HST.582J / 6.555J / 16.456J Biomedical Signal and Image Processing
Spring 2007

Harvard-MIT Division of Health Sciences and Technology
HST.582J: Biomedical Signal and Image Processing, Spring 2007
Course Director: Dr. Julie Greenberg

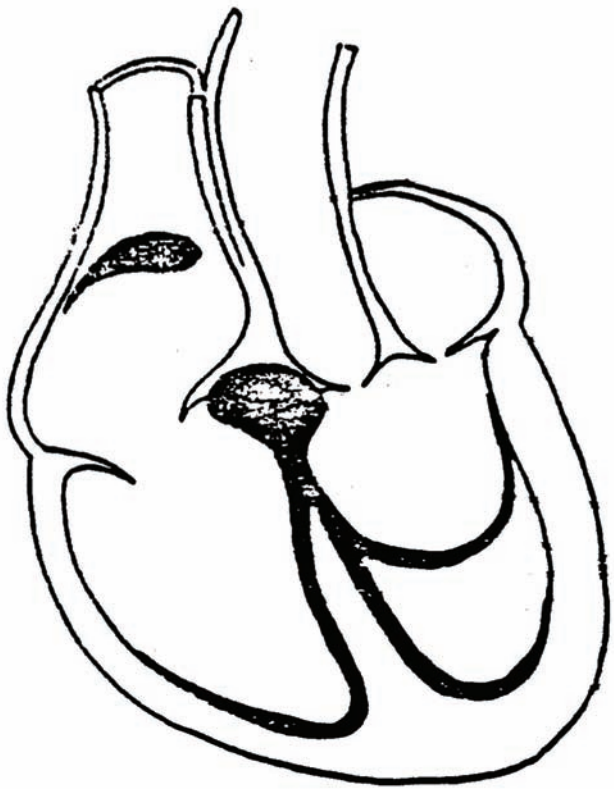
# Introduction to Clinical Electrocardiography

Andrew Reisner, MD
MGH Dept. of Emergency Medicine
Visiting Scientist, HST

# Electrocardiography

- The heart is an electrical organ, and its activity can be measured non-invasively
- Wealth of information related to:
  - The electrical patterns proper
  - The geometry of the heart tissue
  - The metabolic state of the heart
- Standard tool used in a wide-range of medical evaluations

# A heart



- Blood circulates, passing near every cell in the body, driven by this pump
- …actually, two pumps…
- Atria = turbochargers
- Myocardium = muscle
- Mechanical systole
- Electrical systole

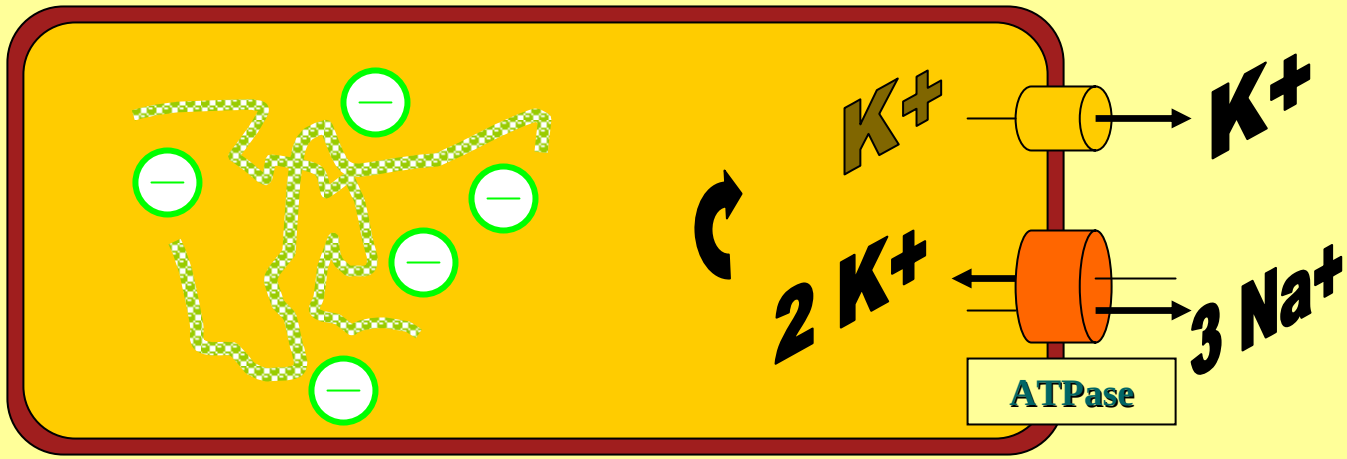
Courtesy of Dr. Roger Mark. HST.542J Quantitative Physiology: Organ Transport Systems, Spring 2004. (Massachusetts Institute of Technology: MIT OpenCourseWare). http://ocw.mit.edu (accessed June 17, 2008).
Figure adapted from Phillips RE, Feeney MK, 1980 The Cardiac Rhythms. Saunders, Philadelphia and from Hoffman BF, Cranefield PF 1960 Electrophysiology of the Heart. McGraw Hill, New York.

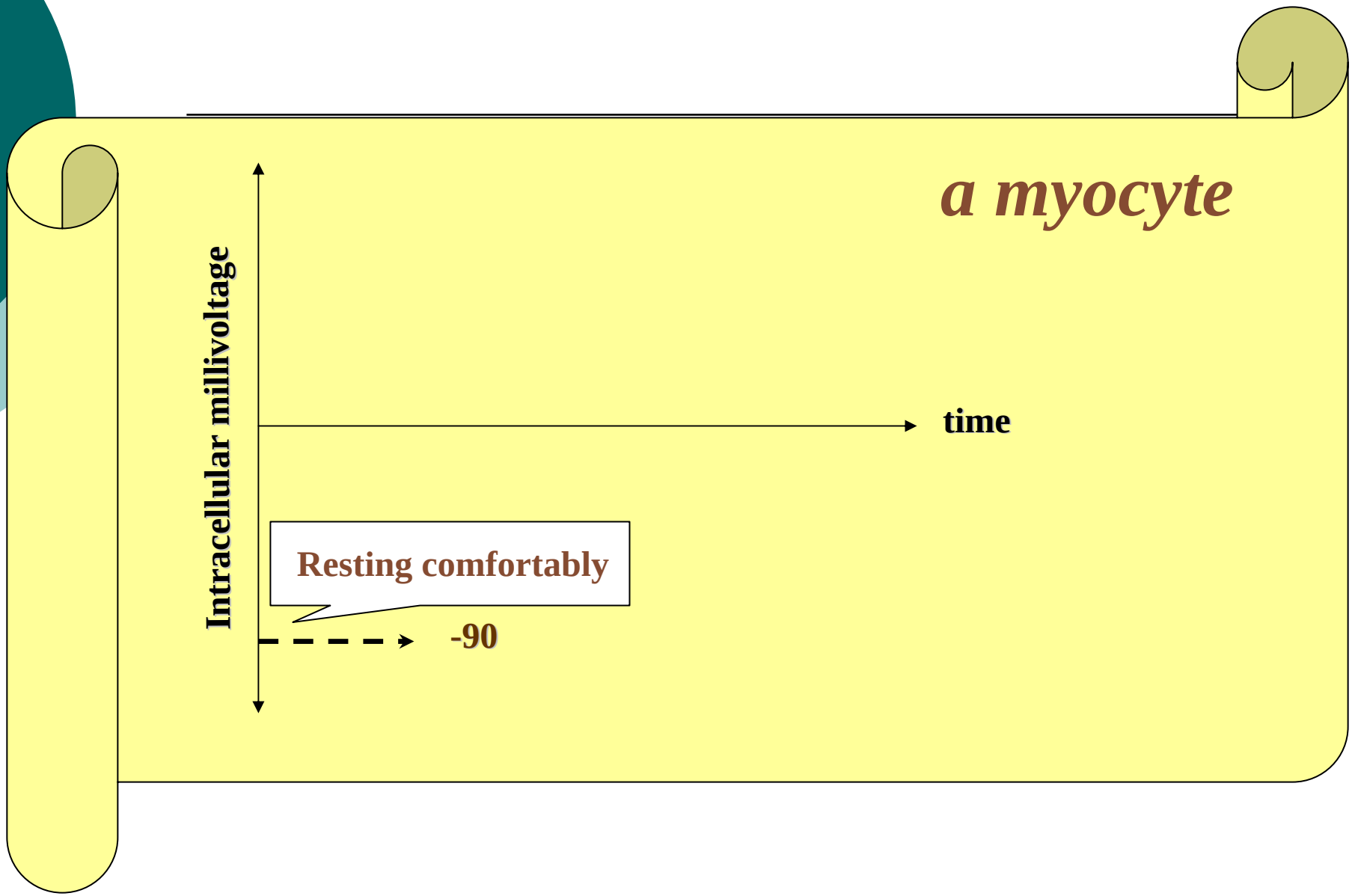
# To understand the ECG:

