront movement
A
Resting
Activated
B
Resting
Activated
C
Still activated
Resting again
D
Still activated
Resting again
E
V1
V2
|V1| < |V2|
P1
P2
|P1| = |P2|
= Activated (depolarized) cell
= Resting (repolarized) cell
= Direction of depolarization or repolarization wavefront
= Polarity of the double layer and its resultant dipole

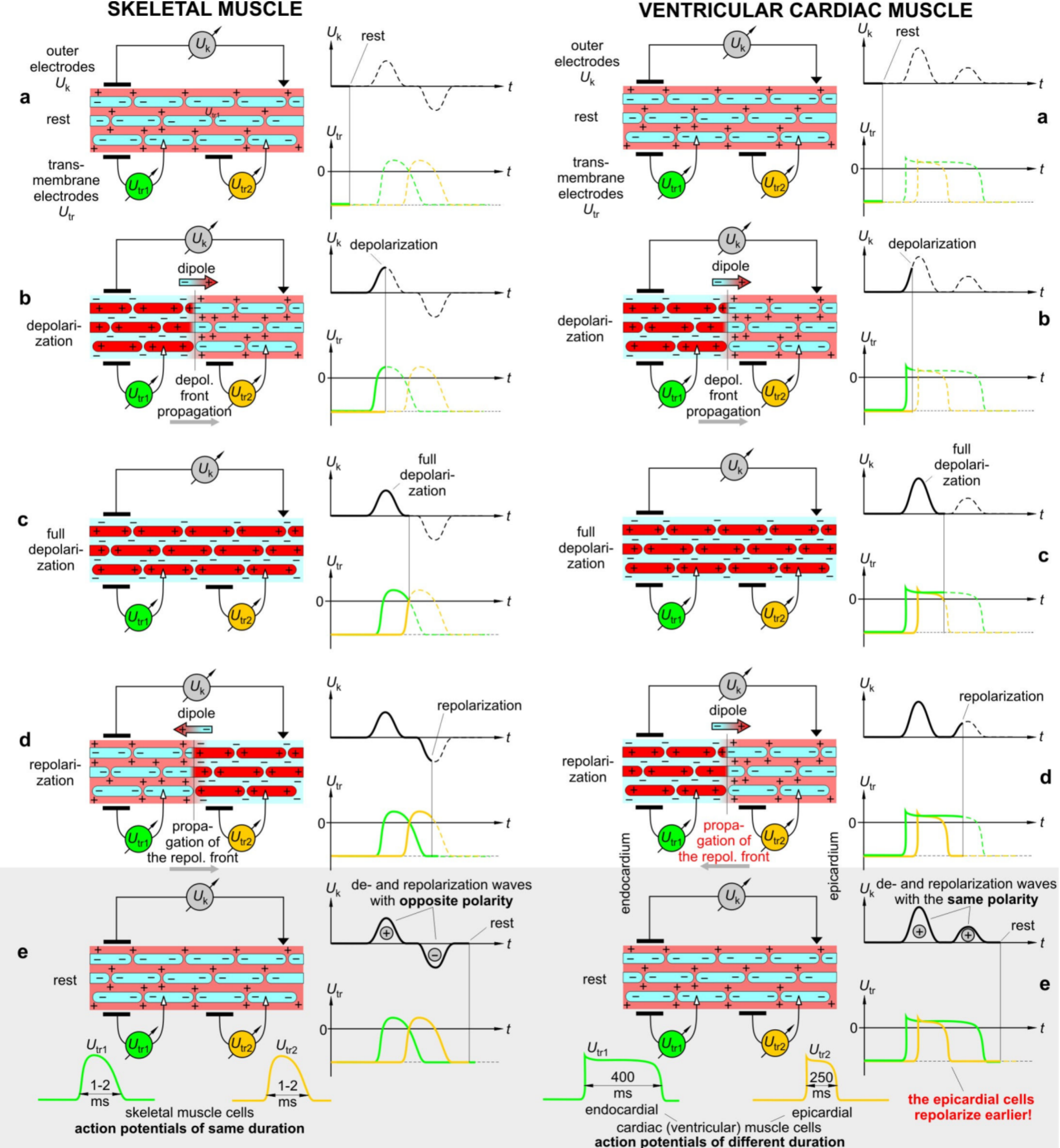

C
B
A
D
Condition 1
At rest
Depolarizing
Depolarized
At rest
Voltage (A-B)
(+)
0
(−)
1
2
3
4
5
At rest
Repolarizing
Voltage (C-D)
(+)
0
(−)
1
2
3
4
5

contraction and electric activity in muscle cells are strictly coupled.

biphasic extracellular signal

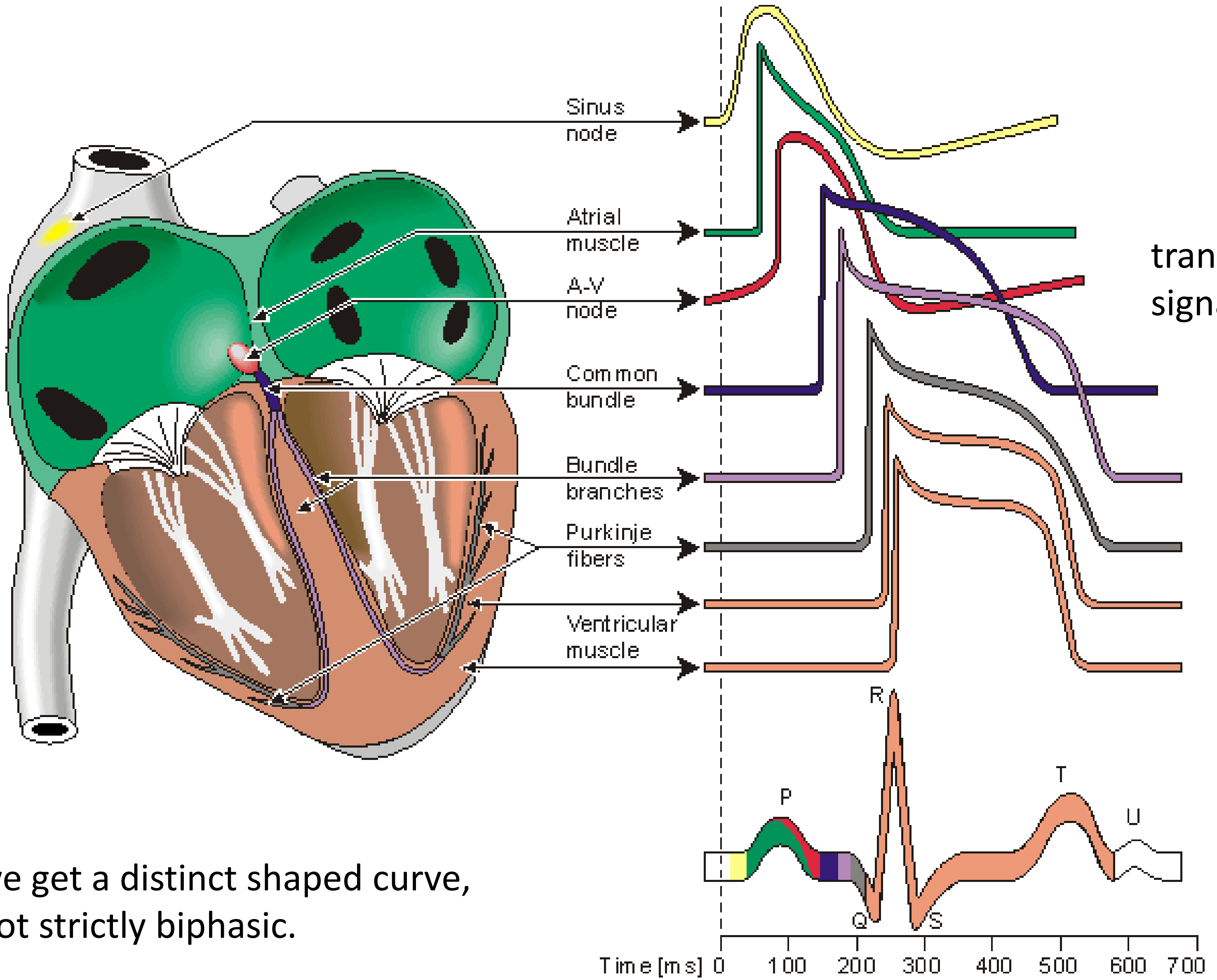




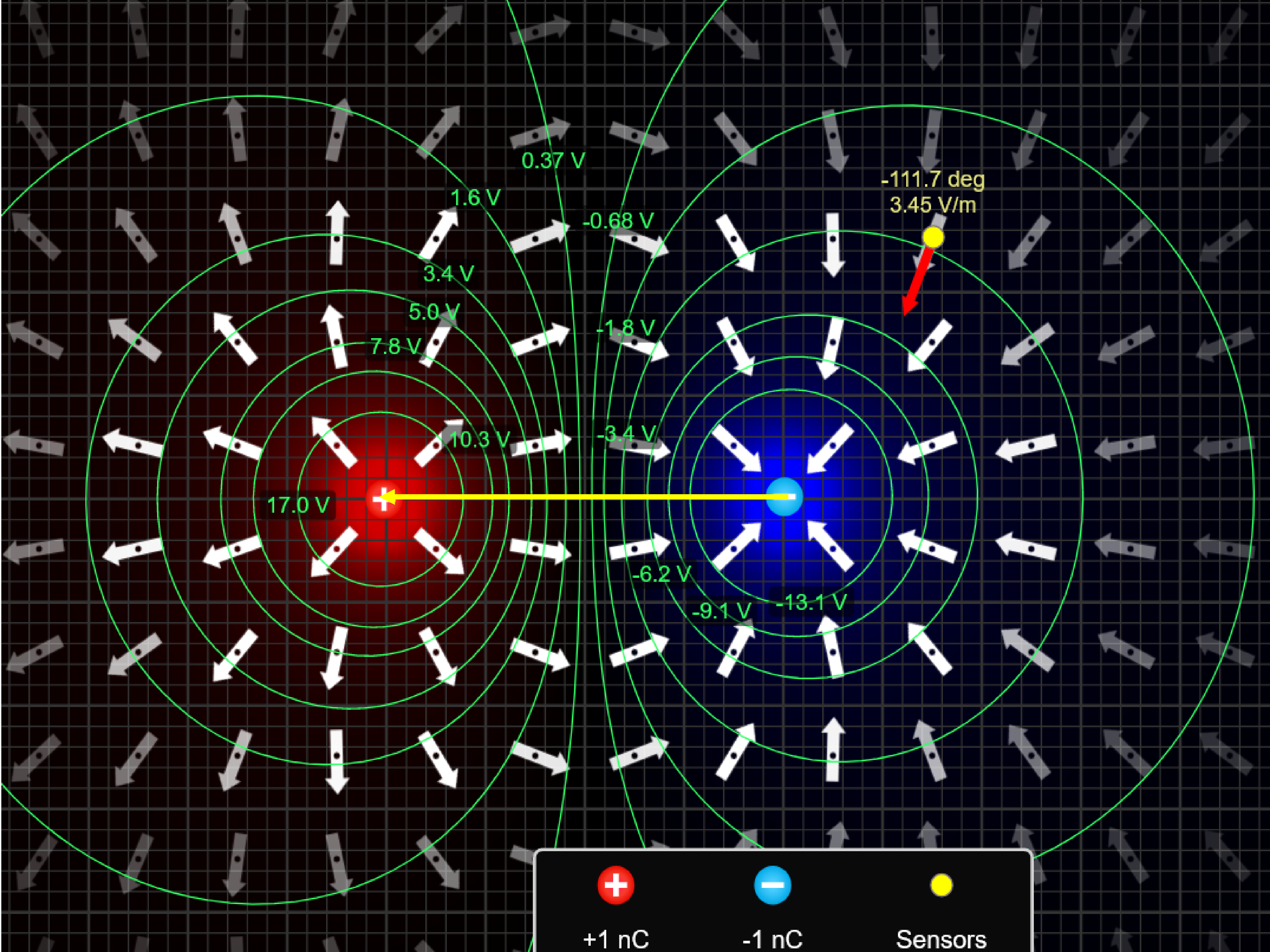

if different type of cells are distributed in space, then we can get a non-biphasic signal.

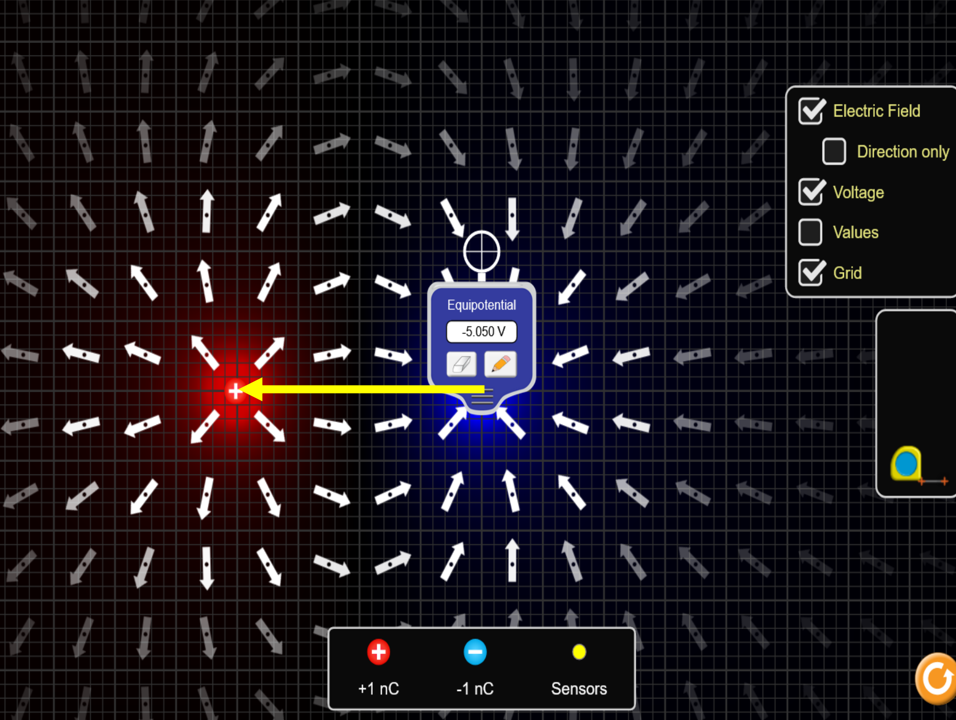
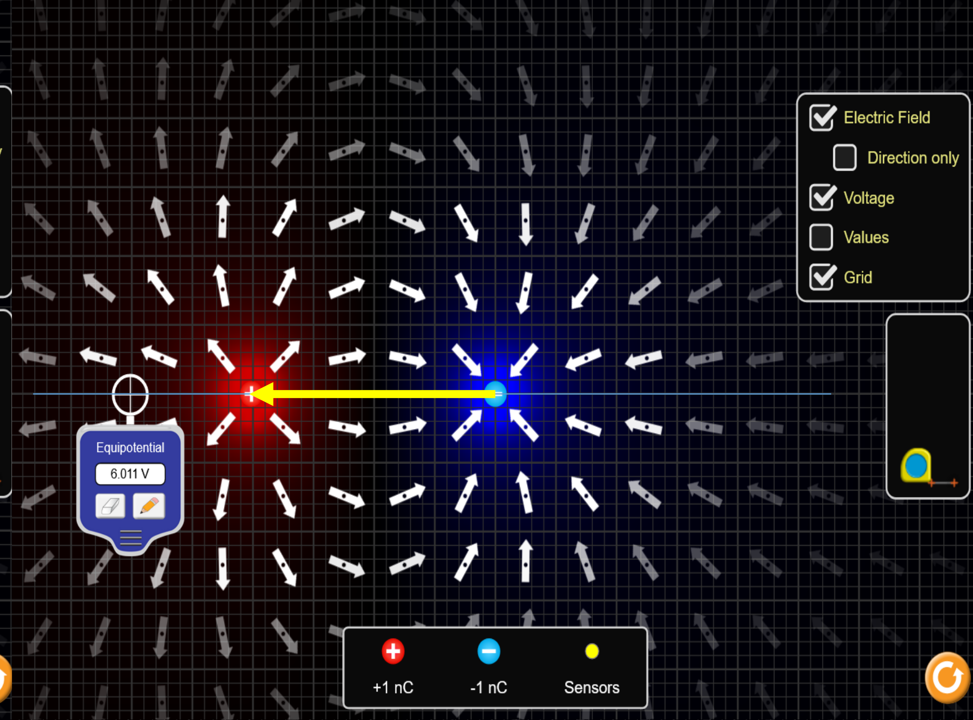
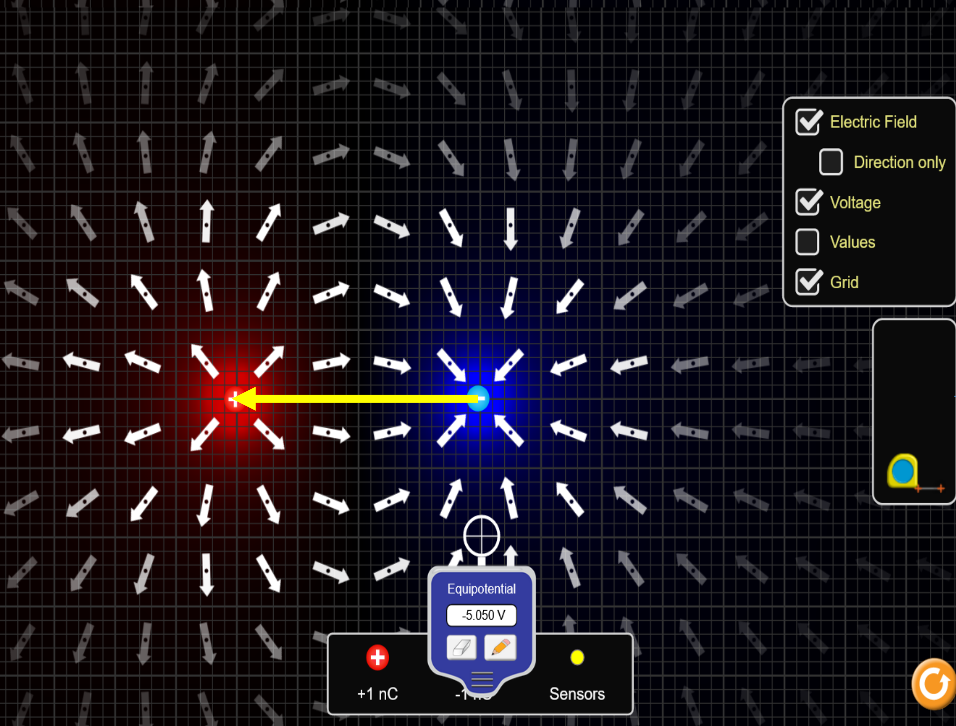
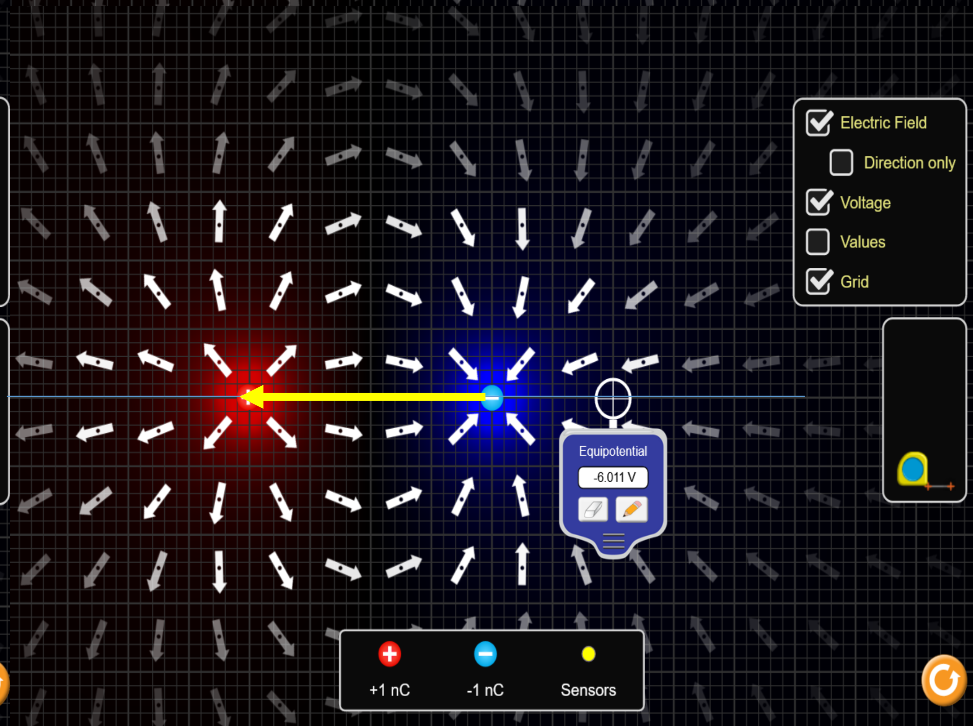
in the heart very different cell types are located at various structures