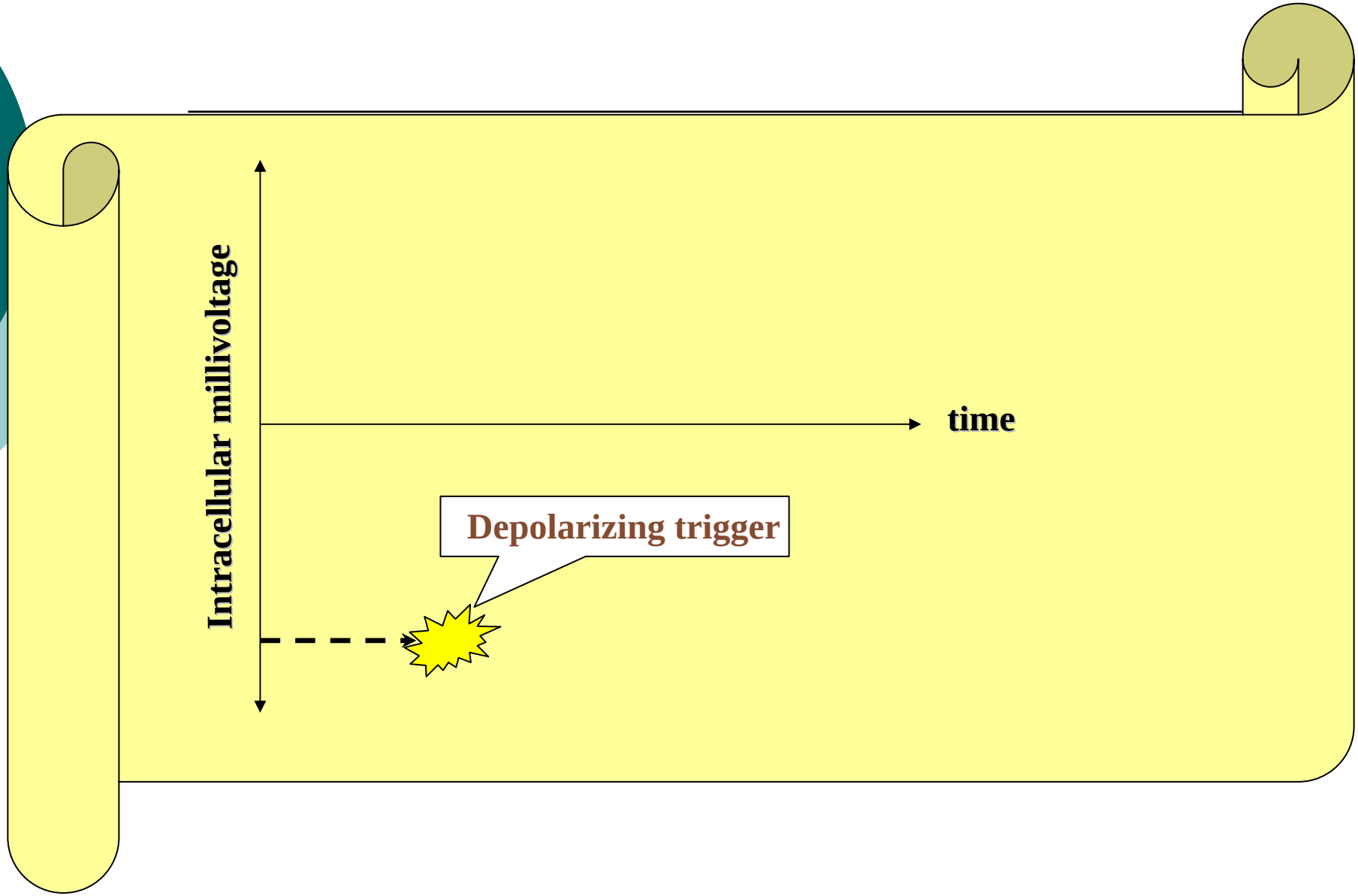
- Electrophysiology of a single cell
- How a wave of electrical current propagates through myocardium
- Specific structures of the heart through which the electrical wave travels
- How that leads to a measurable signal on the surface of the body

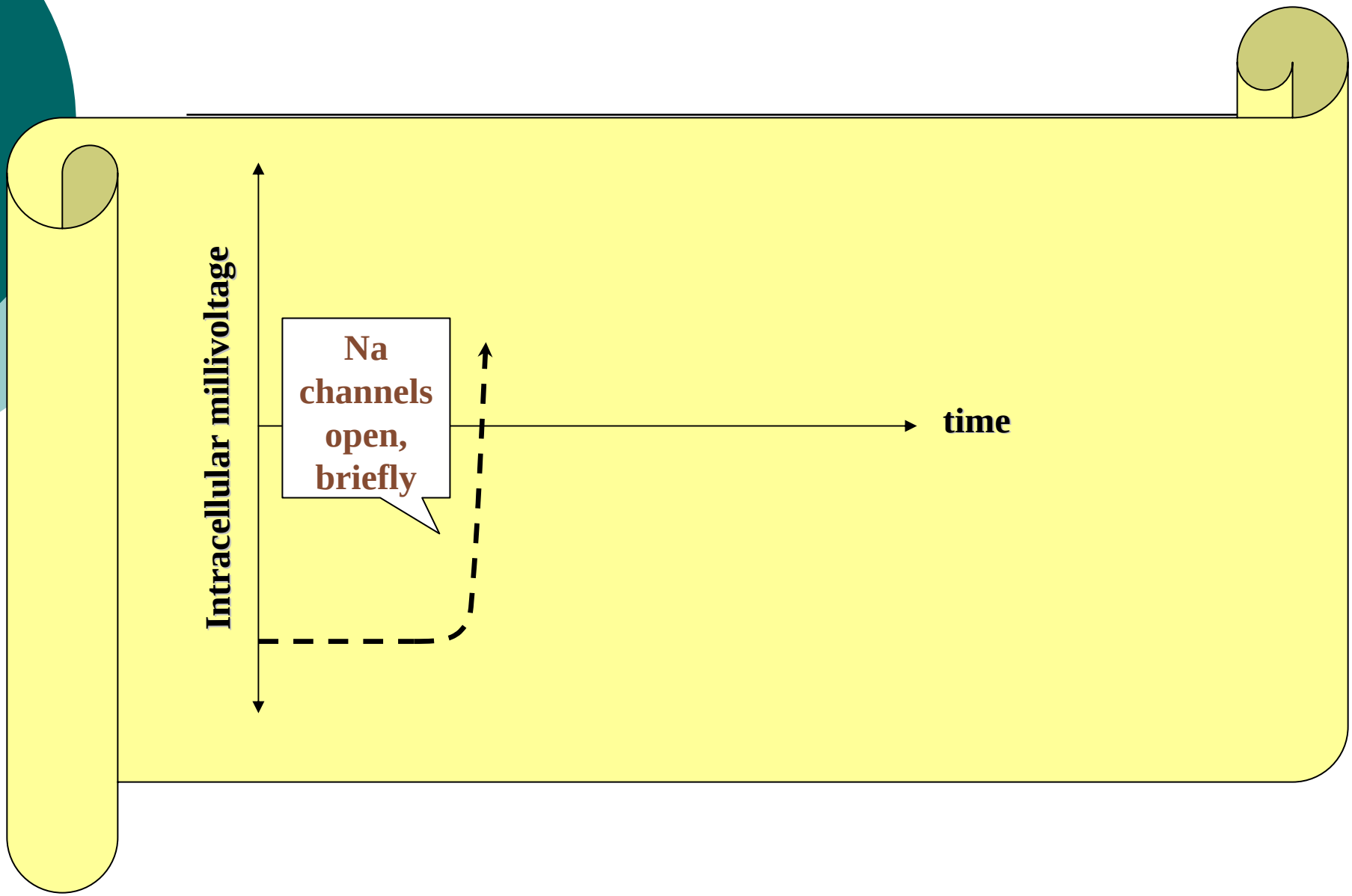
# *Part I: A little electrophysiology*

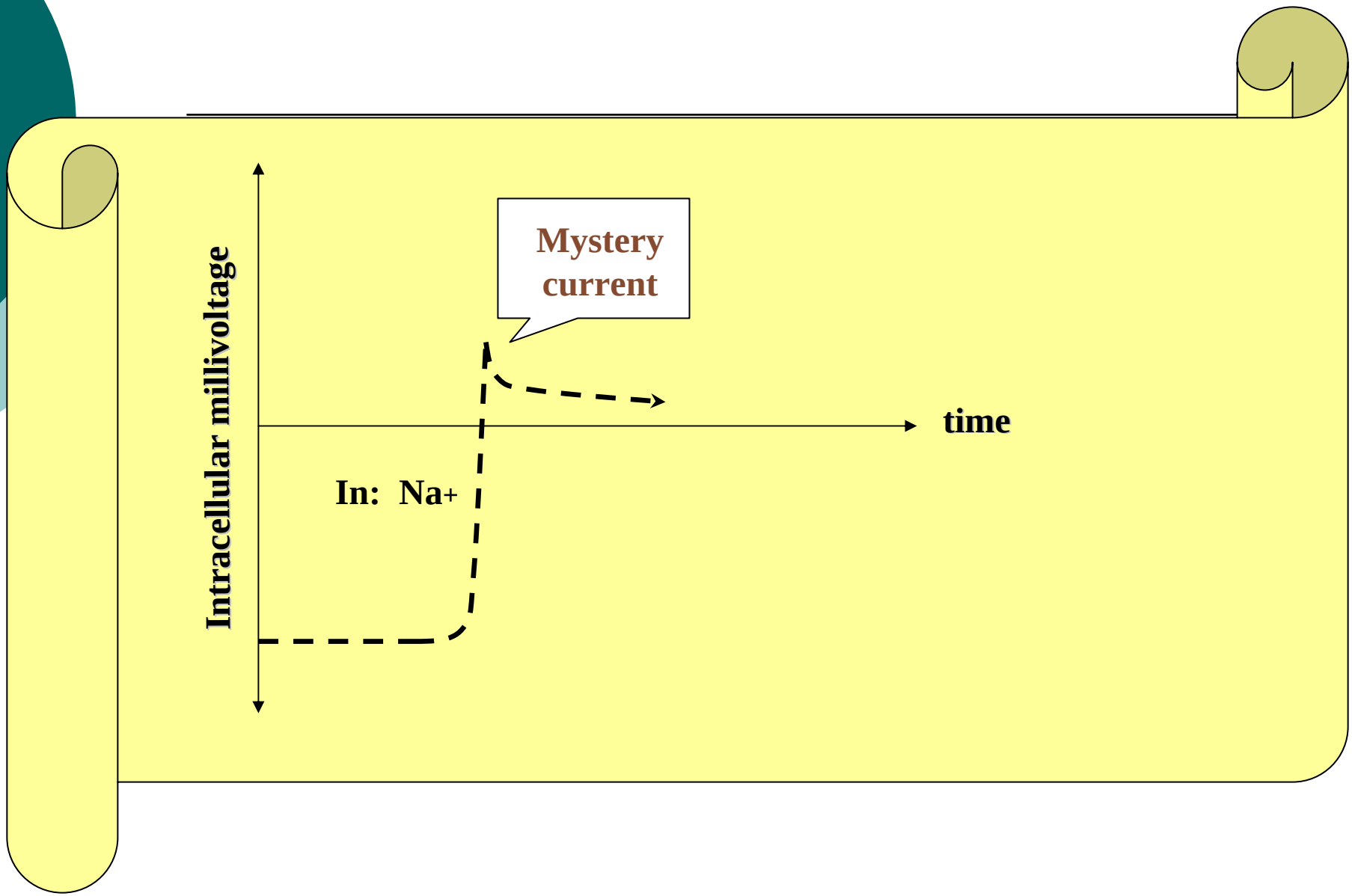
# *Once upon a time, there was a cell:*

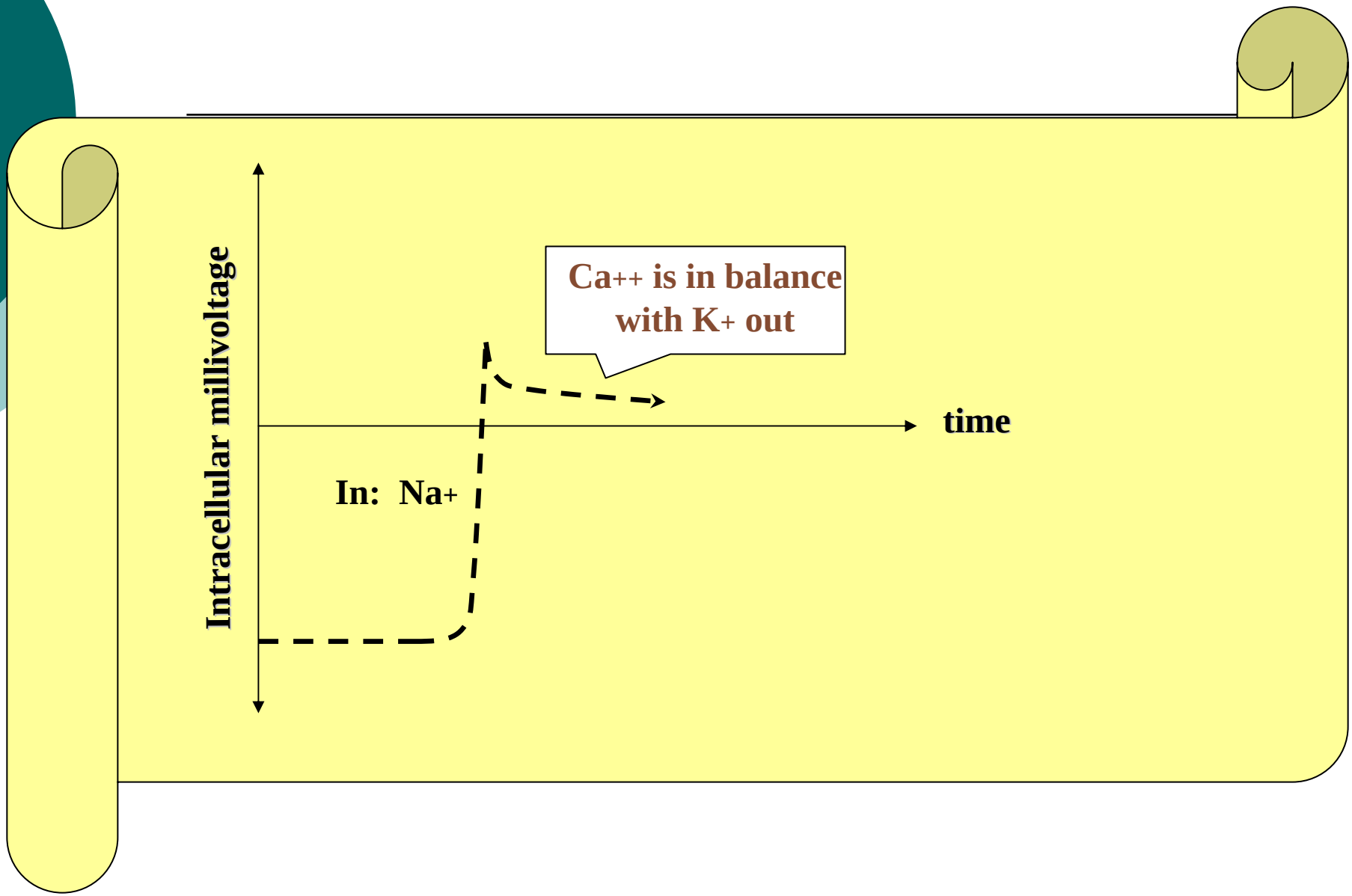


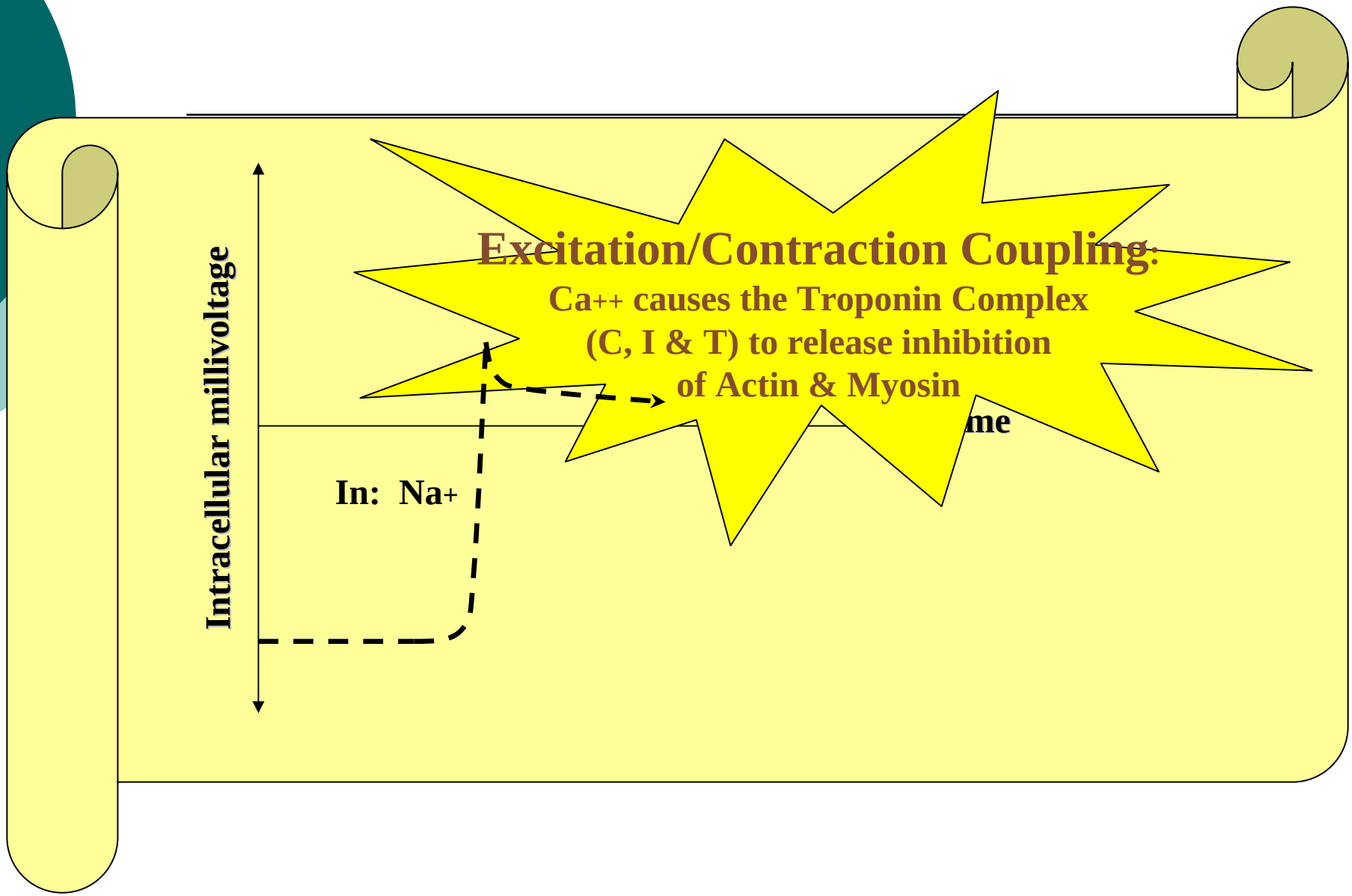


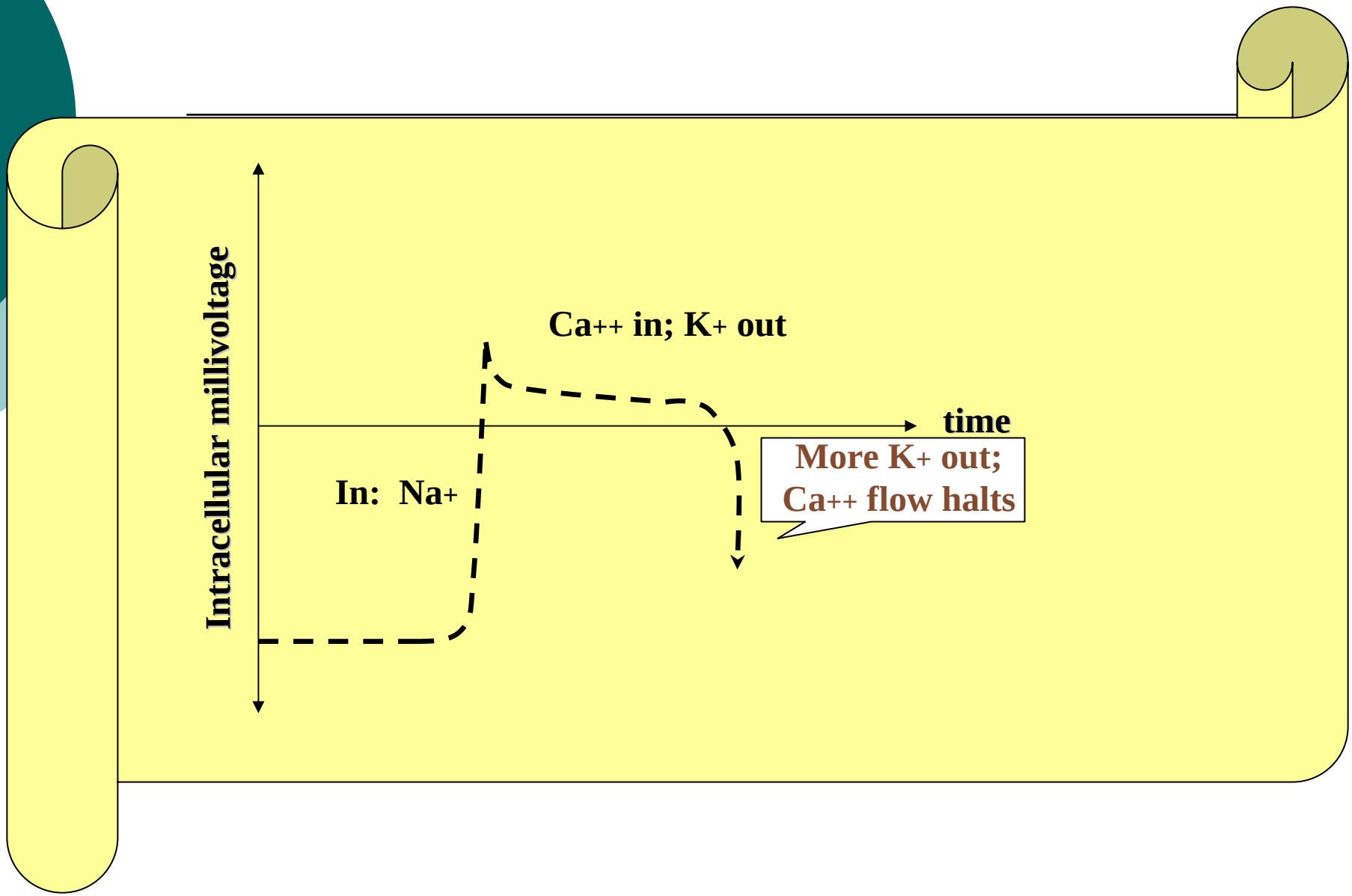


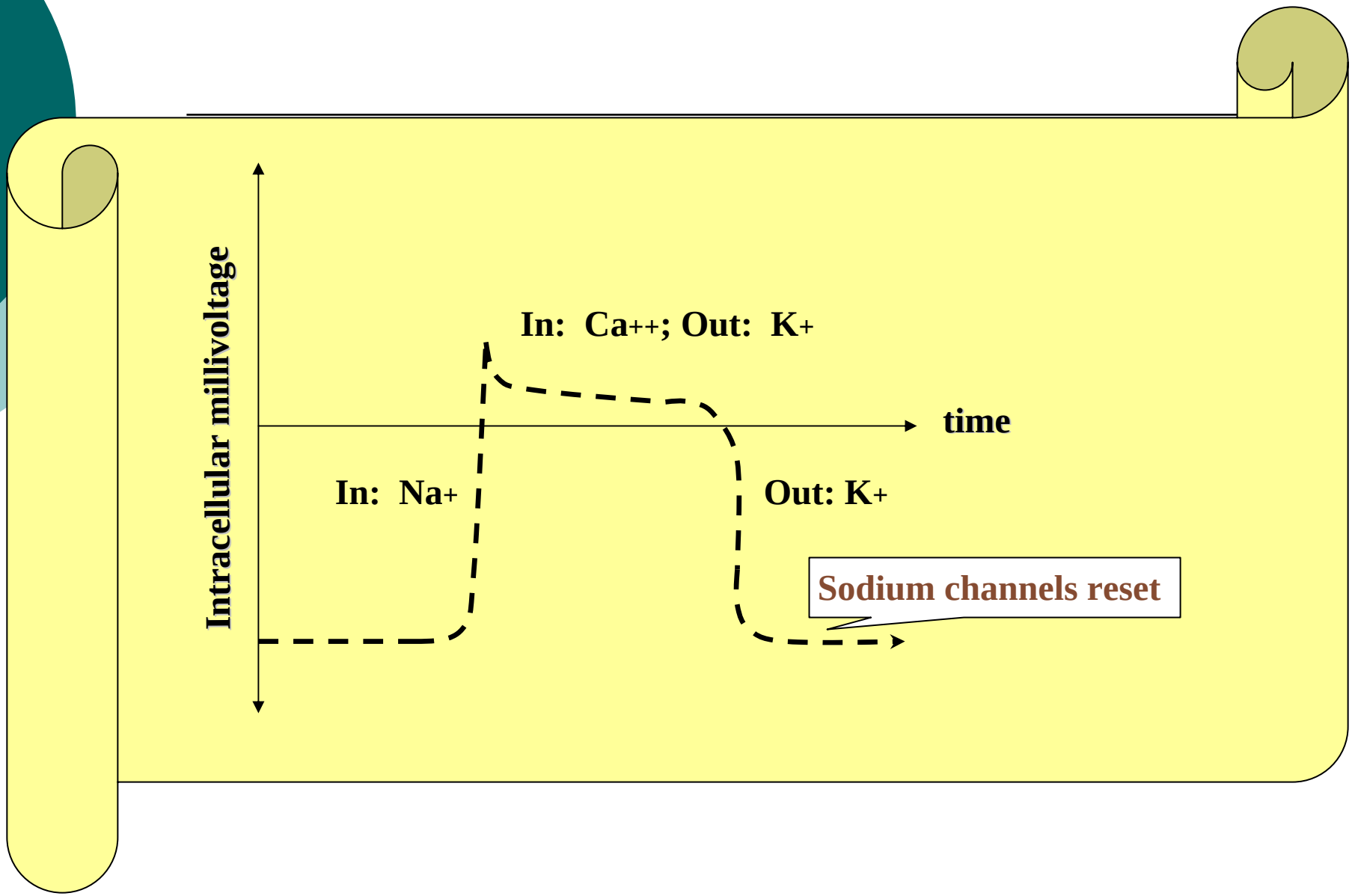


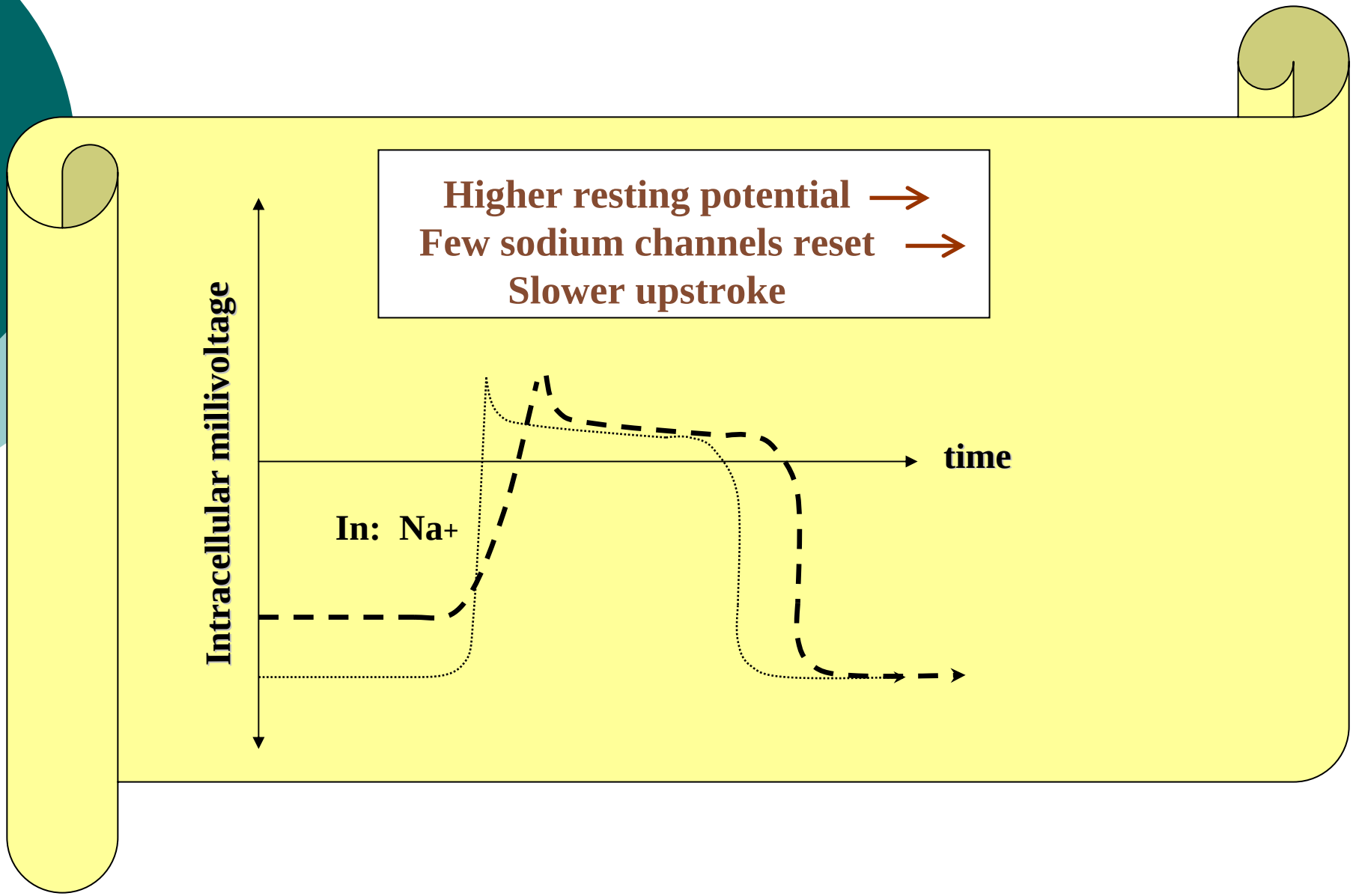




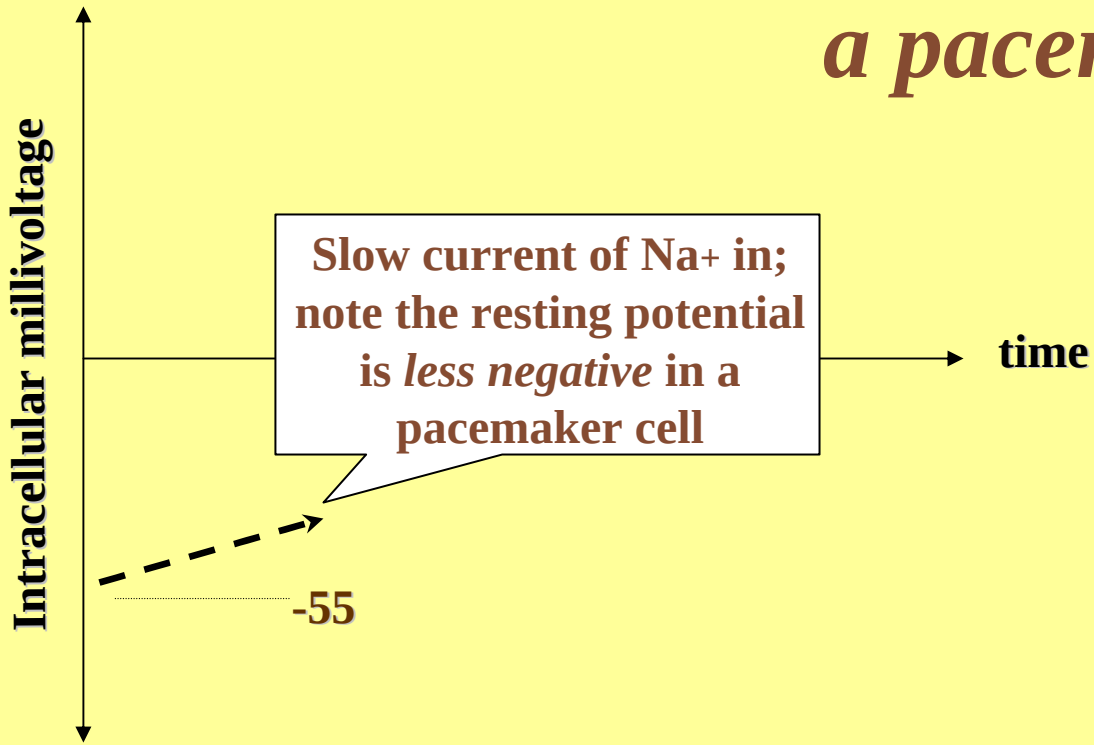