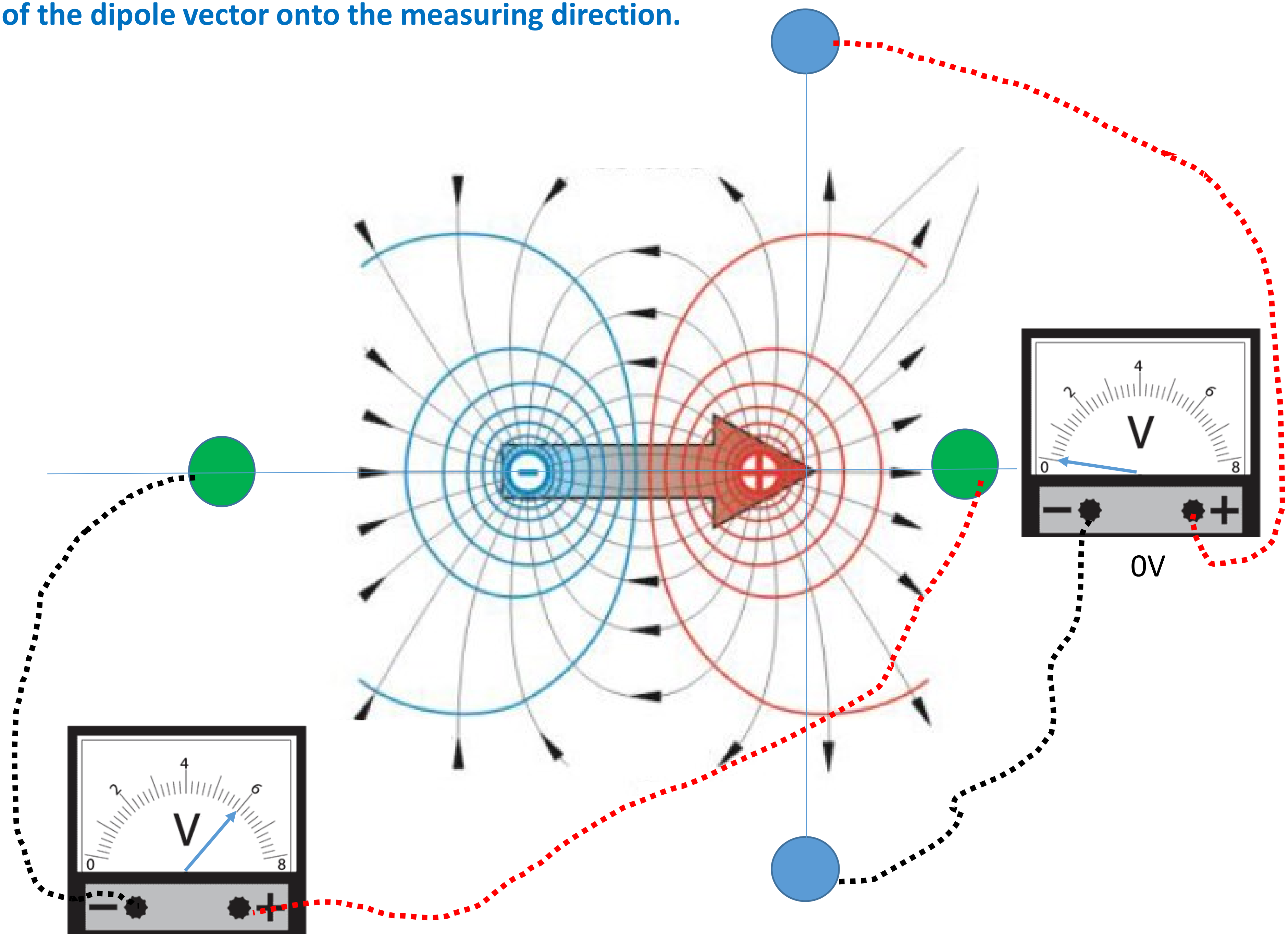

transmembrane signals

we get a distinct shaped curve, not strictly biphasic.

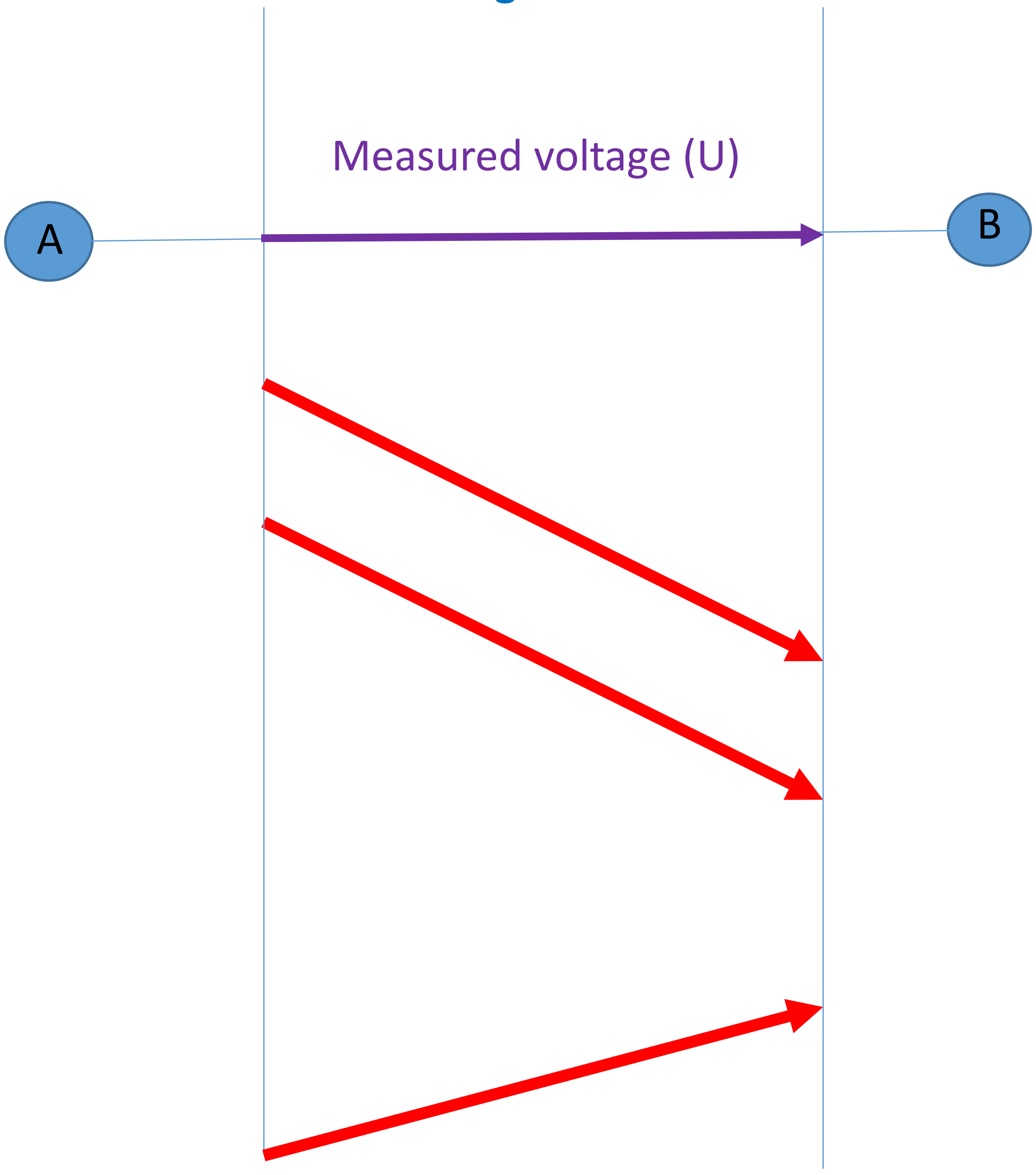

0.37 V
1.6 V
-0.68 V
3.4 V
5.0 V
-1.8 V
7.8 V
10.3 V
-3.4 V
17.0 V
-6.2 V
-9.1 V
-13.1 V
-111.7 deg
3.45 V/m
+1 nC
-1 nC
Sensors

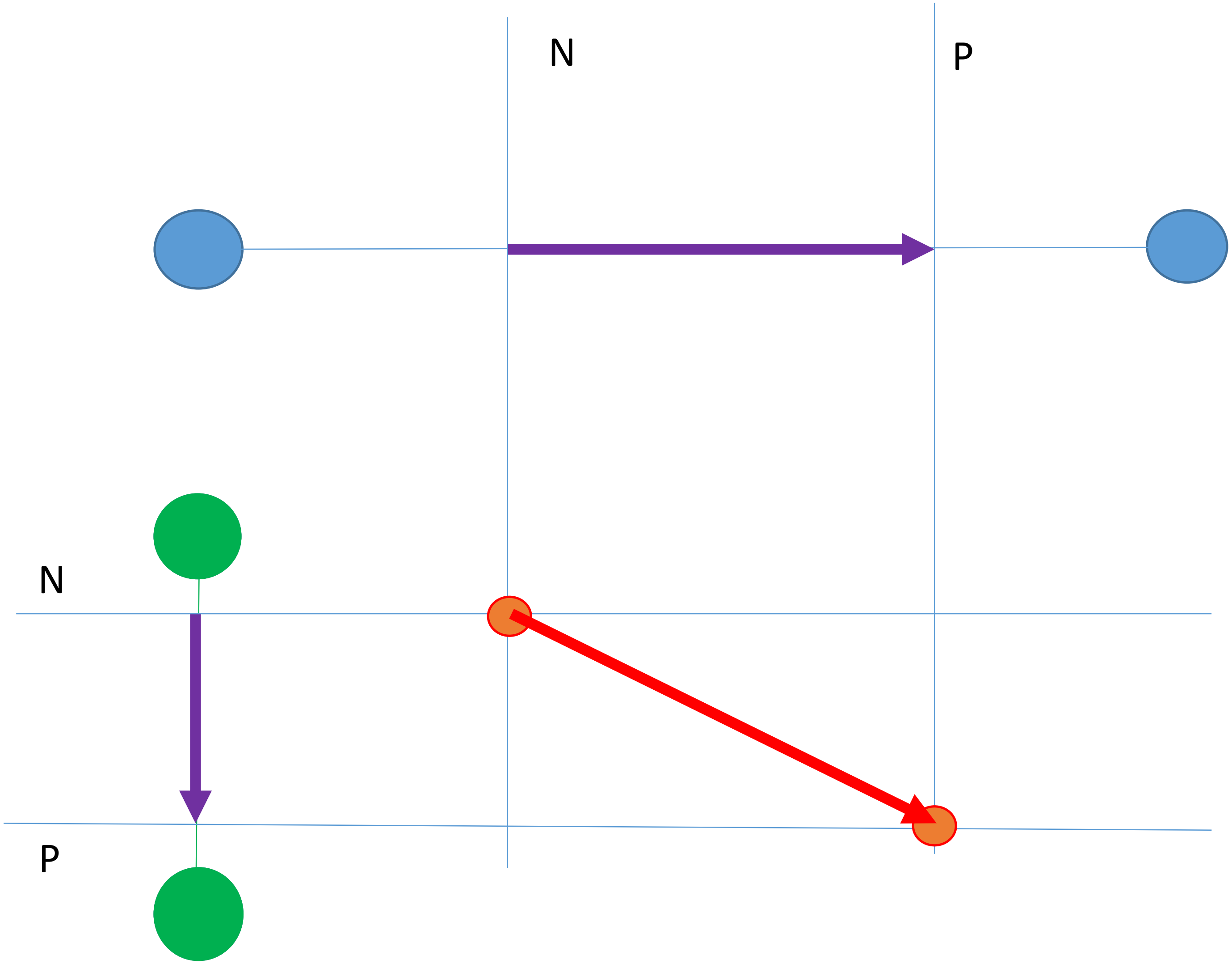

Electric Field
Direction only
Voltage
Values
Grid
Equipotential
-5.050 V
+1 nC
-1 nC
Sensors

Electric Field
Direction only
Voltage
Values
Grid
Equipotential
6.011 V
+1 nC
-1 nC
Sensors

Electric Field
Direction only
Voltage
Values
Grid
Equipotential
-5.050 V
+1 nC
Sensors

Electric Field
Direction only
Voltage
Values
Grid
Equipotential
-6.011 V
+1 nC
-1 nC
Sensors

**The measured voltage is proportional to the projection of the dipole vector onto the measuring direction.**

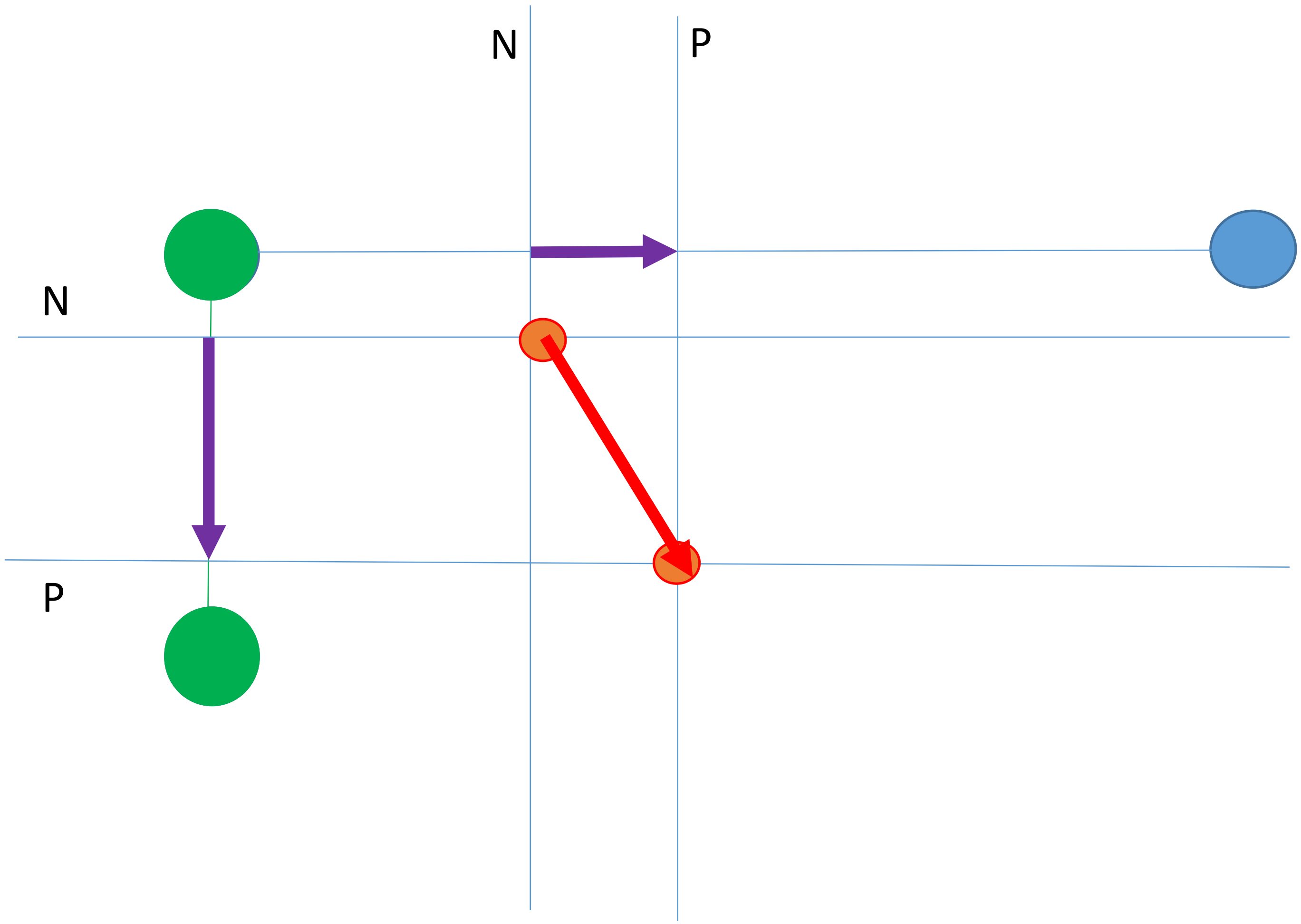


**The measured voltage is proportional to the projection of the dipole vector onto the measuring direction.**



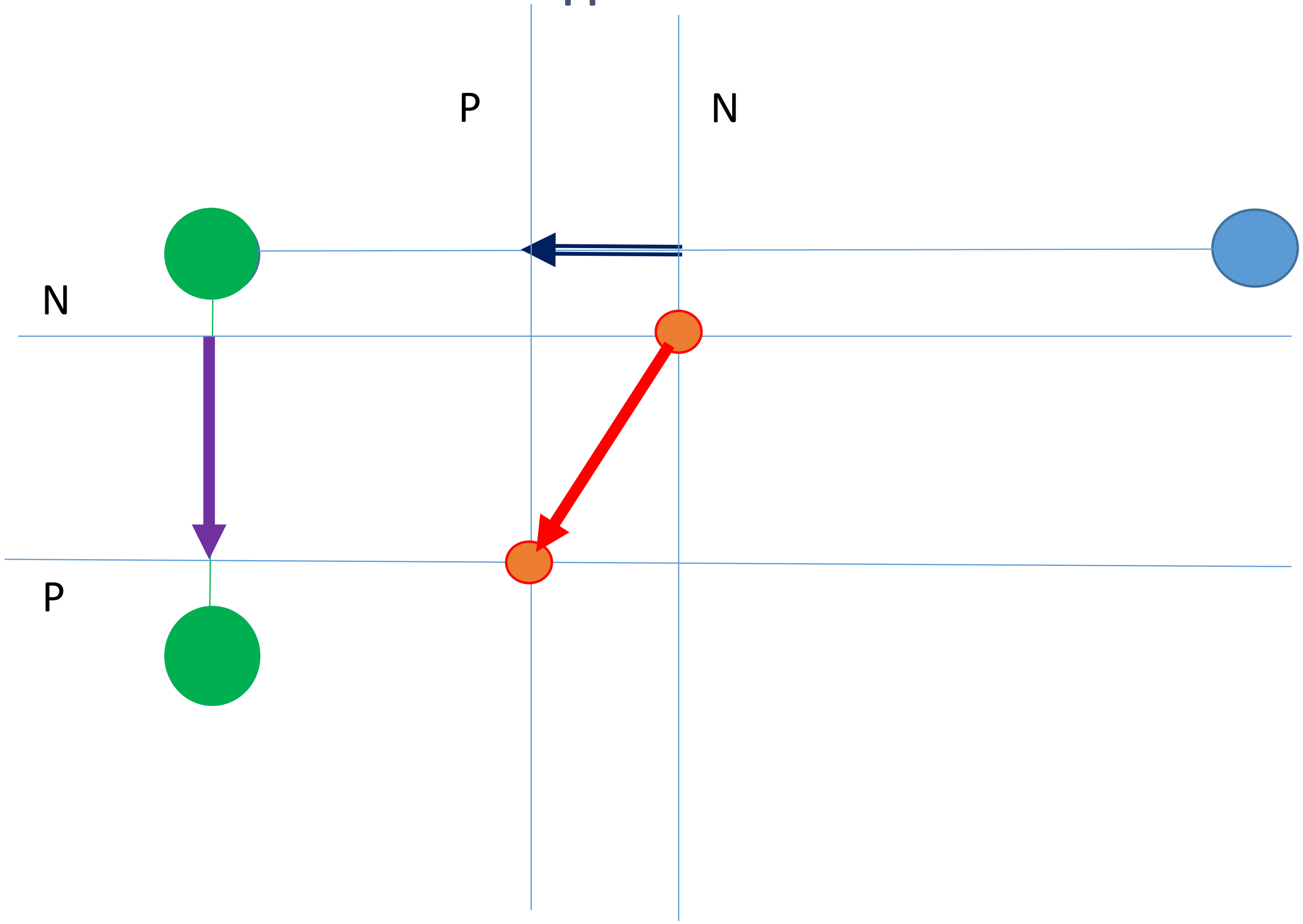



the original dipole can be reconstructed

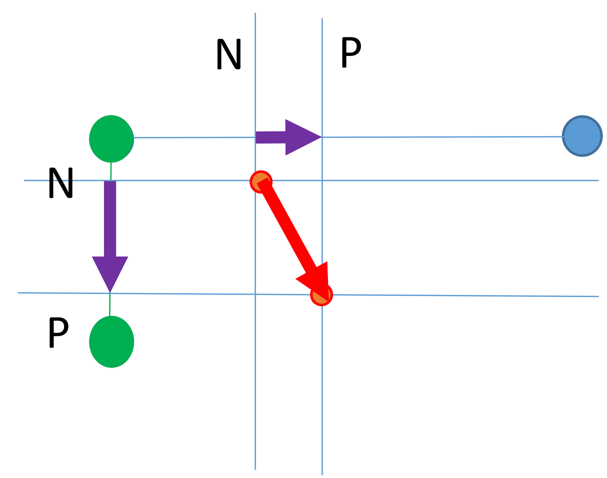



uncontrolled leads: risk of wrong data!