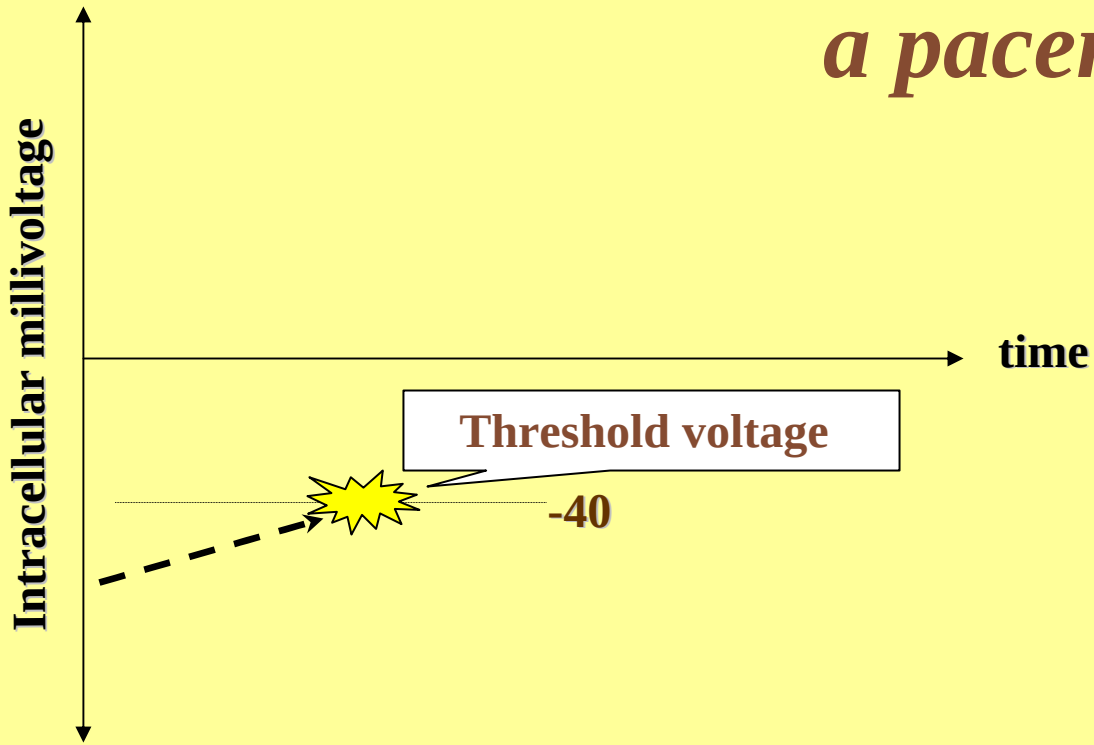


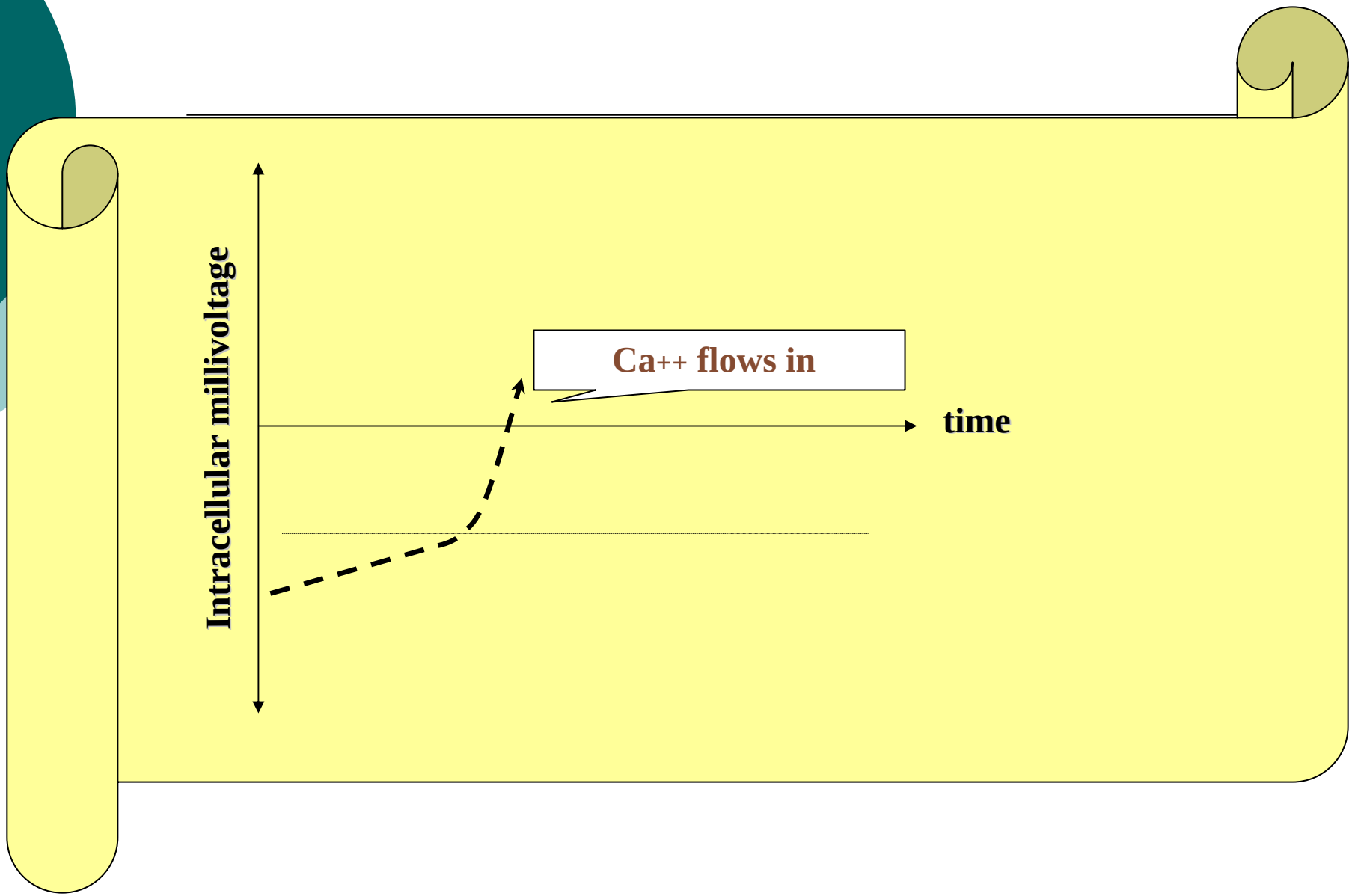


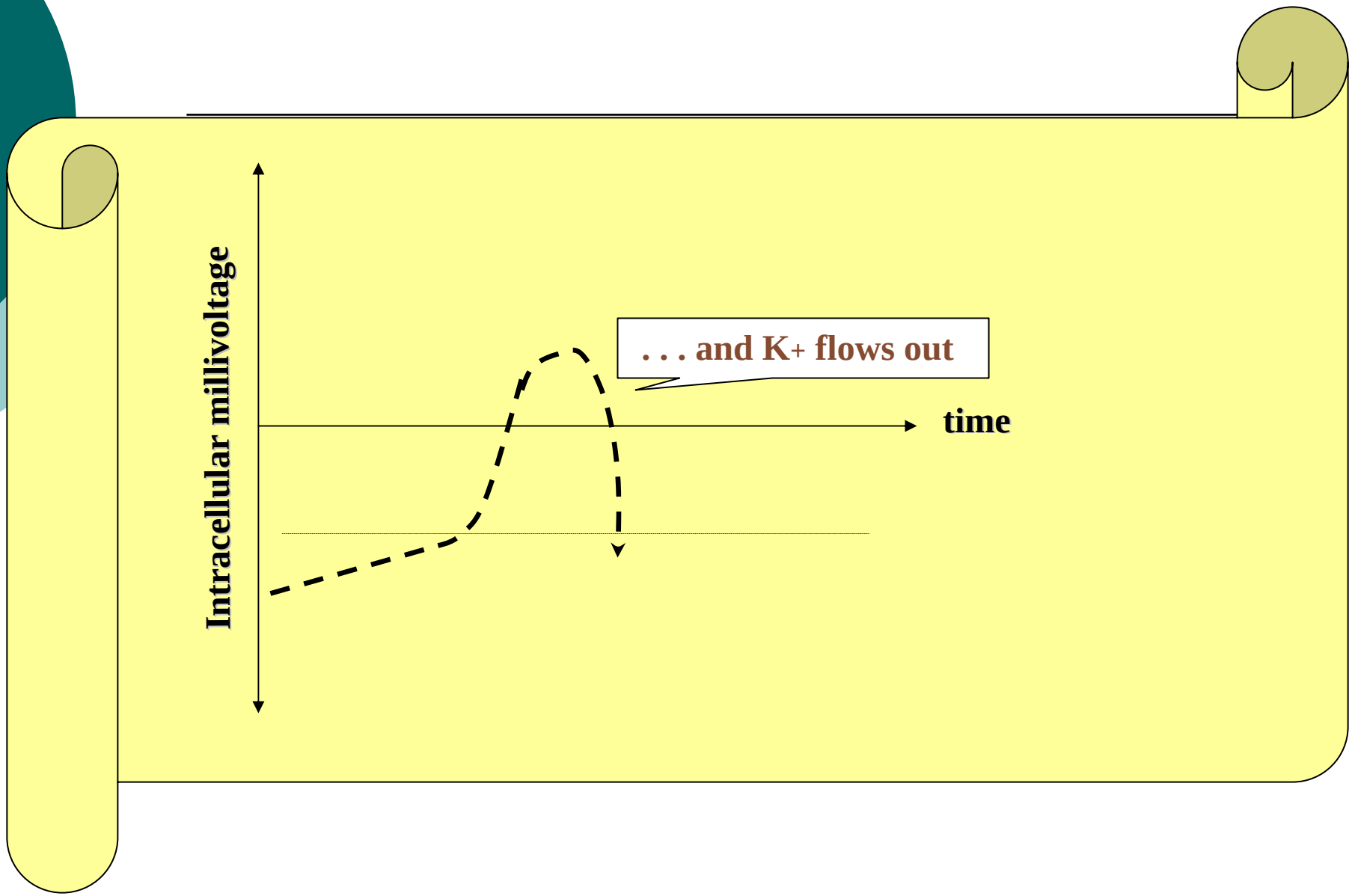
# *a pacemaker cell*

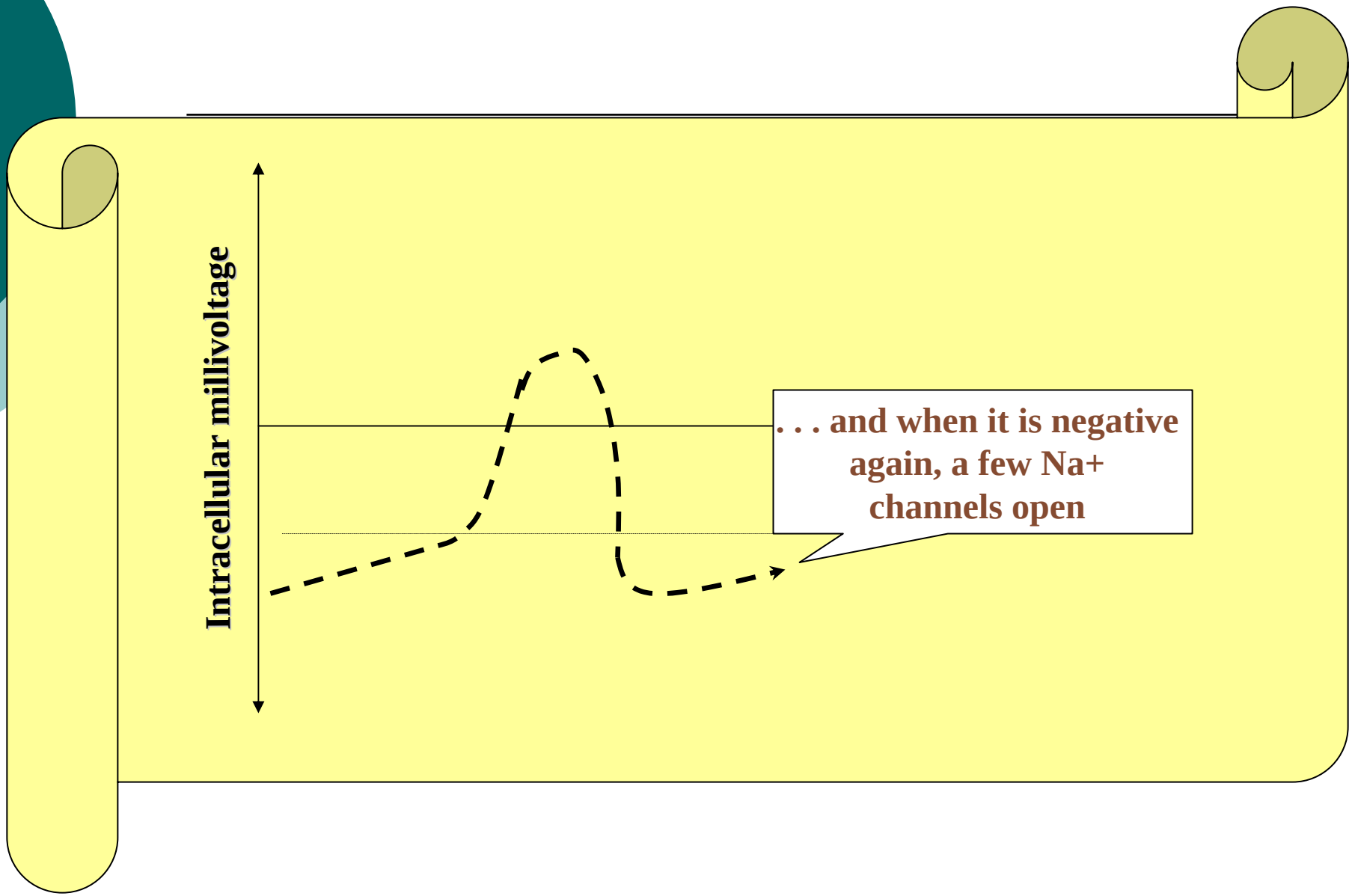


# *a pacemaker cell*







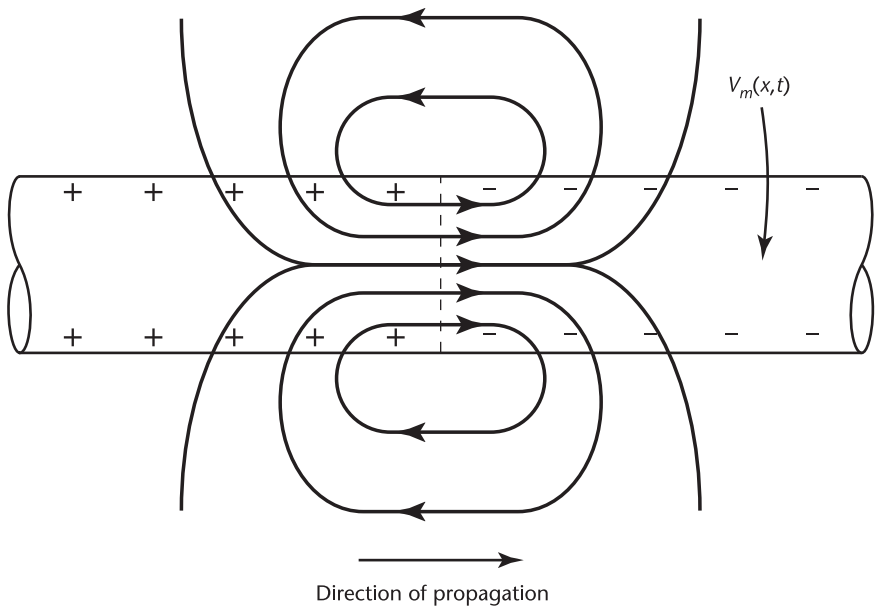


# How a wave of electrical current propagates through myocardium

- Typically, an impulse originating anywhere in the myocardium will propagate throughout the heart
- Cells communicate electrically via "gap junctions"
- Behaves as a "syncytium"
- Think of the "wave" at a football game!

# The dipole field due to current flow in a myocardial cell at the advancing front of depolarization.

***Vm*** is the transmembrane potential.




Courtesy of Dr. Roger Mark. *HST.542J Quantitative Physiology: Organ Transport Systems, Spring 2004*. (Massachusetts Institute of Technology: MIT OpenCourseWare). http://ocw.mit.edu (accessed June 17, 2008).

# Cardiac Electrical Activity

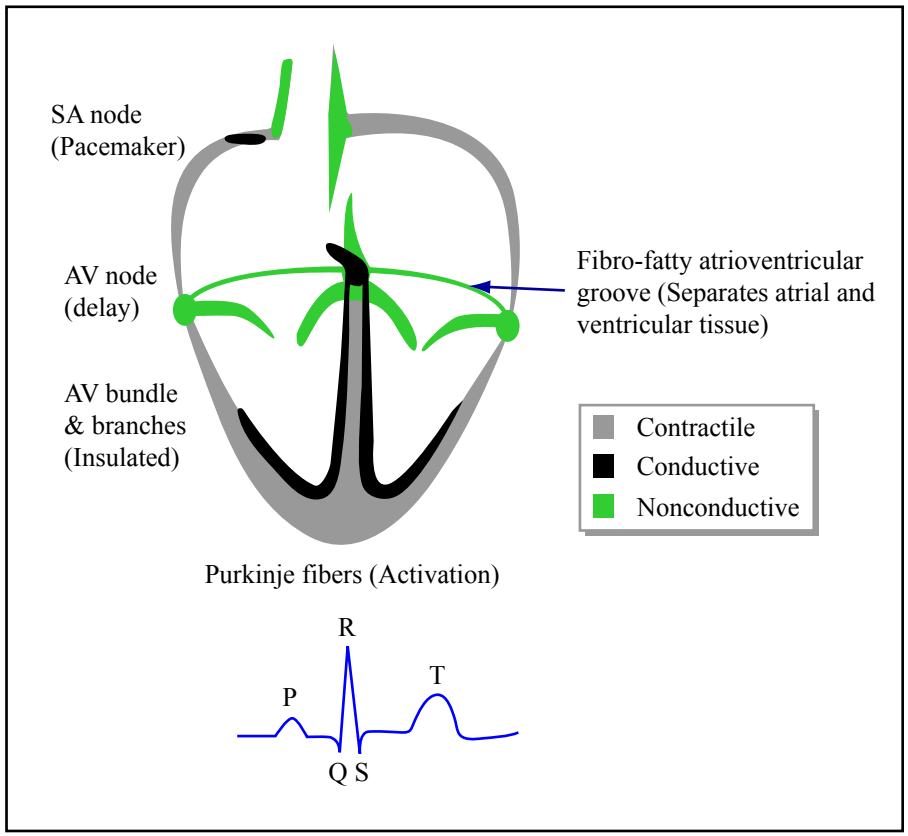
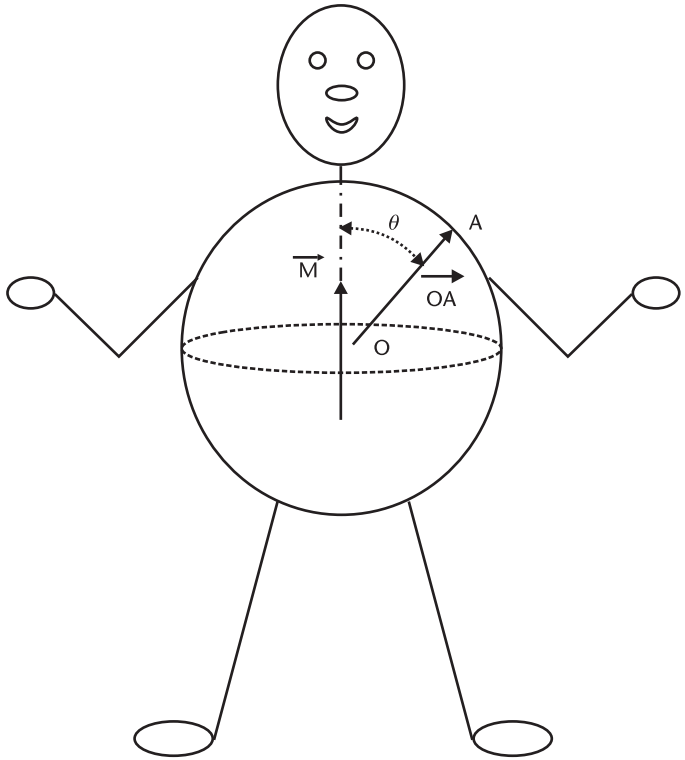



Figure by MIT OpenCourseWare.

# Important specific structures

- Sino-atrial node = pacemaker (usually)
- Atria
- After electrical excitation: contraction
- Atrioventricular node (a tactical pause)
- Ventricular conducting fibers (freeways)
- Ventricular myocardium (surface roads)
- After electrical excitation: contraction