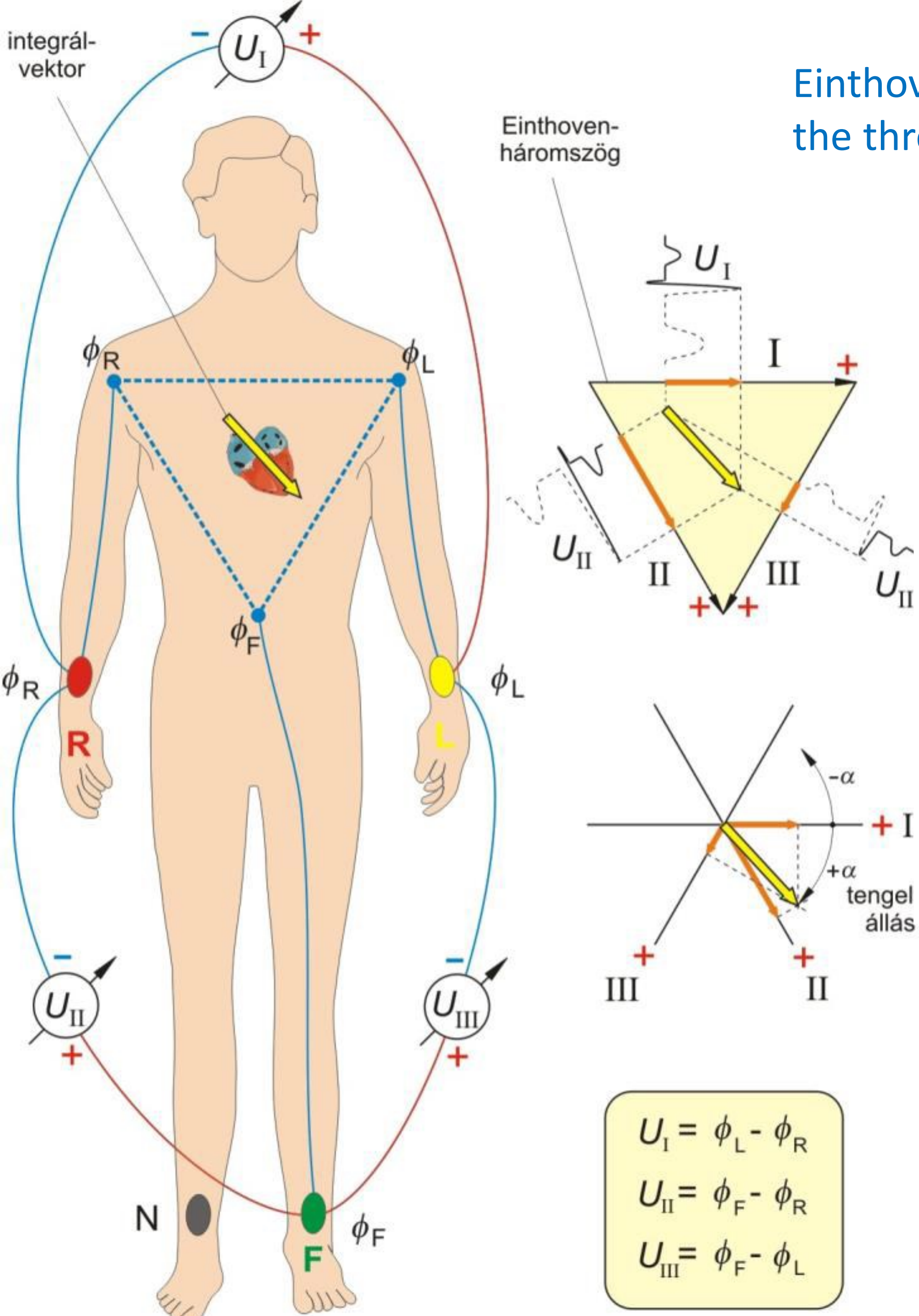
**swapped electrodes here**

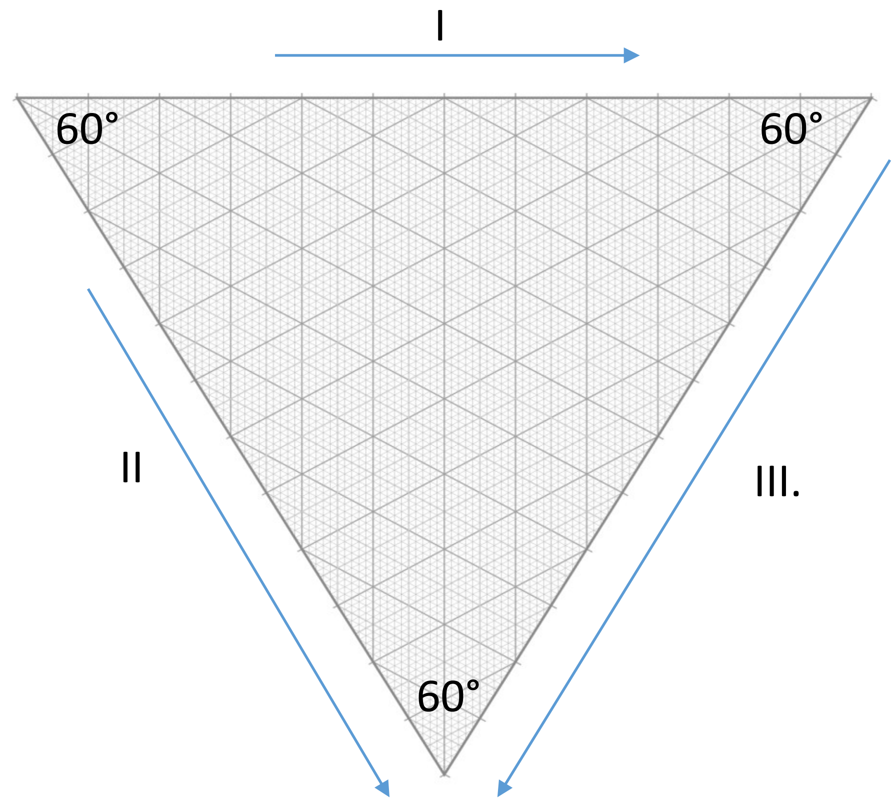


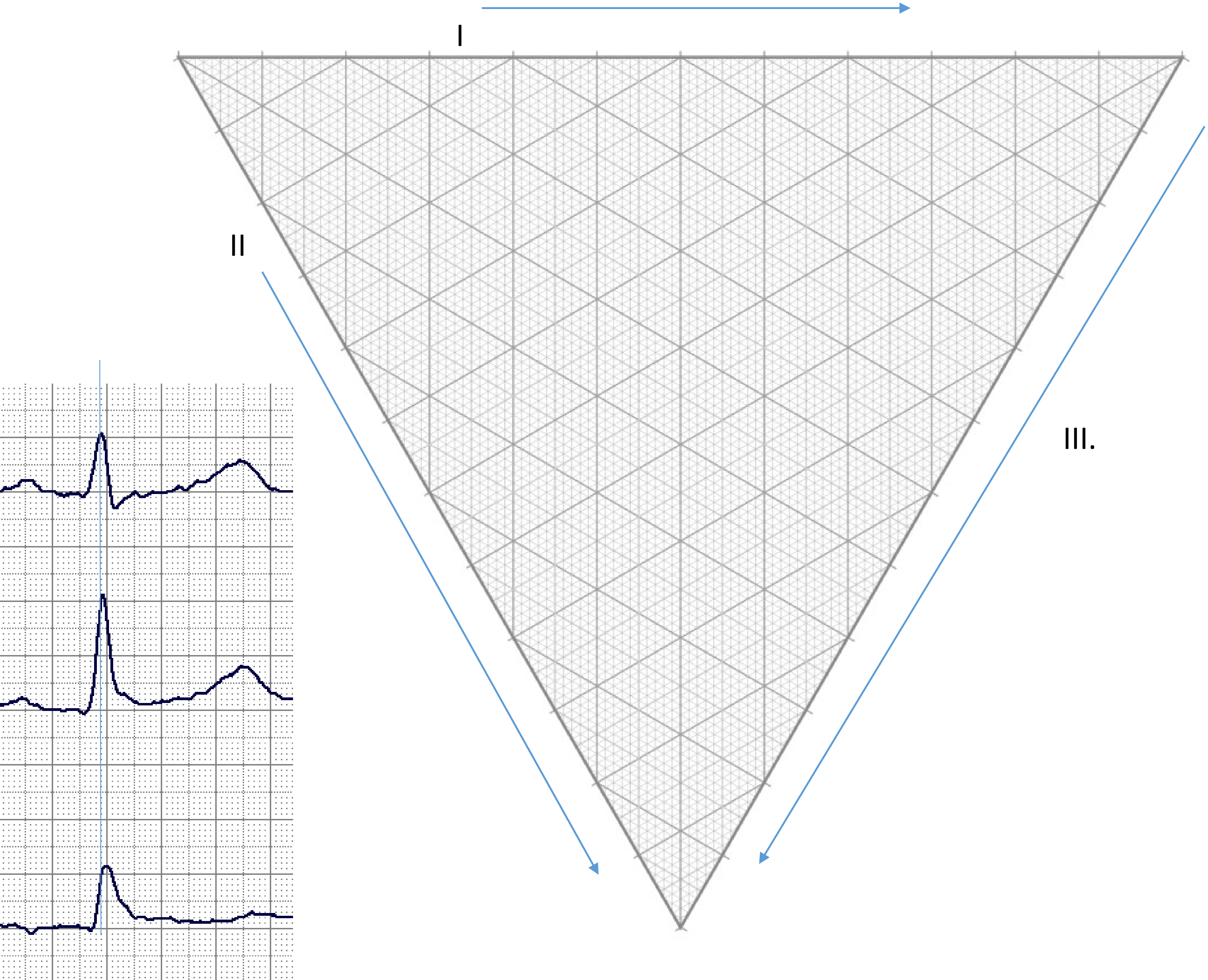

uncontrolled leads: risk of wrong data!



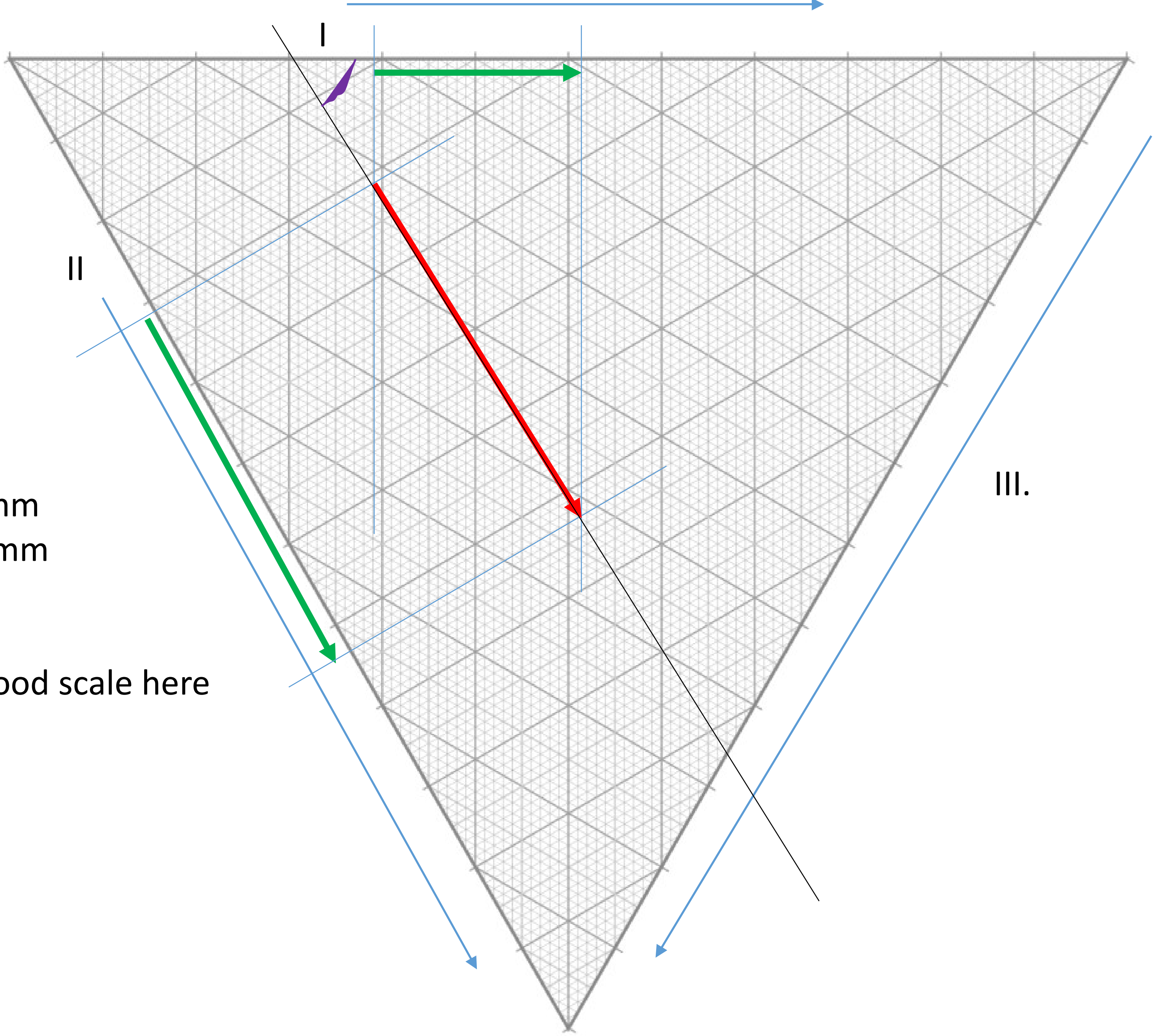
Einthoven : controlled leads,
the three projections are NOT independent.





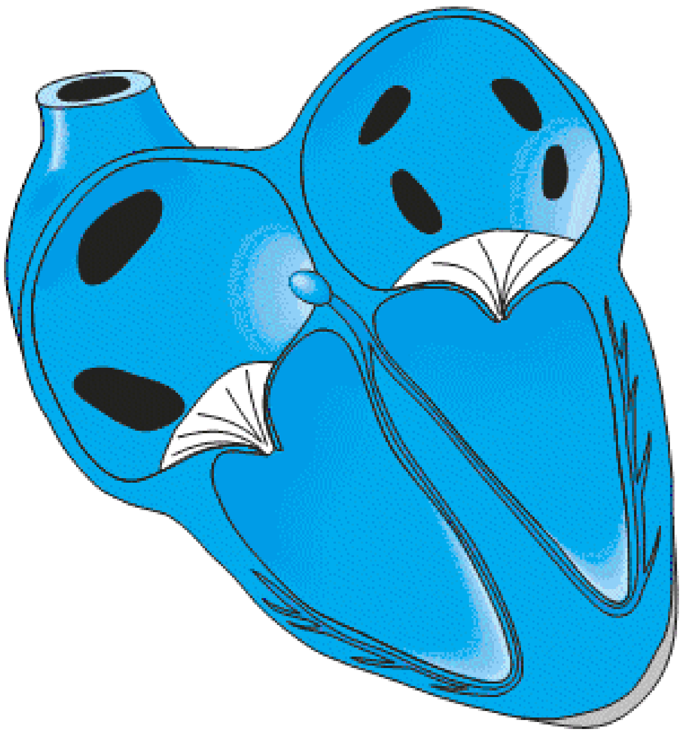
I
II
III.

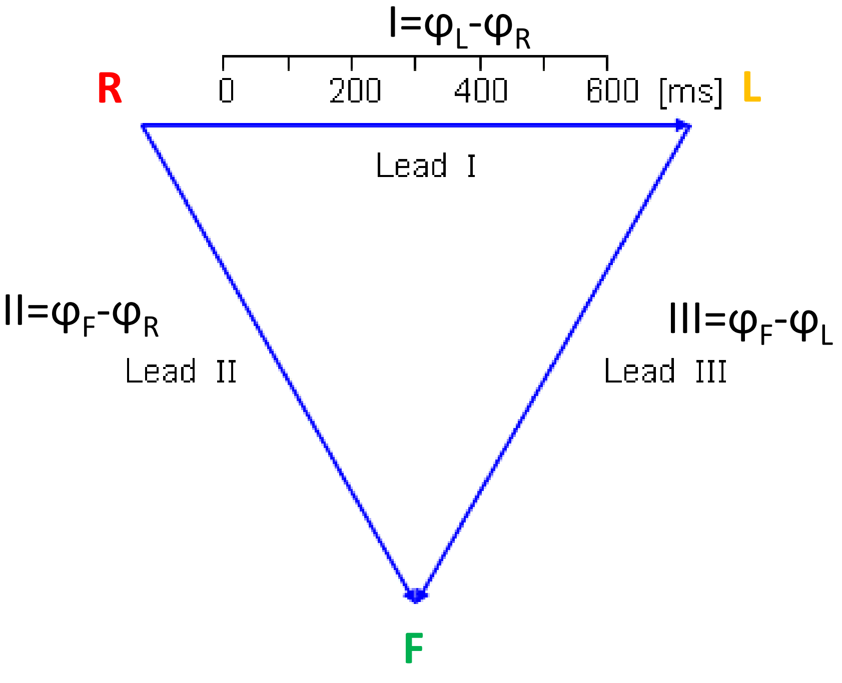


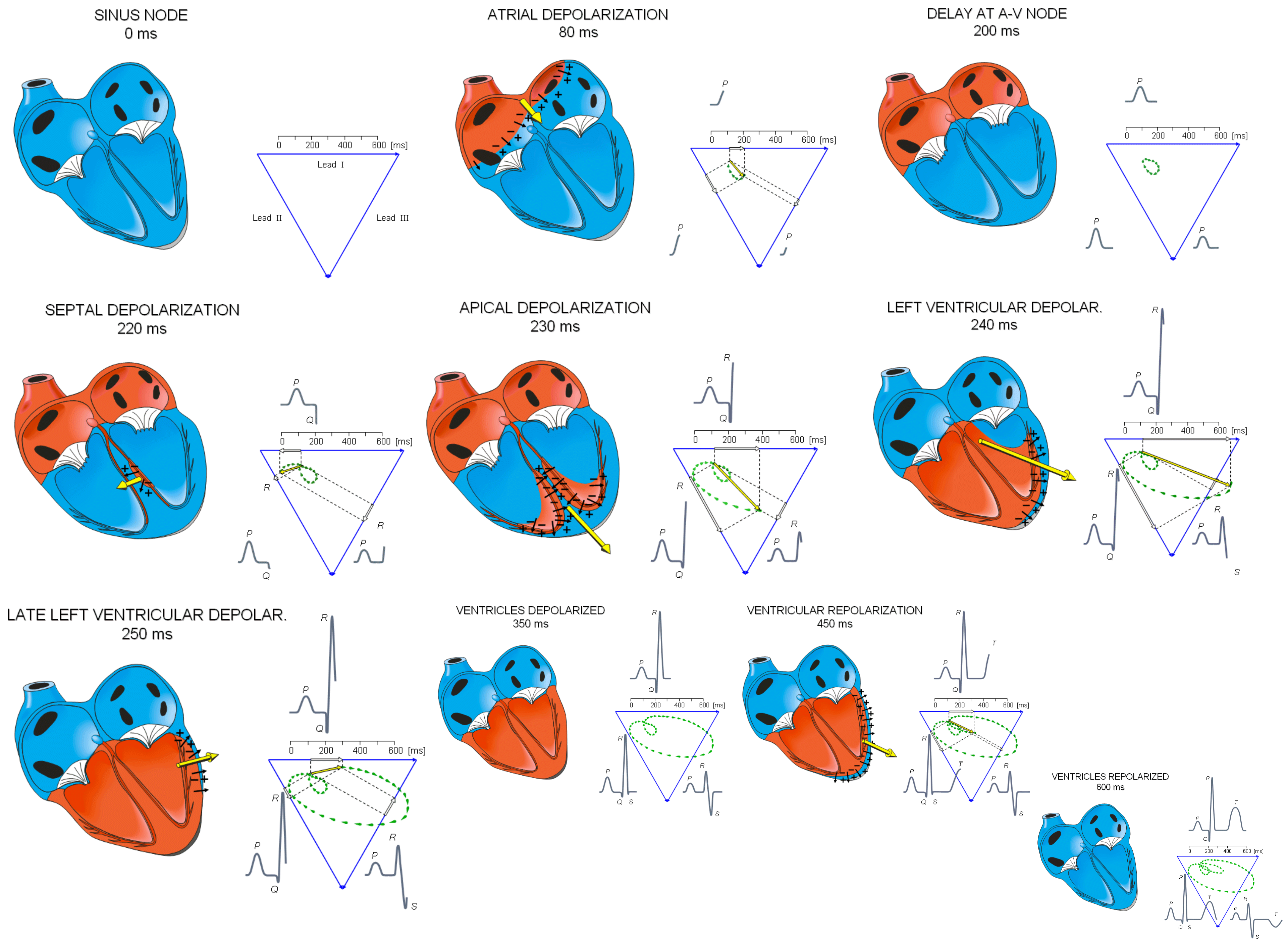

U_I: 11mm
U_II: 21mm

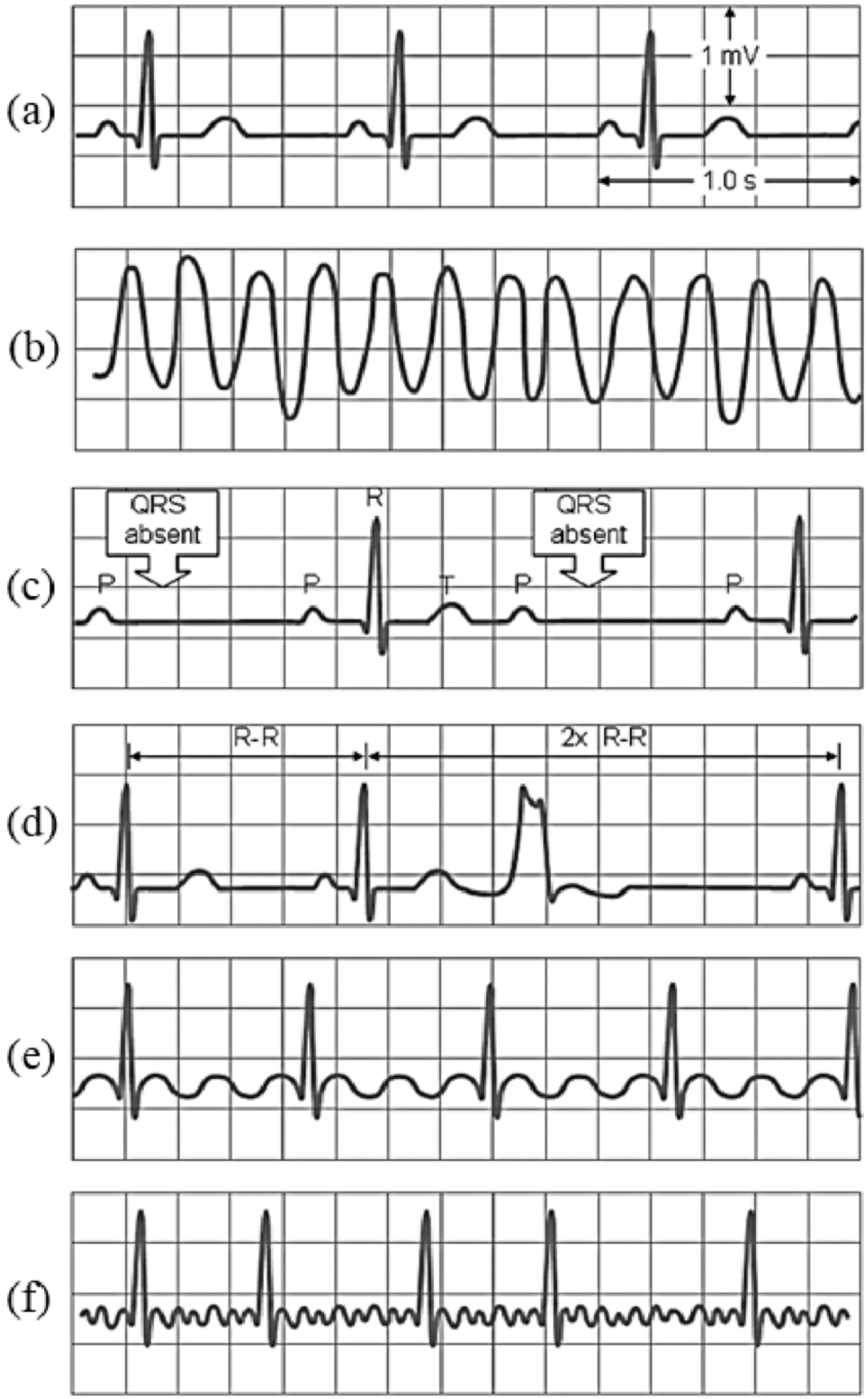
2x is a good scale here

SINUS NODE
0 ms






SINUS NODE
0 ms
0 200 400 600 [ms]
Lead I
Lead II
Lead III
ATRIAL DEPOLARIZATION
80 ms
DELAY AT A-V NODE
200 ms
SEPTAL DEPOLARIZATION
220 ms
APICAL DEPOLARIZATION
230 ms
LEFT VENTRICULAR DEPOLAR.
240 ms
LATE LEFT VENTRICULAR DEPOLAR.
250 ms
VENTRICLES DEPOLARIZED
350 ms
VENTRICULAR REPOLARIZATION
450 ms
VENTRICLES REPOLARIZED
600 ms
P
Q
R
S
T




**(a) Normal Sinus Rhythm**

**Practically ANY functional disorder will result in the change of the curve -> diagnosis**

**(b) Ventricular Fibrillation**

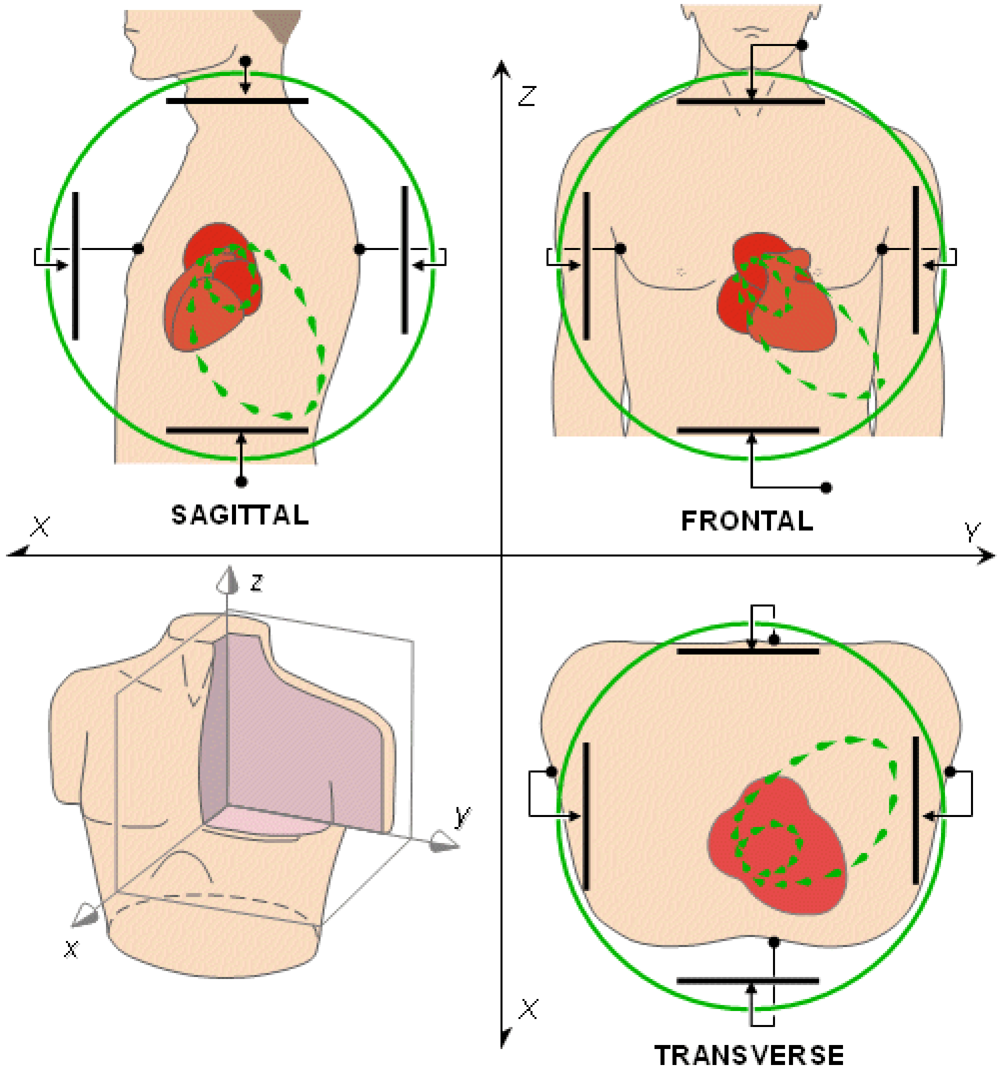
**(c) Atrioventricular Block**

**(d) Premature Ventricular Contraction**

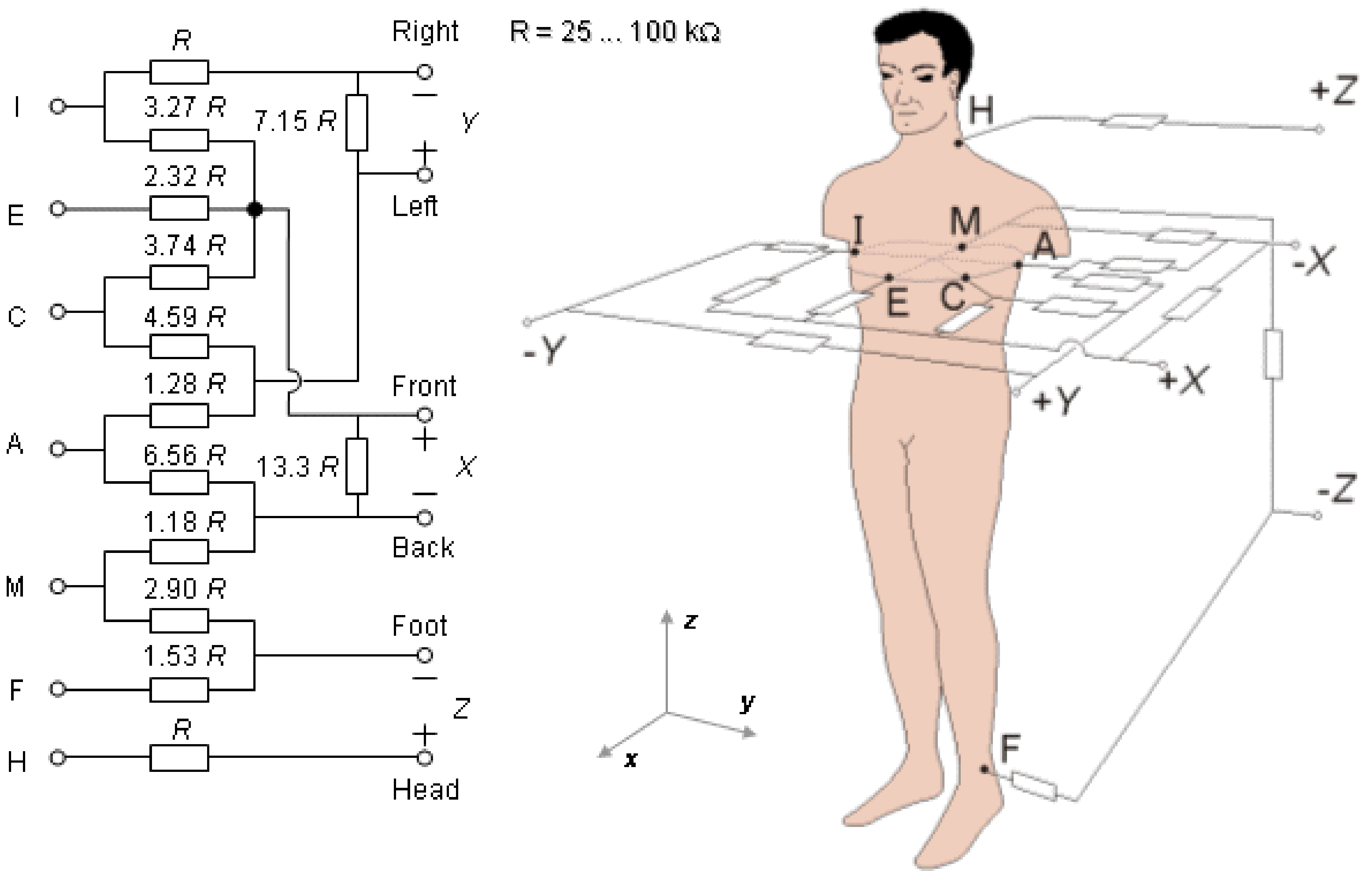
**(e) Atrial Flutter**

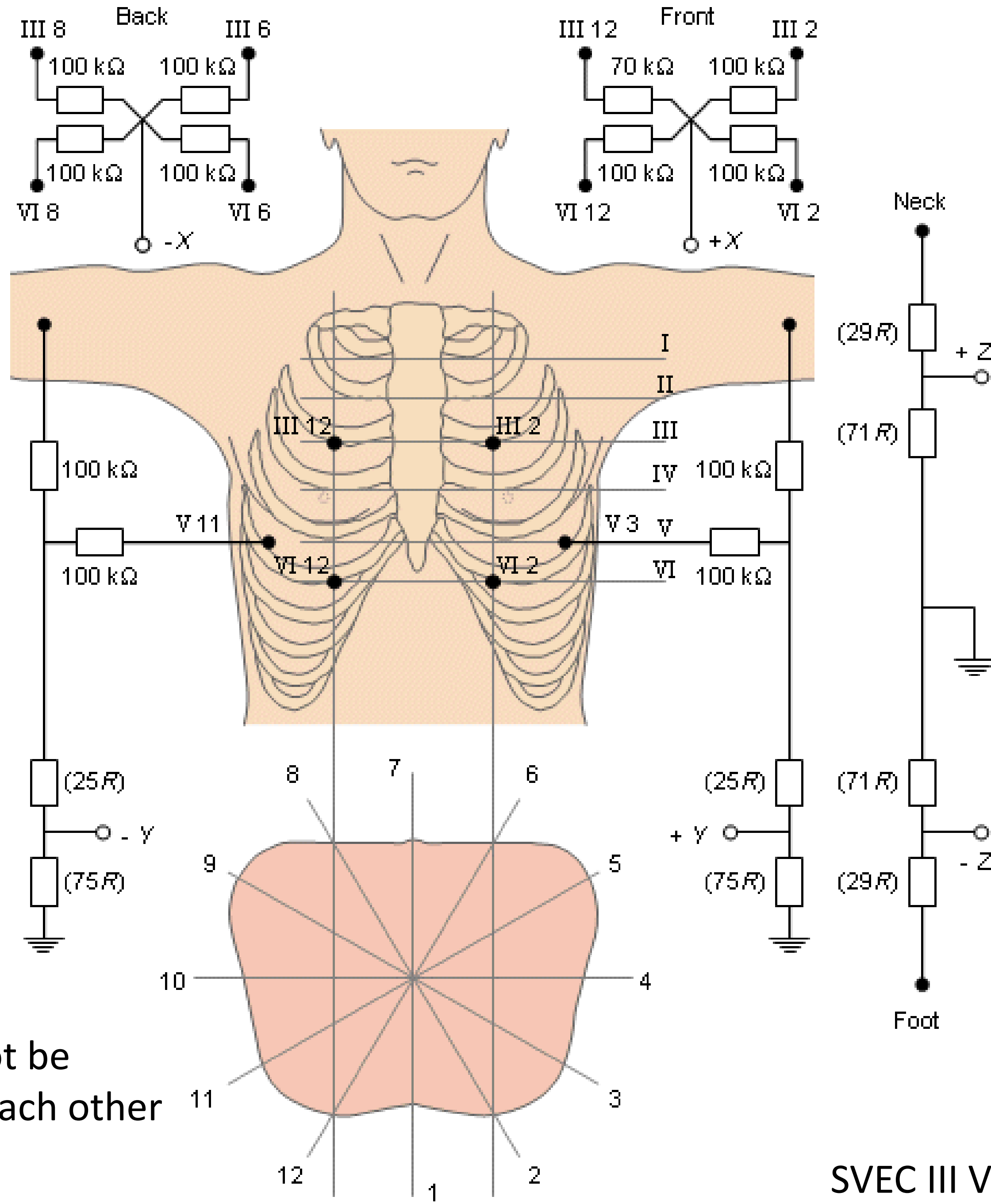
**(f) Atrial Fibrillation.**

Vectorcardiography (vcg)