# The Idealized Spherical Torso with the Centrally Located Cardiac Source (Simple dipole model)




Courtesy of Dr. Roger Mark. *HST.542J Quantitative Physiology: Organ Transport Systems, Spring 2004*. (Massachusetts Institute of Technology: MIT OpenCourseWare). http://ocw.mit.edu (accessed June 17, 2008).

# Excitation of the Heart

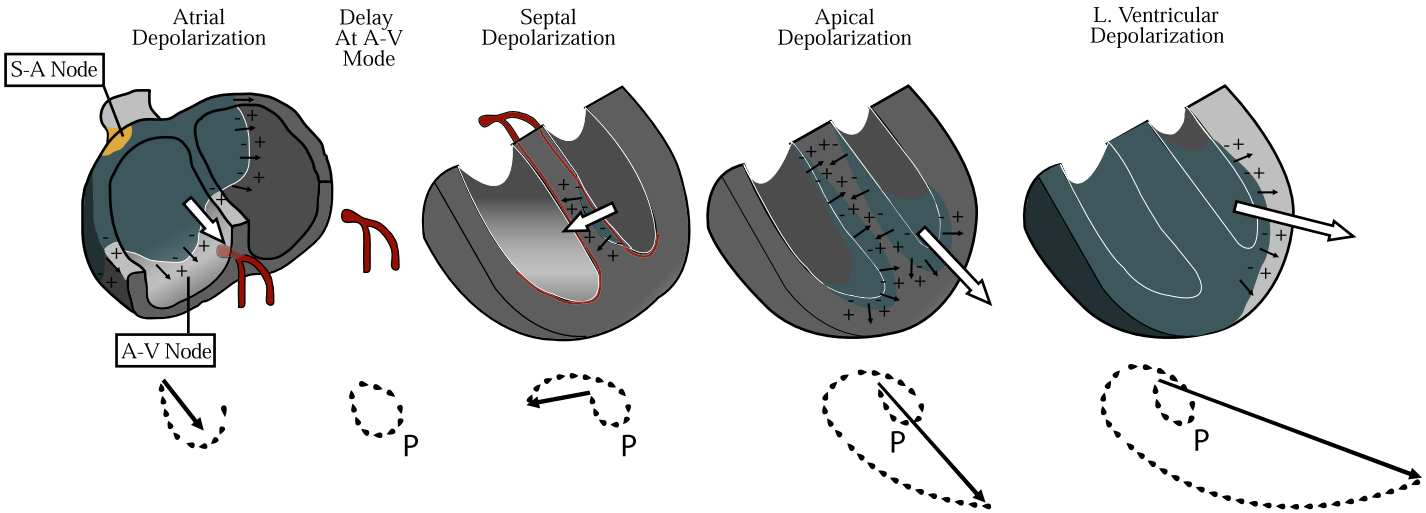



Figure by MIT OpenCourseWare. After F. Netter.