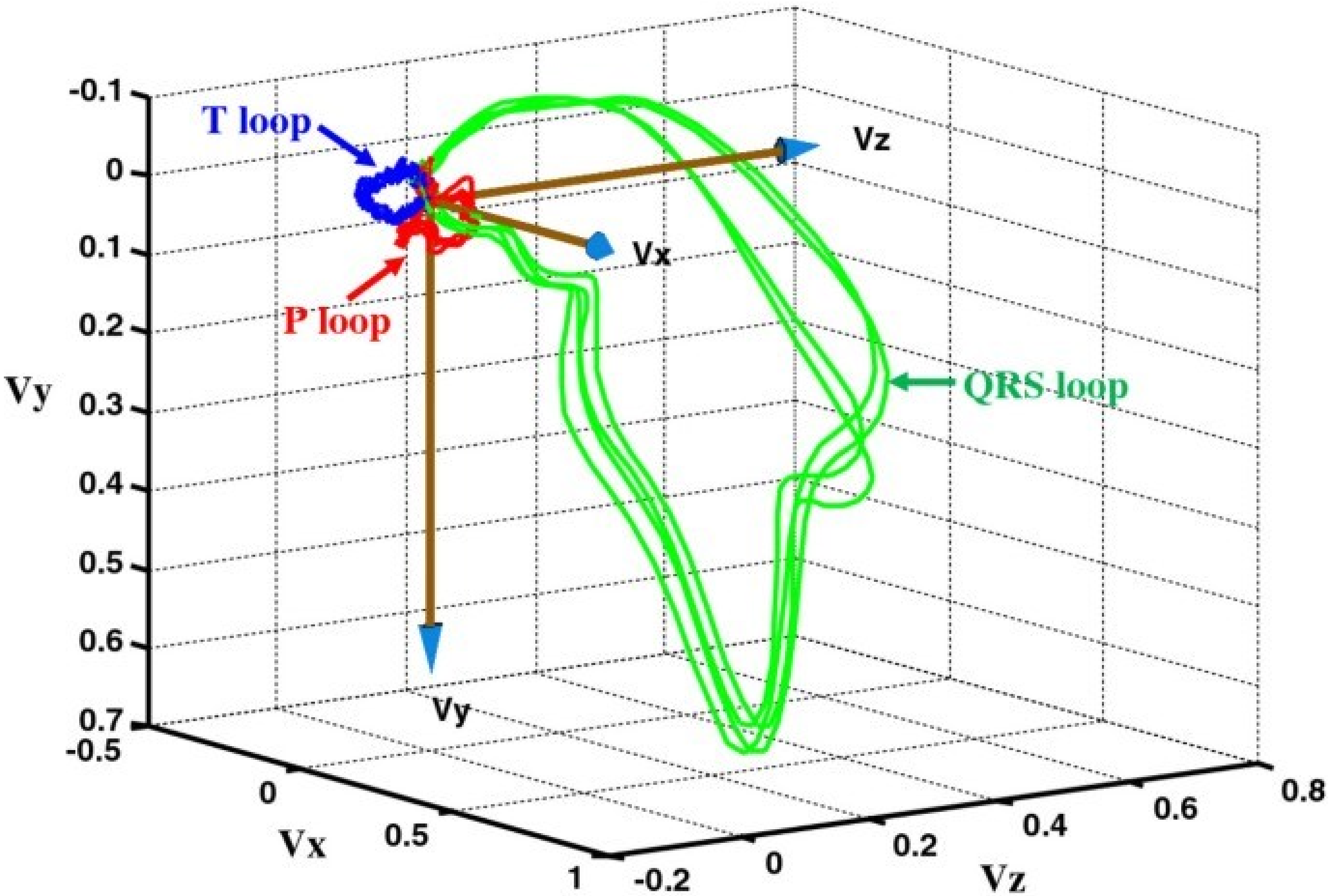
# Frank Lead Matrix



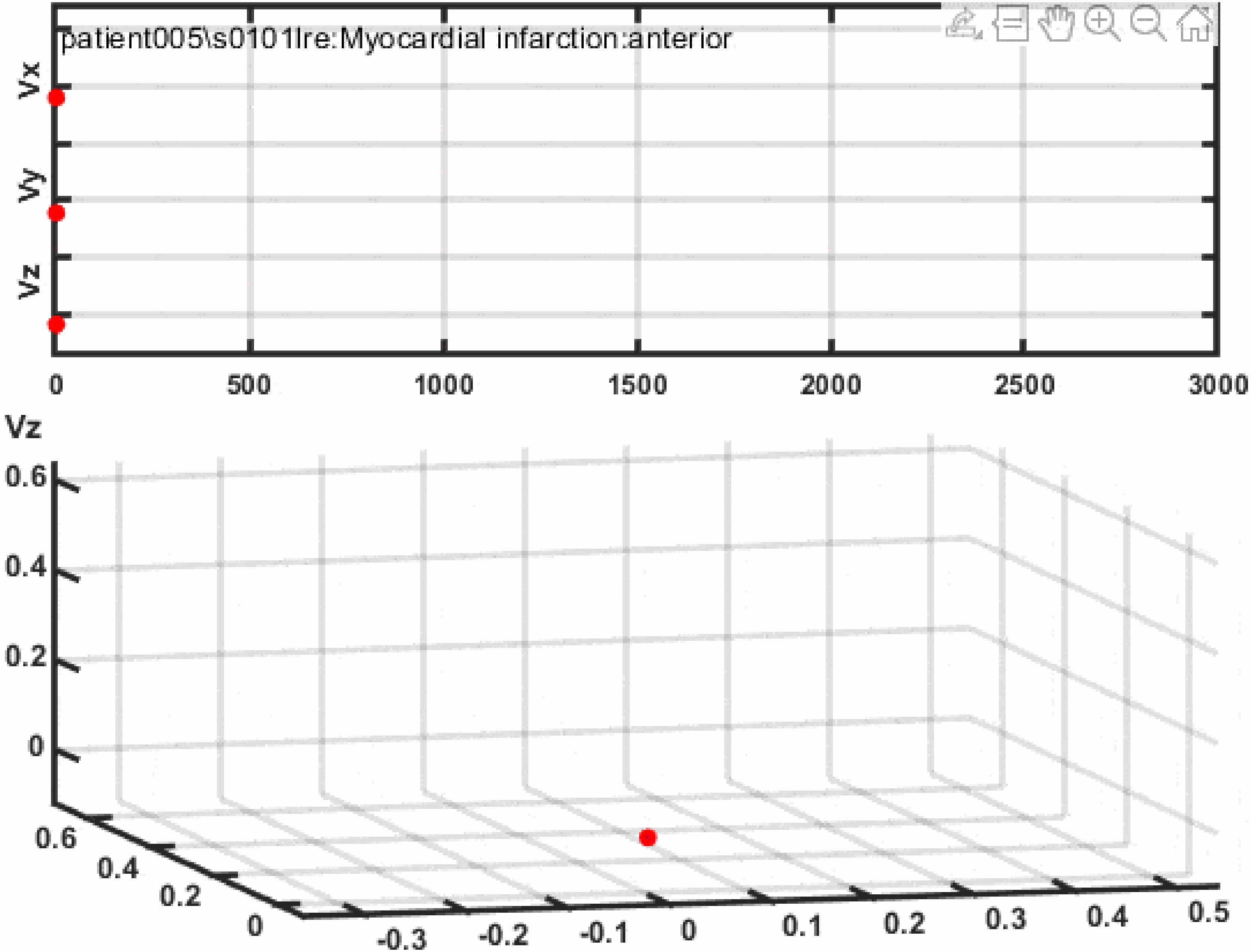


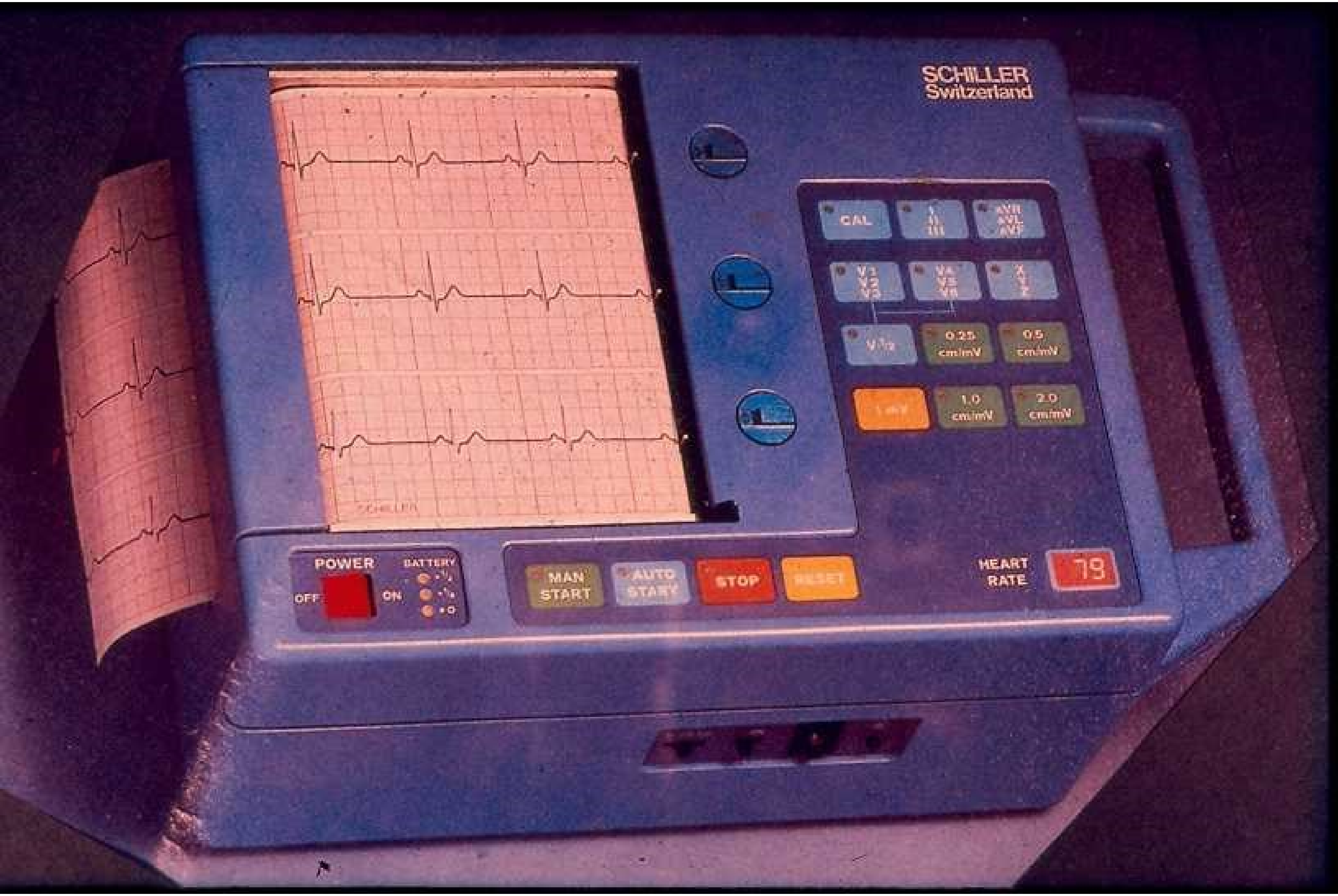

the systems can not be transformed into each other unambigously

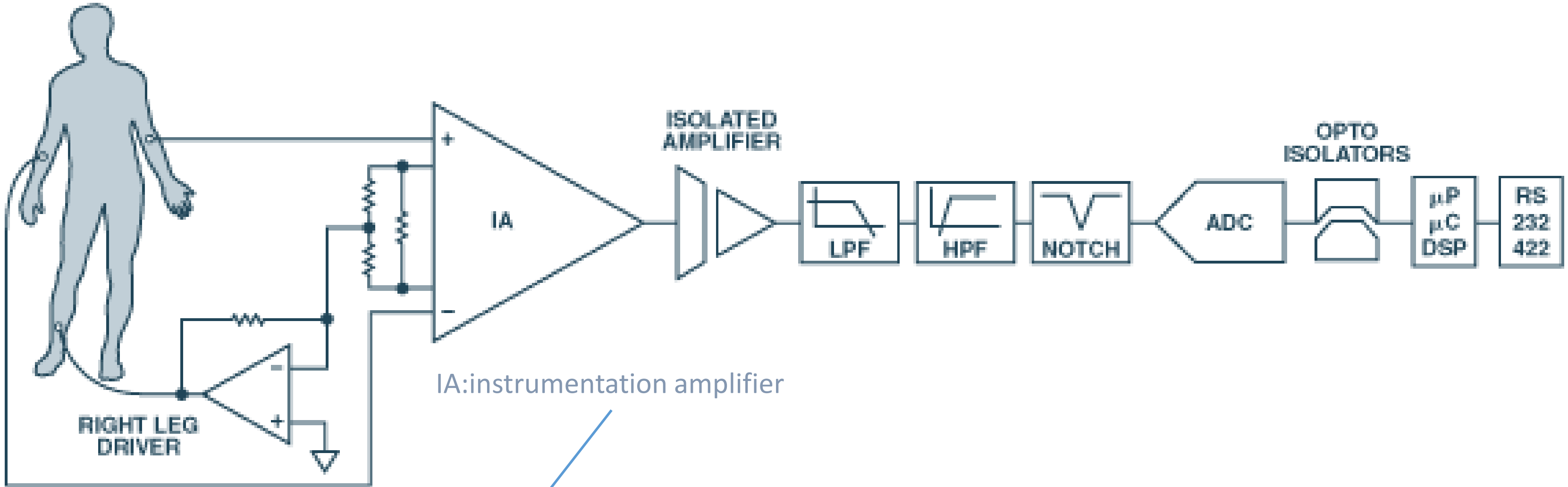
SVEC III VCG lead system.



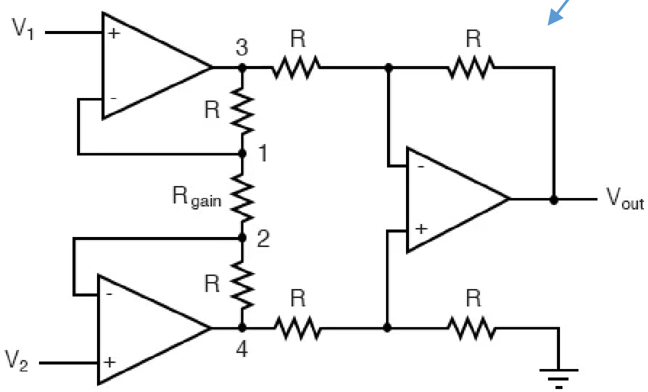

3D representation


patient005\s0101lre:Myocardial infarction:anterior
Vx
Vy
Vz
0
500
1000
1500
2000
2500
3000
Vz
0.6
0.4
0.2
0
0.6
0.4
0.2
0
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5


SCHILLER
Switzerland
CAL
aVR
aVL
aVF
0.25
cm/mV
0.5
cm/mV
1.0
cm/mV
2.0
cm/mV
POWER
BATTERY
OFF
ON
MAN
START
AUTO
START
STOP
RESET
HEART
RATE
79



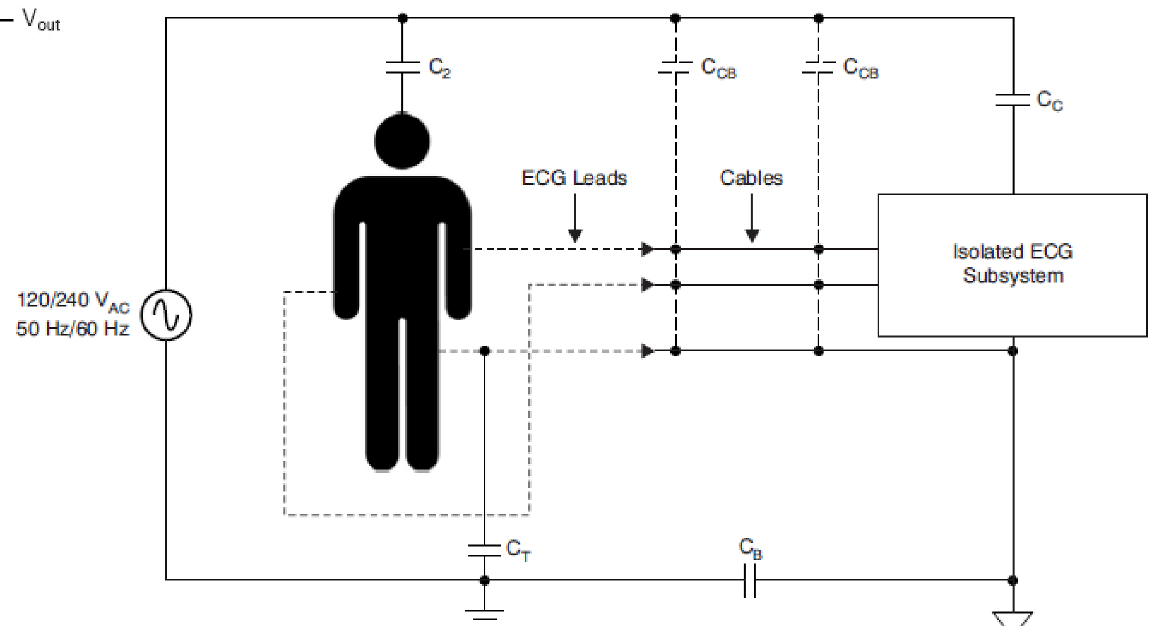

IA:instrumentation amplifier




capacitive noise sources

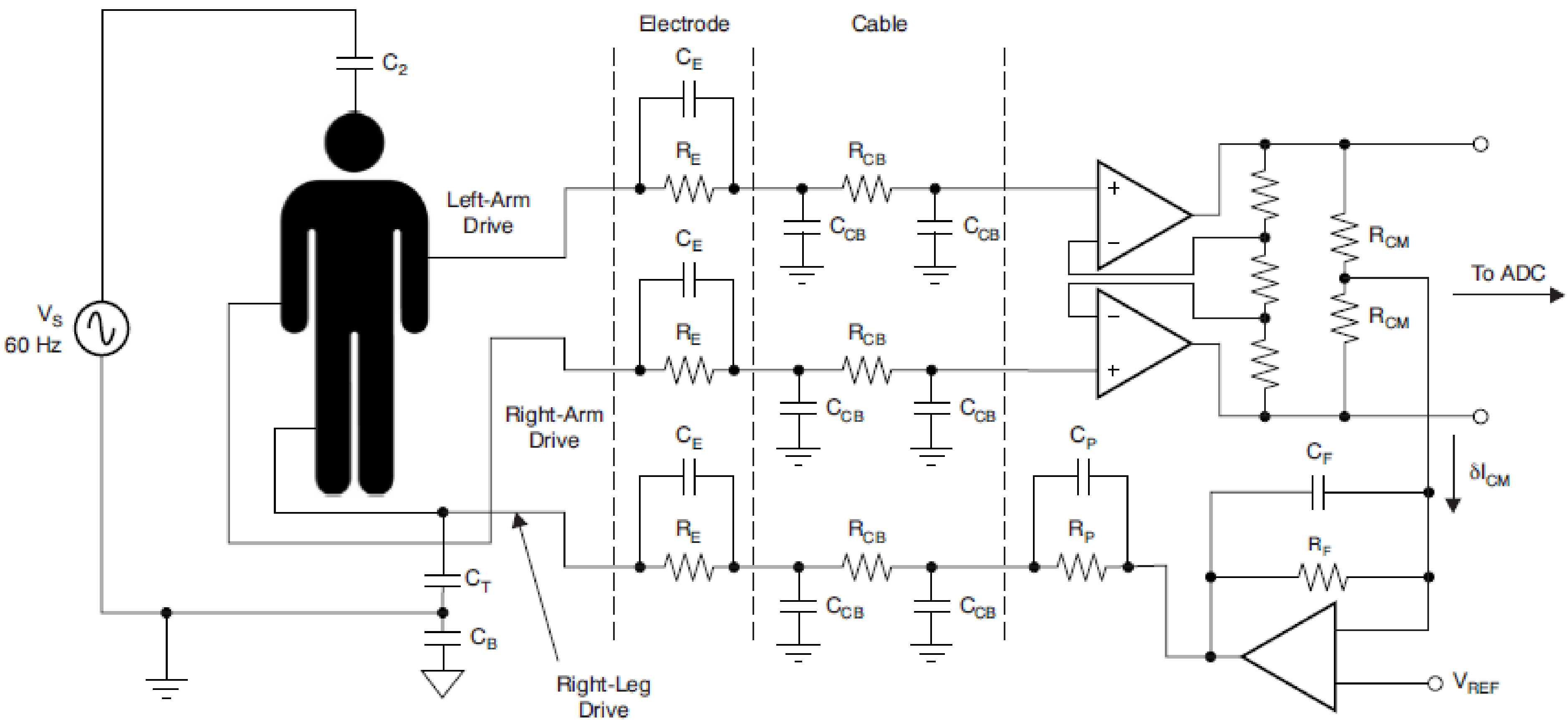
50/60 Hz civilian power network

16 $^{2}/_{3}$ Hz vagy 25 Hz railway traction networks



the **F** (right leg) is not just a reference input, but the CMR is feed back to it, hence common mode rejection improves. (-96dB with RLD feedback from -60dB)

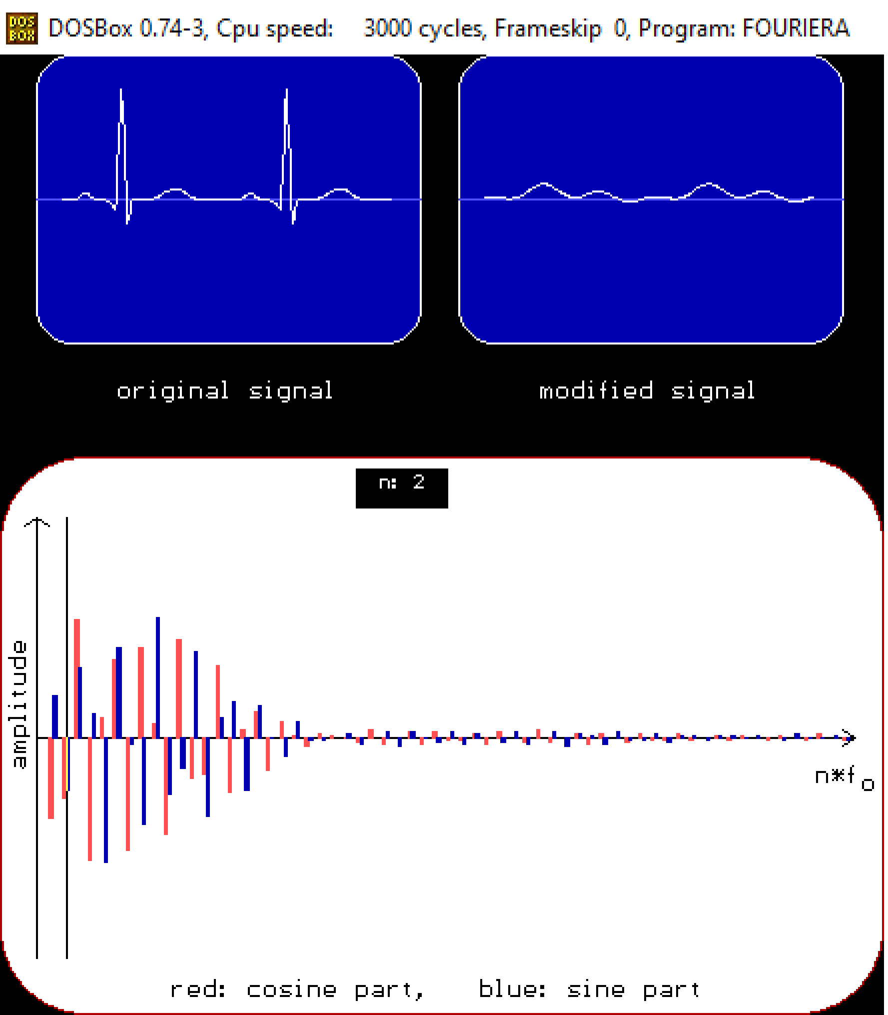
CMR



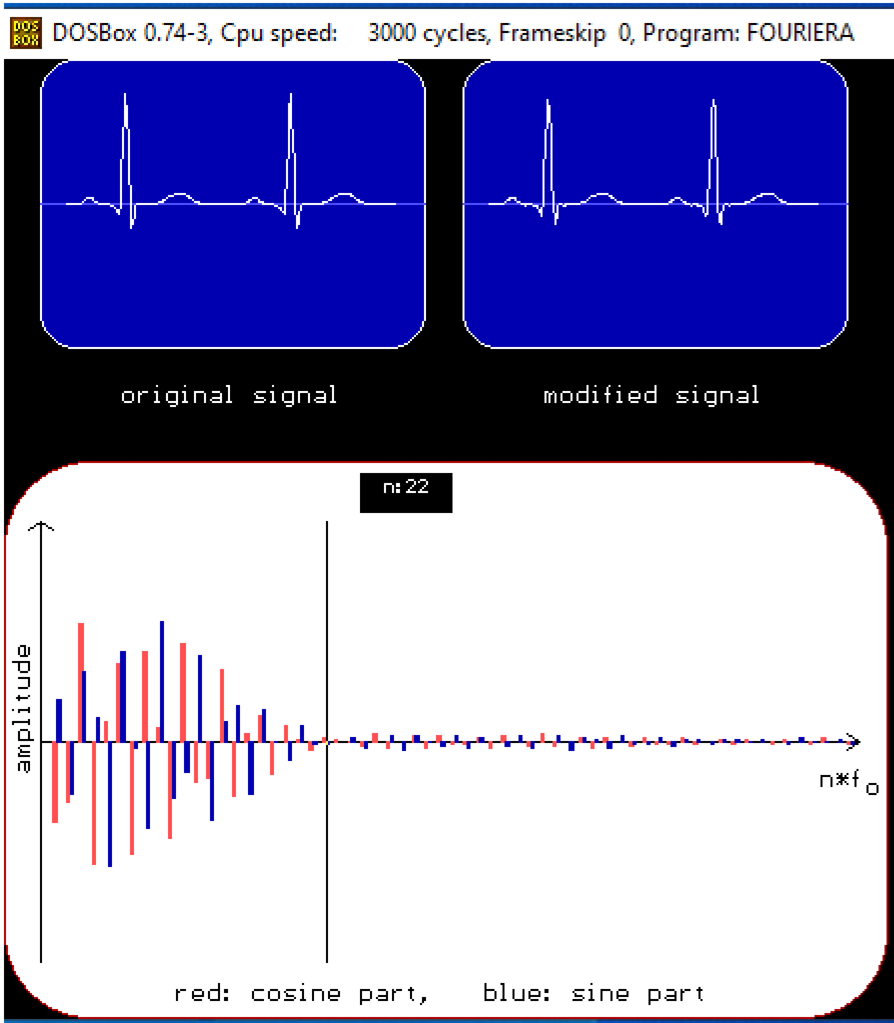

one channel of the ECG amplifier system

$$Signal(t) \leftarrow\rightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

first few components



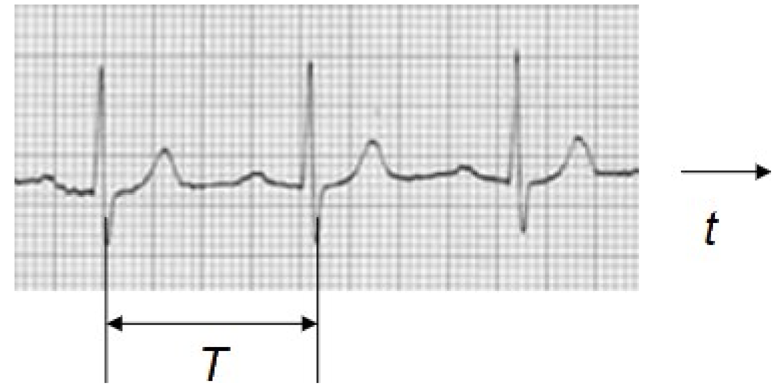

the full band

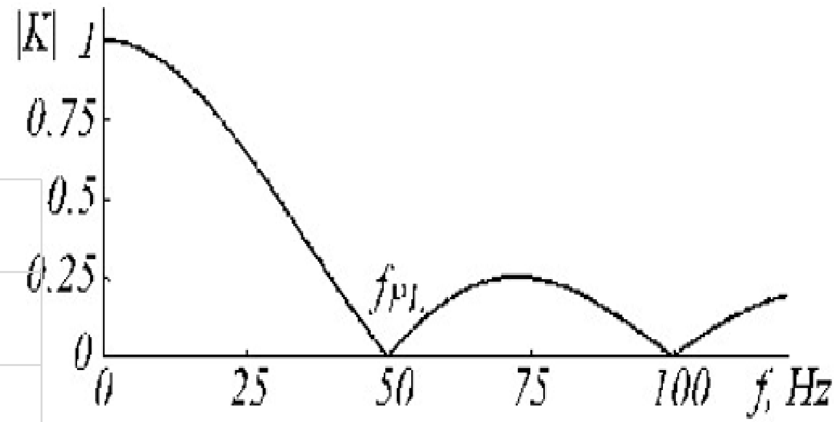


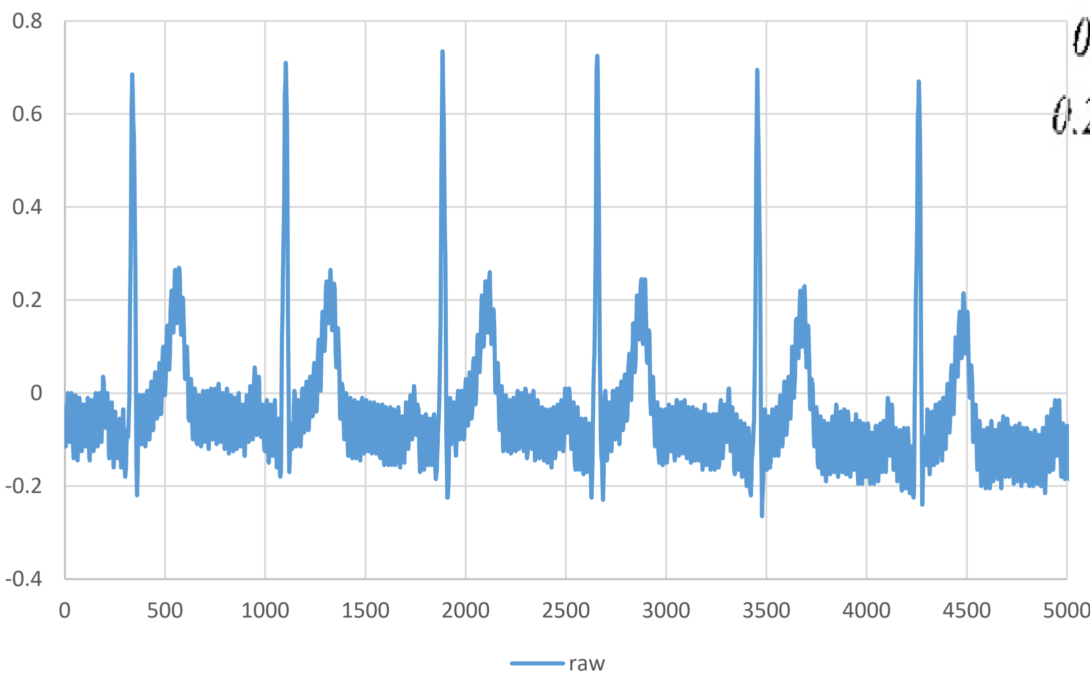
$$Signal(t) \leftarrow\rightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

$$\omega_i = 2\pi i/T$$

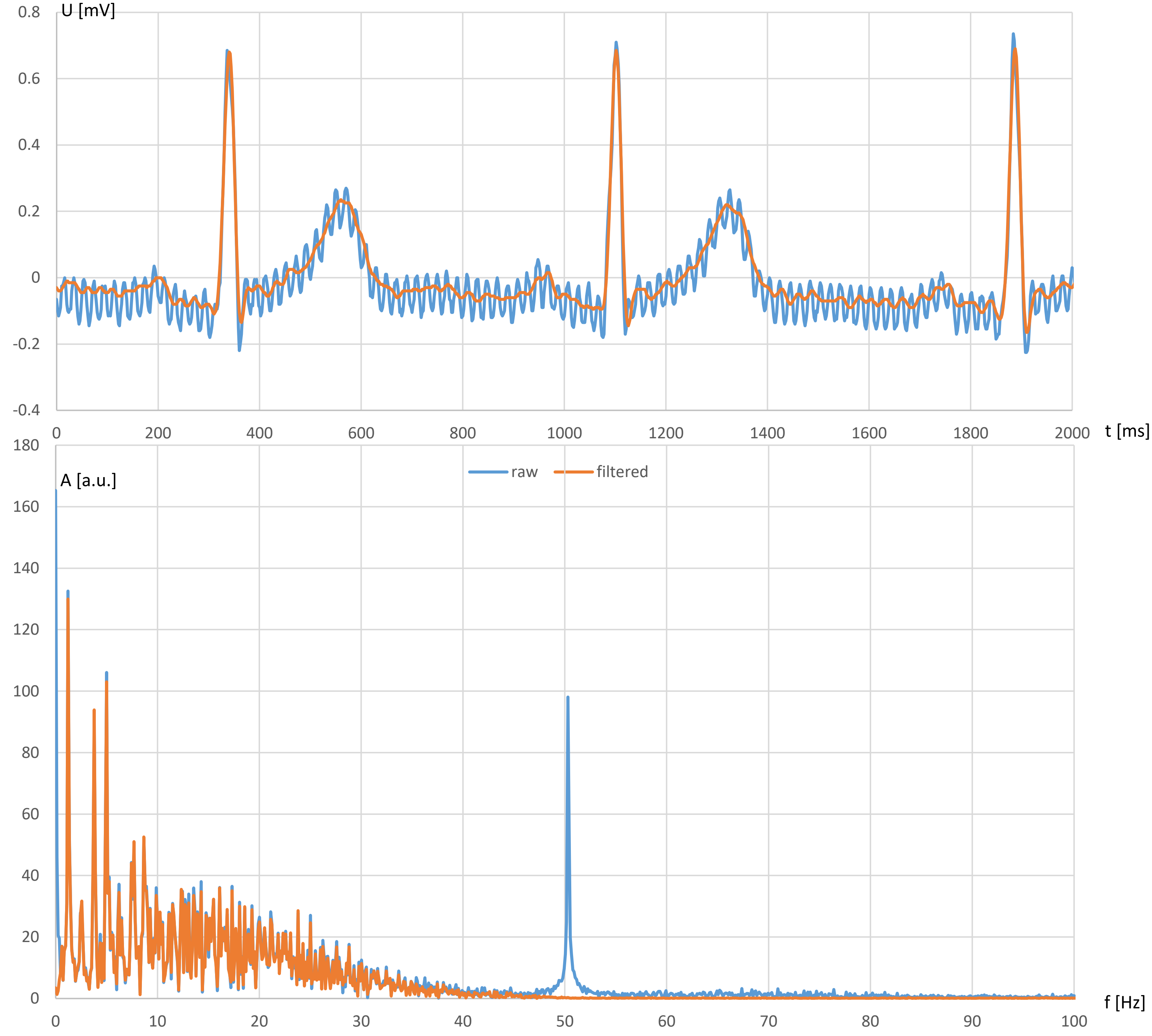
$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$



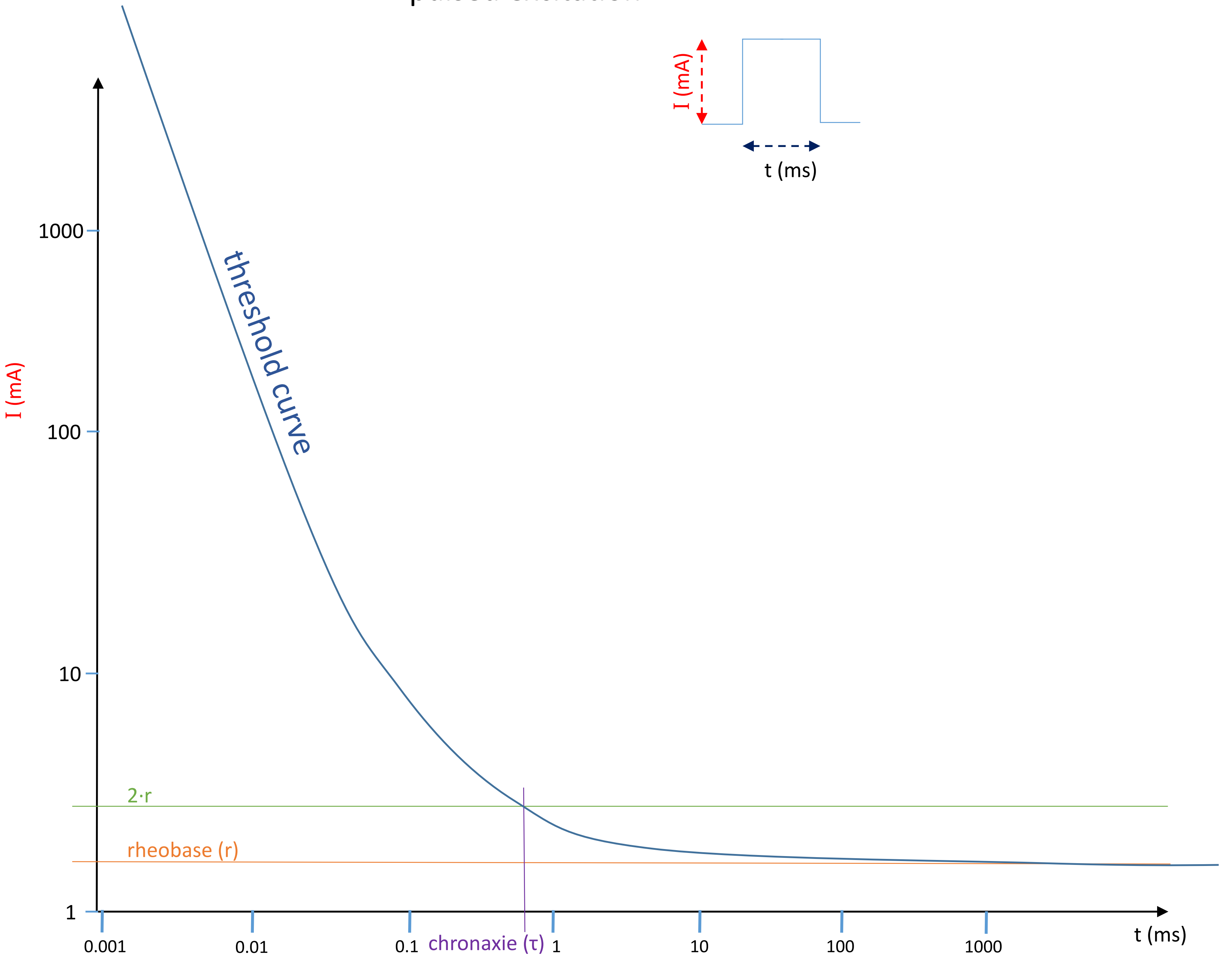



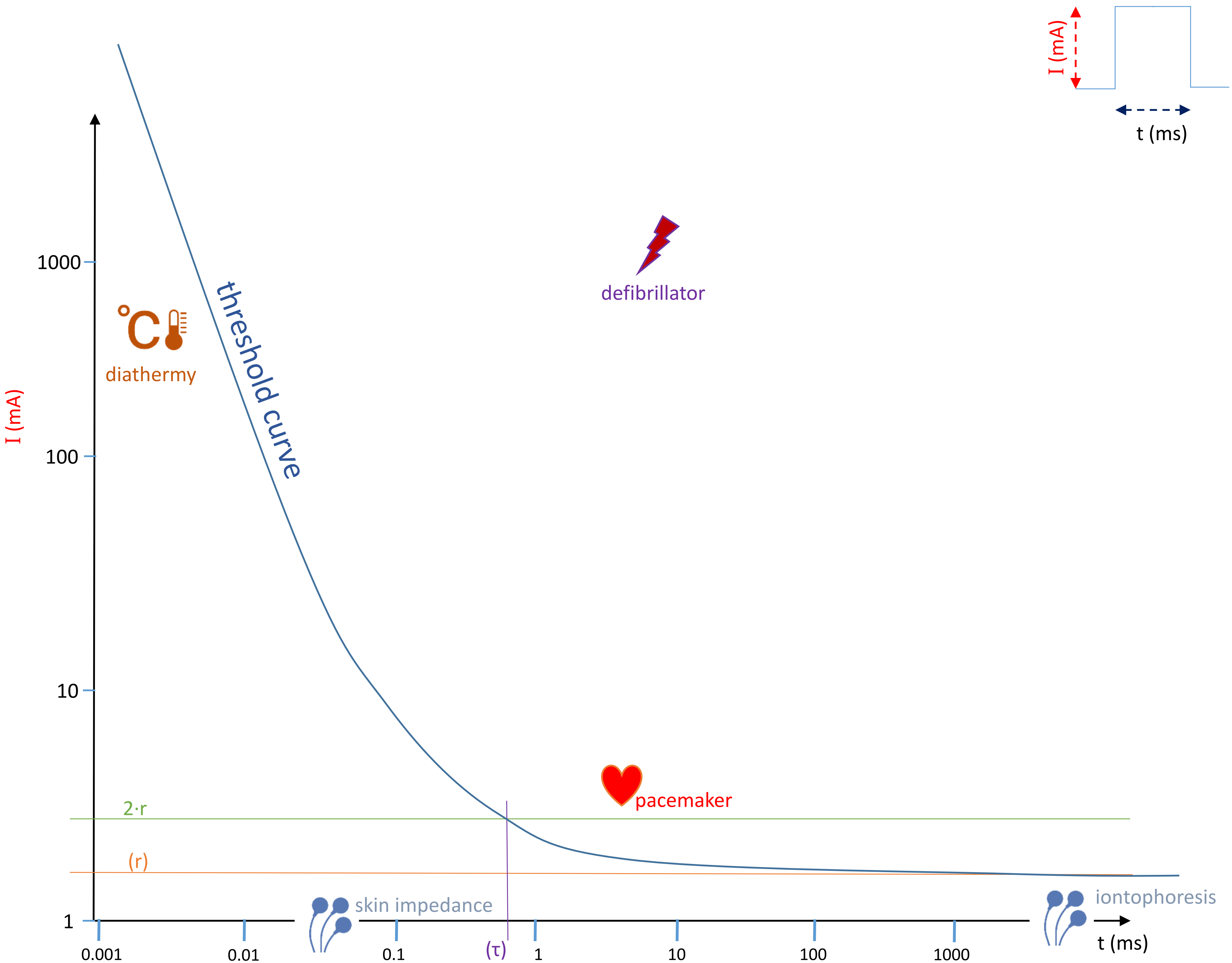

https://physionet.org/lightwave/?db=ecgiddb/1.0.0



U [mV]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
t [ms]
A [a.u.]
raw
filtered
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
f [Hz]

pulsed excitation

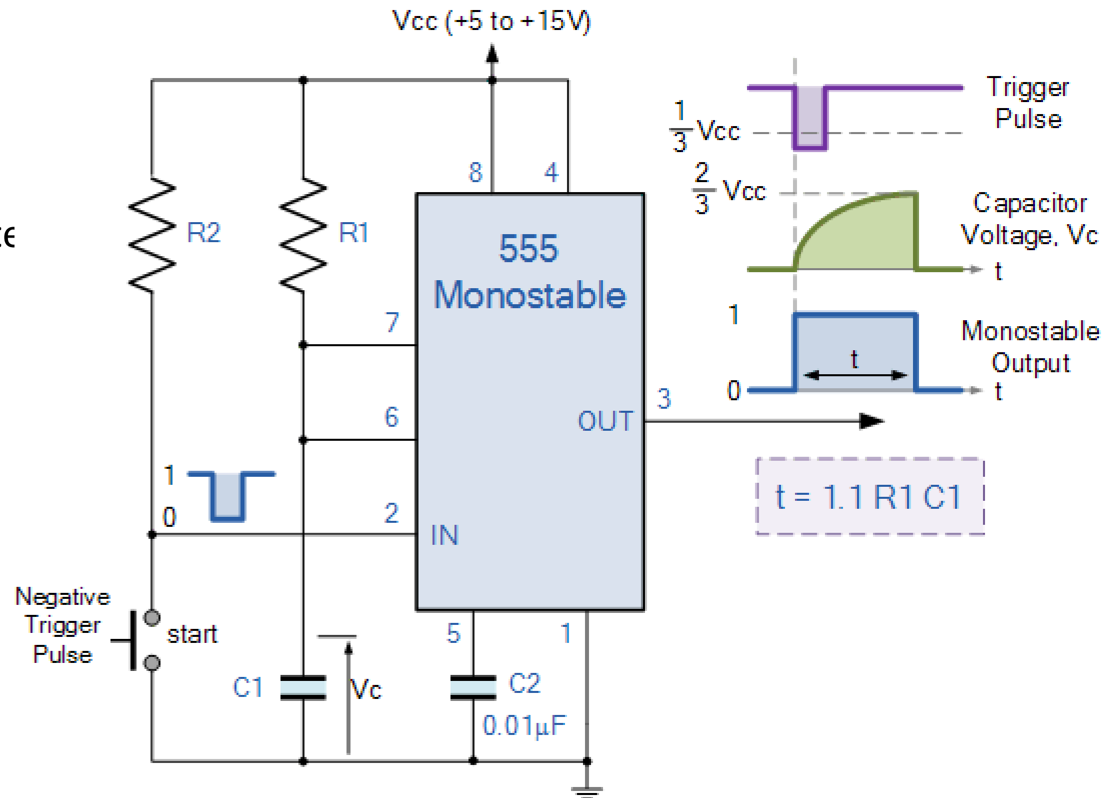


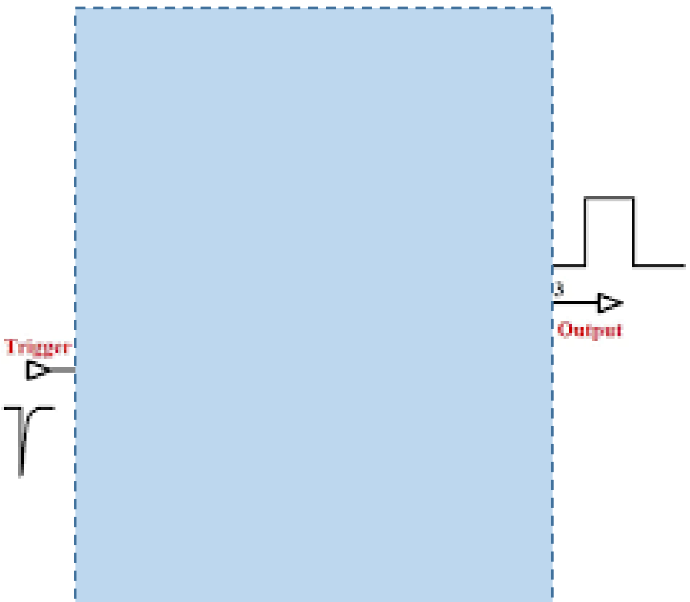


I (mA)
t (ms)
threshold curve
defibrillator
diathermy
1000
100
10
1
I (mA)
2·r
(r)
pacemaker
skin impedance
iontophoresis
0.001
0.01
0.1
(τ)
1
10
100
1000
t (ms)

## Pulse generators

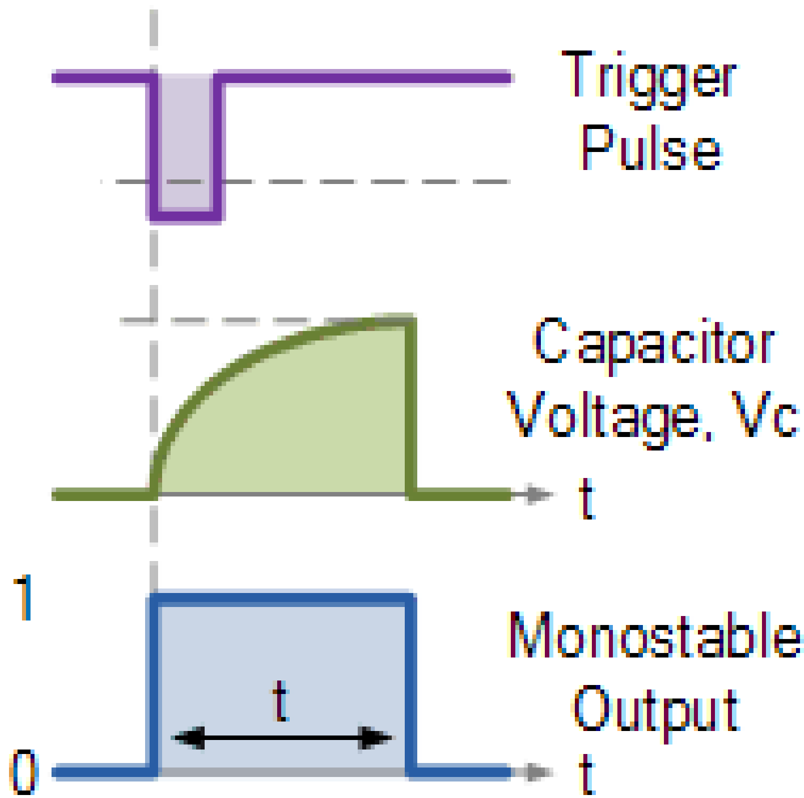
Trigger is an INPUT signal which generate controlled voltage-duration pulse at the output of the monostable circuit.

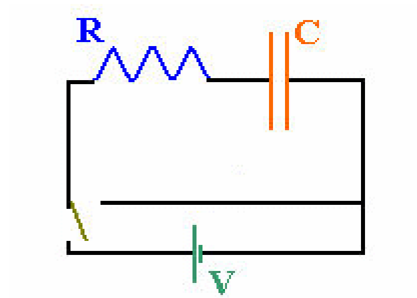


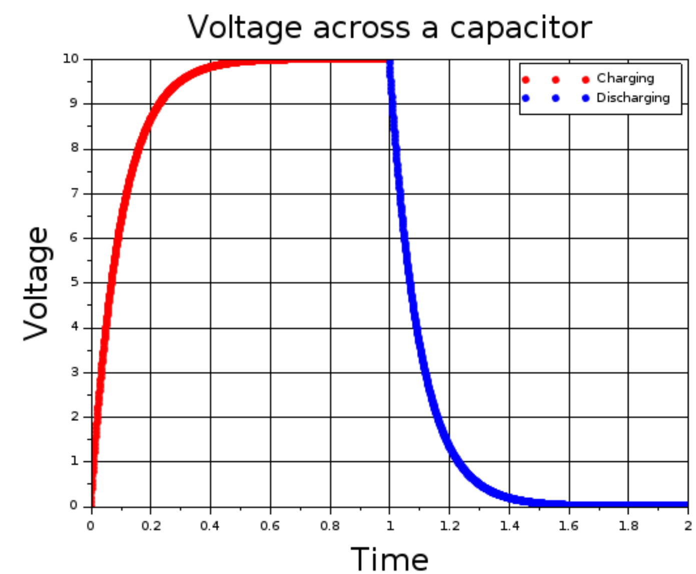

The **monostable** has ONE stable state, which is the inactive one.
The active output state is transient, and will be automatically switched off by the device without further external intervention.

The easiest/robust way to measure time is to charge or discharge a capacitor.

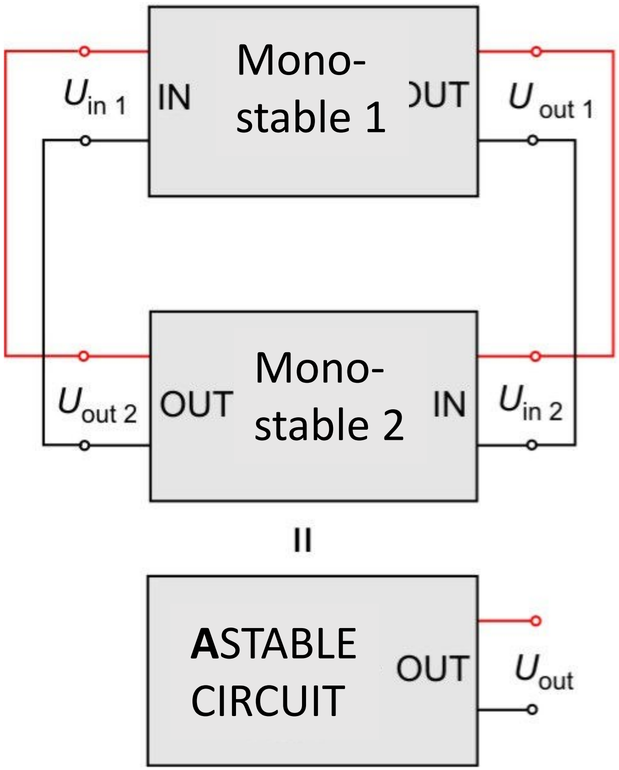


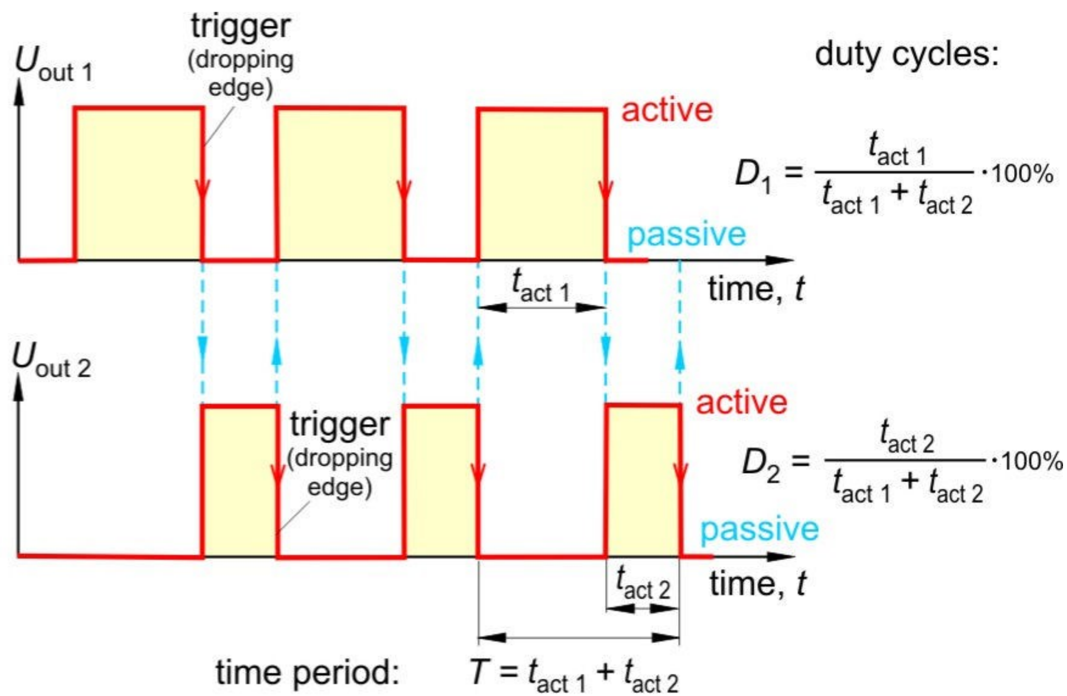



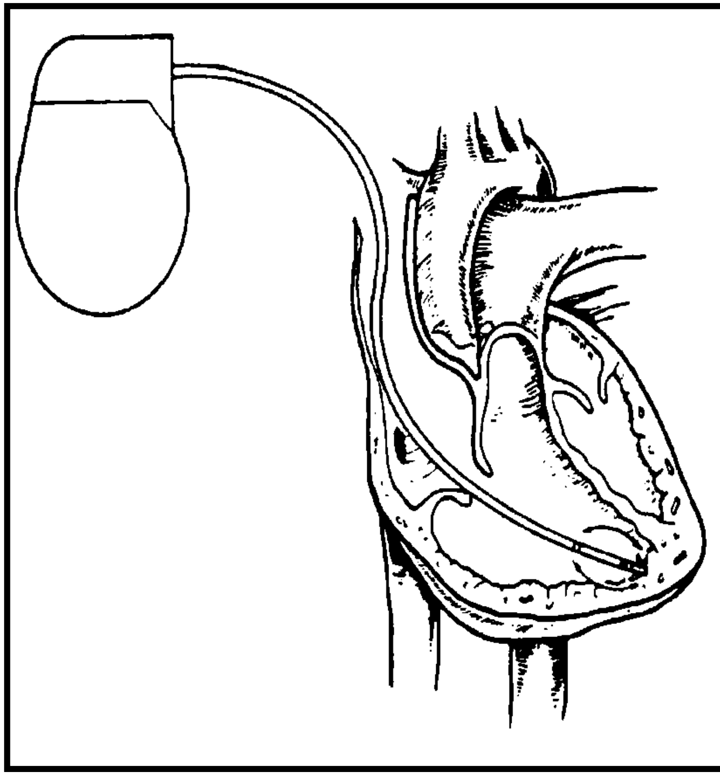

RC circuit charging or discharging

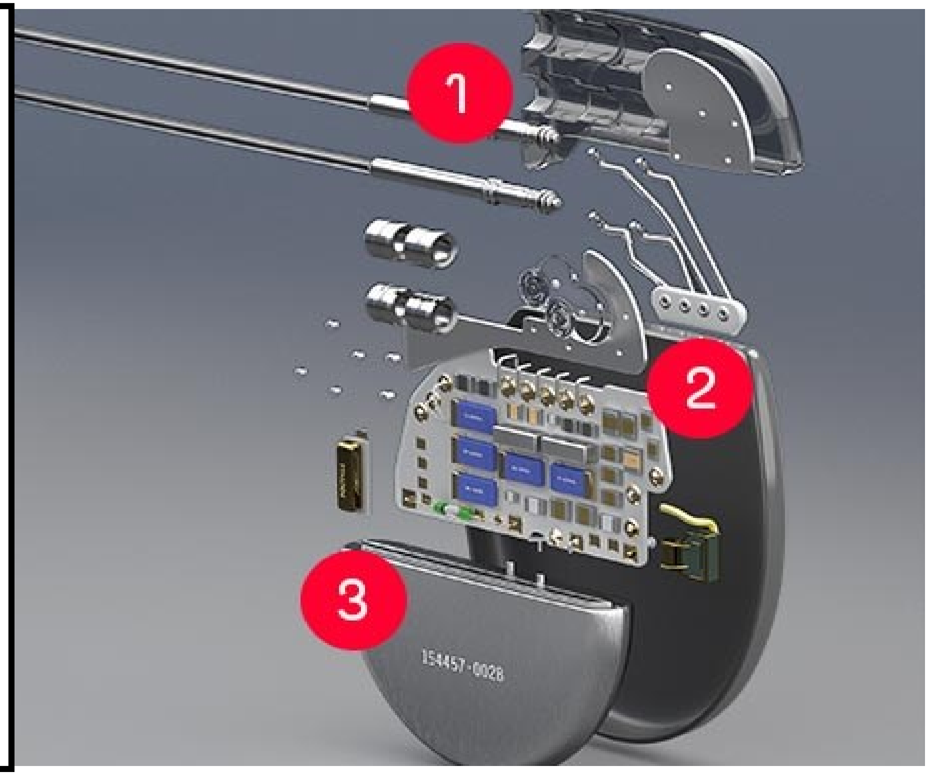


**Astable circuit**: generates a pulse train without external intervention, has no stable, persistent state.

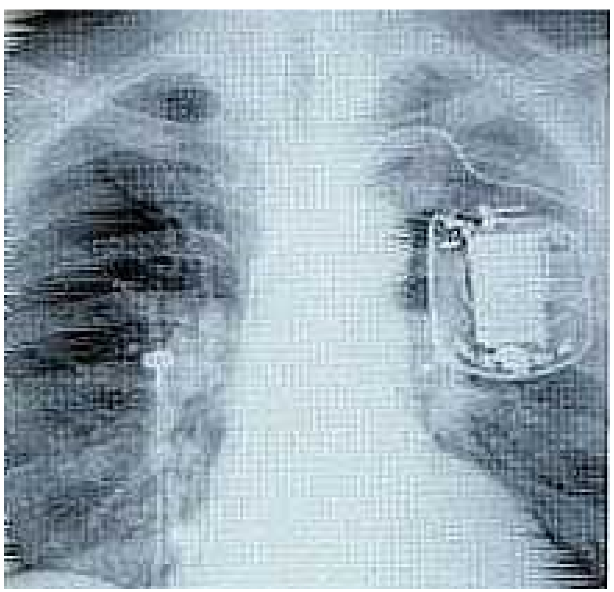





1
2
3
154457-0028

## Pacemaker



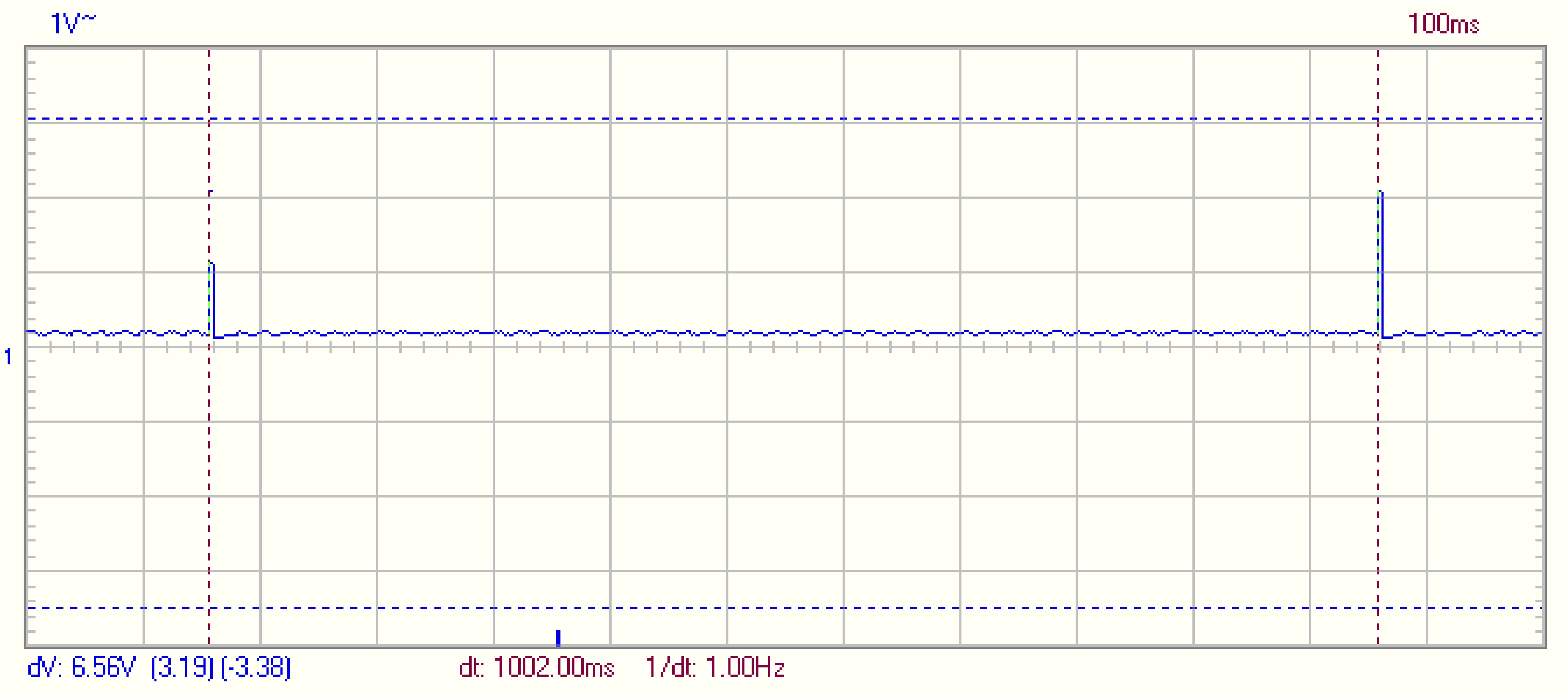

Enticos 4 SR
68505678
VVIR/AAIR
BIOTRONIK
Made in Germany
IS-1

# Pacemaker

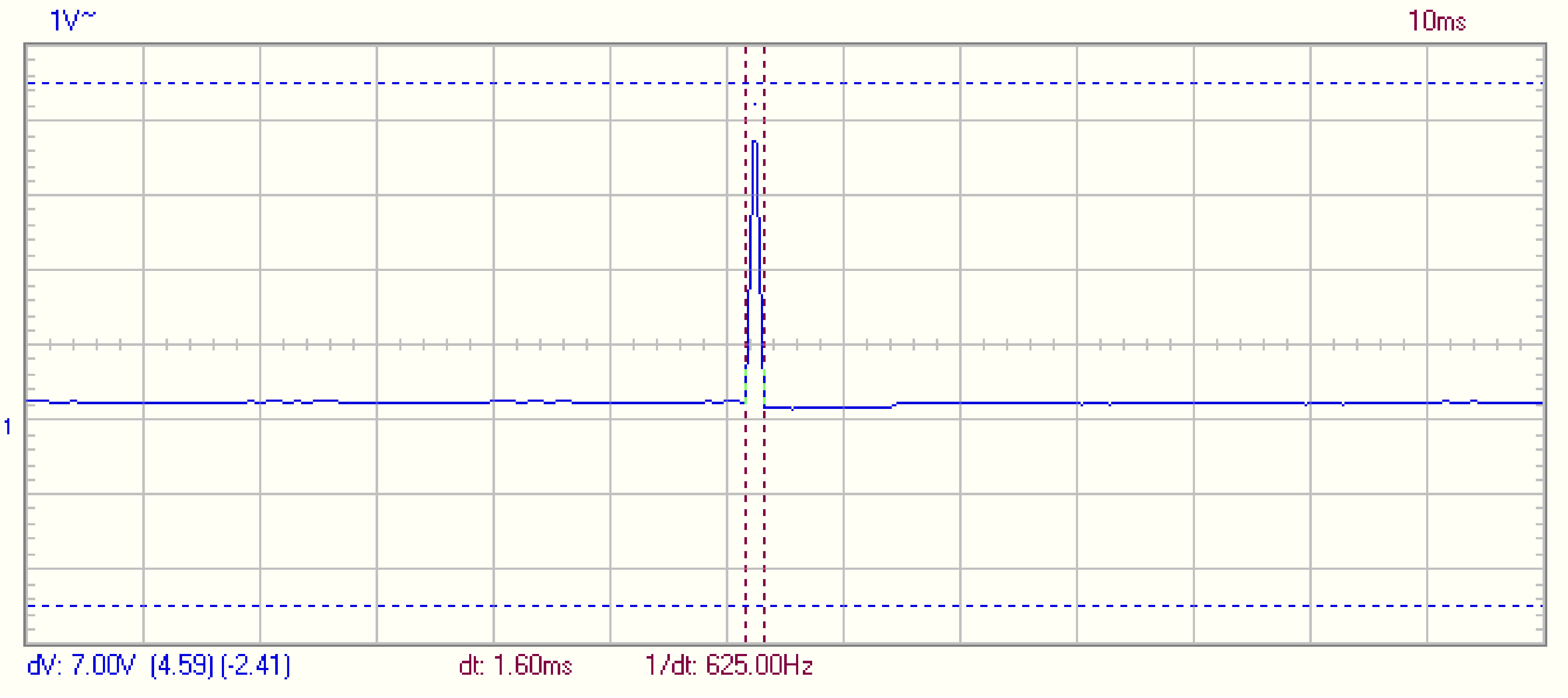
| I. | II. | III. | IV. | V. |
|---|---|---|---|---|
| Chamber(s) Paced | Chamber(s) Sensed | Response to Sensing | Rate Modulation | Multisite Pacing |
| 0 = None | 0 = None | 0 = None | 0 = None | 0 = None |
| A = Atrium | A = Atrium | I = Inhibited | R = Rate Modulation | A = Atrium |
| V = Ventricle | V = Ventricle | T = Triggered | | V = Ventricle |
| D = Dual (A+V) | D = Dual (A+V) | D = Dual (I+T) | | D =Dual (A+V) |


Here we have: VVIR/AAIR

The time period is approx. 1s without regulation



Typical pulse duration is 1-2 ms



# Calculation of pulse energy

Known voltage and tissue resistance, known pulse duration time

$$E = \frac{U^2}{R}\tau$$

$$Q = \frac{U}{R}\tau$$

P=U*I , I=U/R
$P=U^2/R$
R=P*t

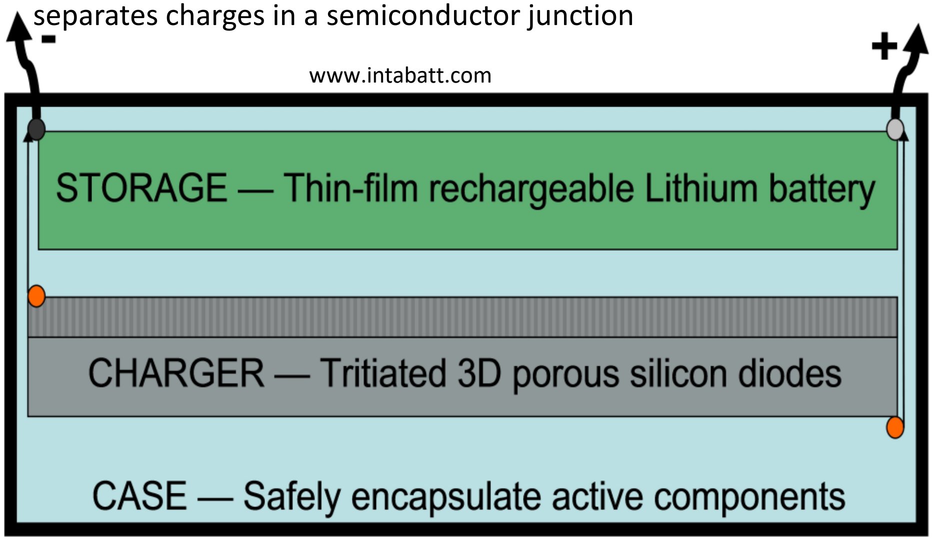
t=τ=R*C

Q=I*t

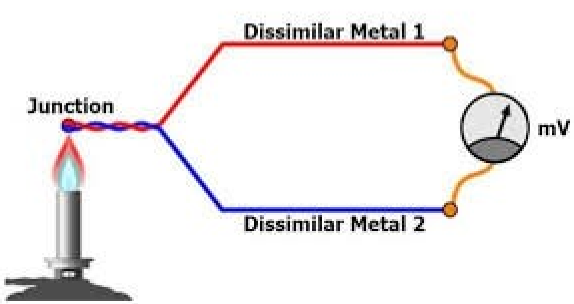
**A LONG lasting battery is needed.**
**A battery change = exchange of the whole device = operation!**

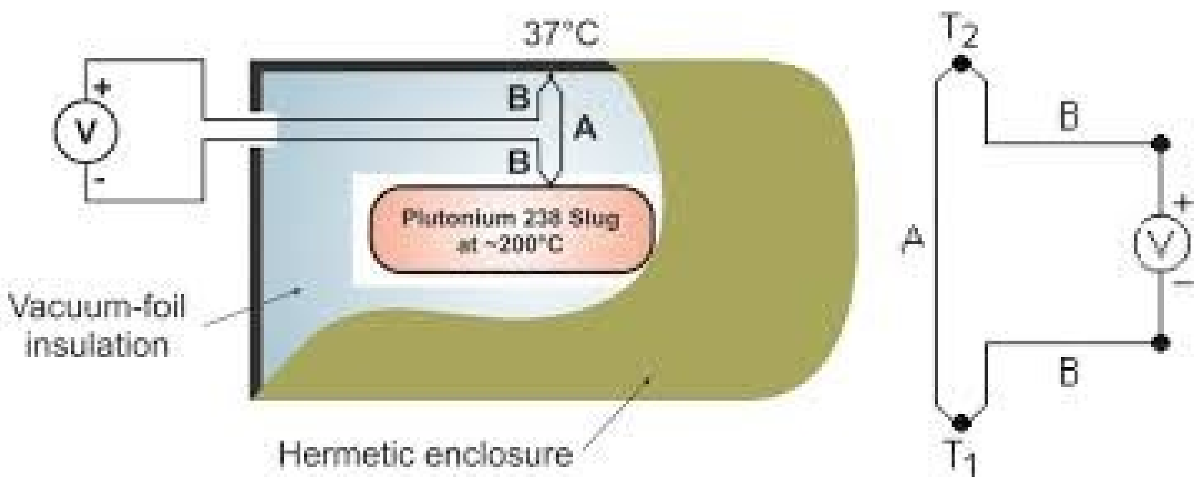
## β-radiation powered cell.

Betavoltaic cell: similar to photovoltaics, the ionization separates charges in a semiconductor junction



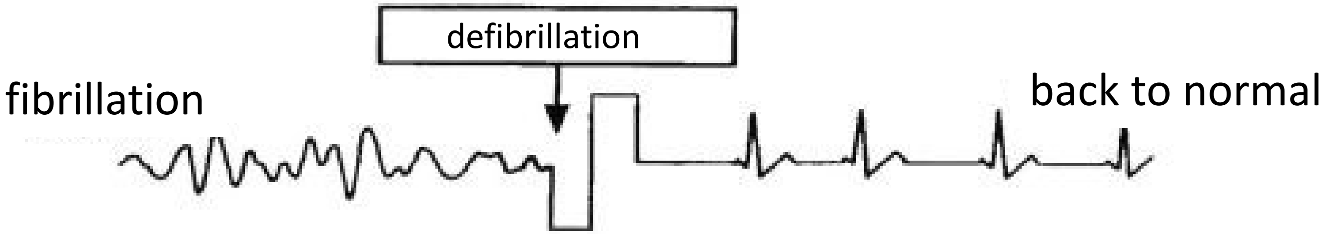

## RTG : radioaktive thermoelectric generator

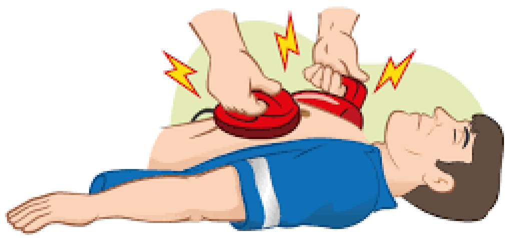



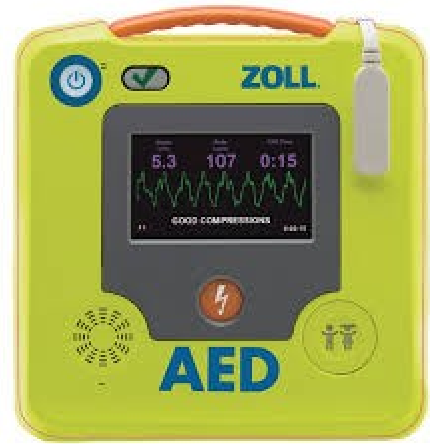



## Defibrillator

(monostable)



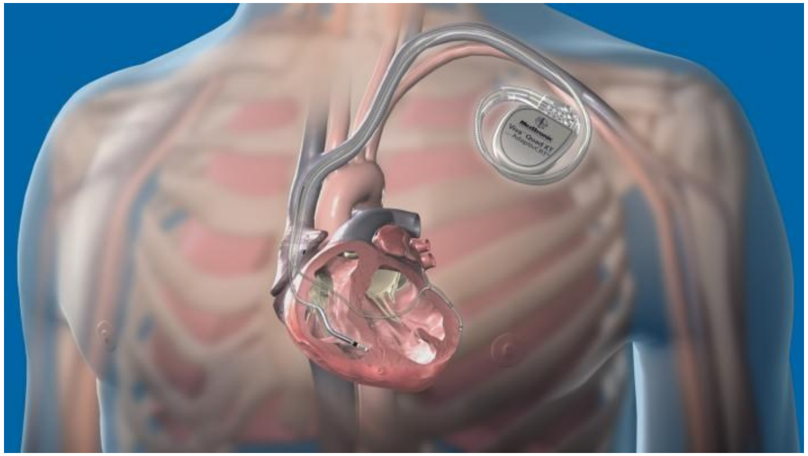



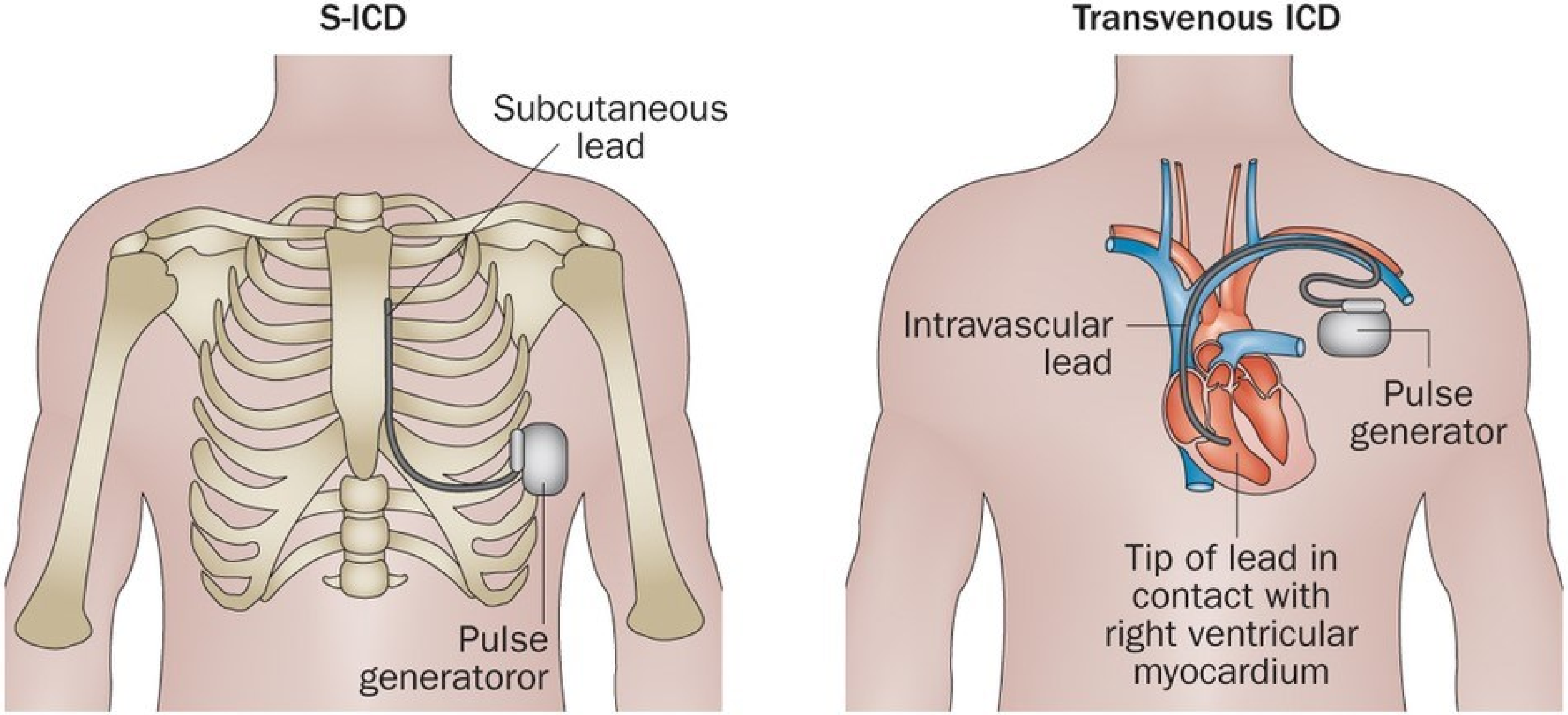



AED: Automated External Defibrillator

## Cardioverter

ICD: Implantable Cardioverter Defibrillator



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