# Excitation of the Heart

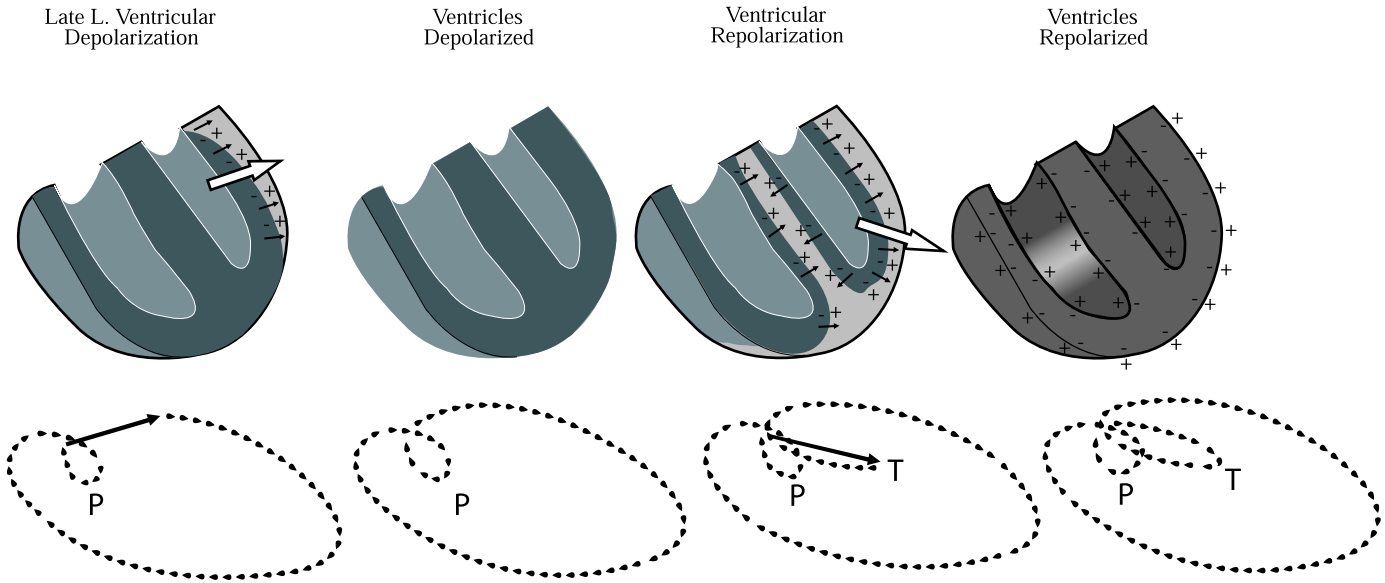



Figure by MIT OpenCourseWare. After F. Netter.

The location of these leads is as follows:

$V_1$: on the fourth intercostal space at the right sternal margin

$V_2$: on the fourth intercostal space at the left sternal margin

$V_3$: midway between leads V2 and V4

$V_4$: on the fifth intercostal space at the midclavicular line

$V_5$: on the anterior axillary line at the horizontal level of lead V4

$V_6$: on the midaxillary line at the horizontal level of lead V4

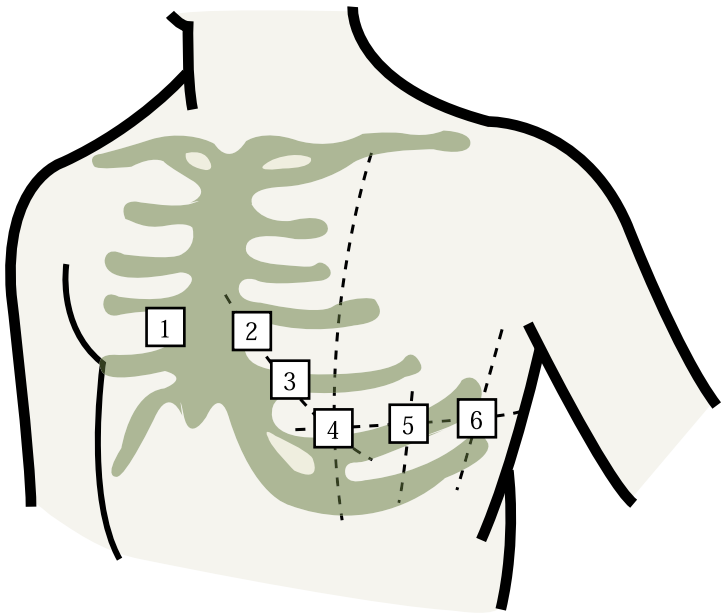



Figure by MIT OpenCourseWare.

# Figure 4 — Frontal Plane Limb Leads

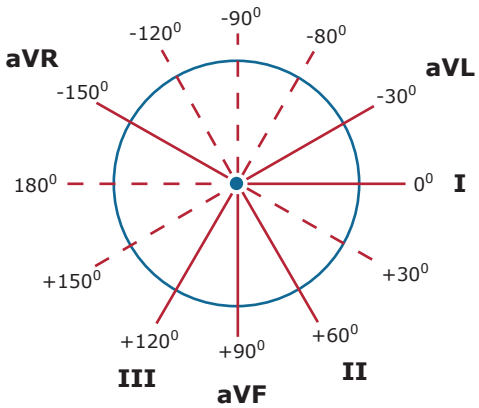



Figure by MIT OpenCourseWare.

# The temporal pattern of the heart vector combined with the geometry of the standard frontal plane limb leads.

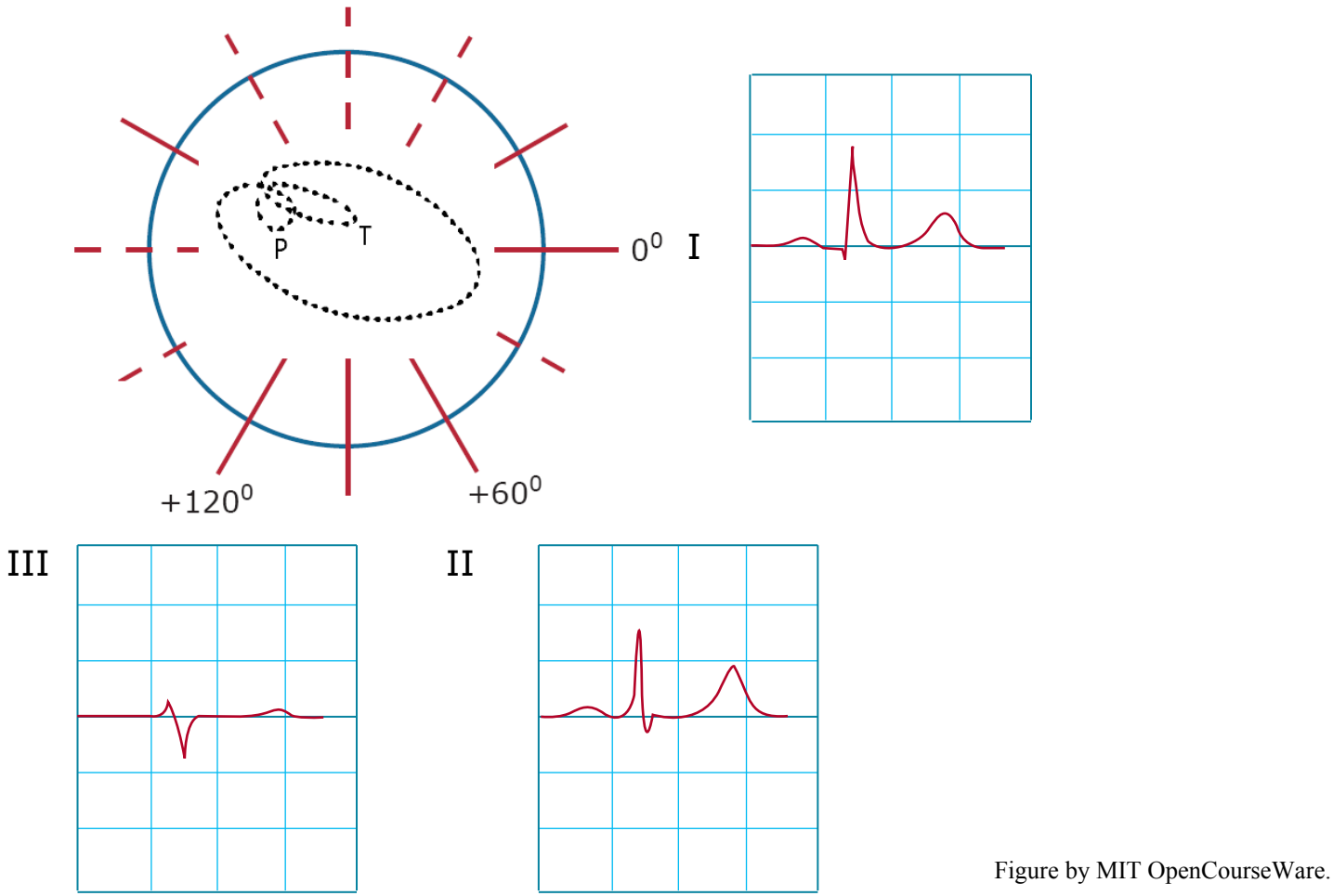
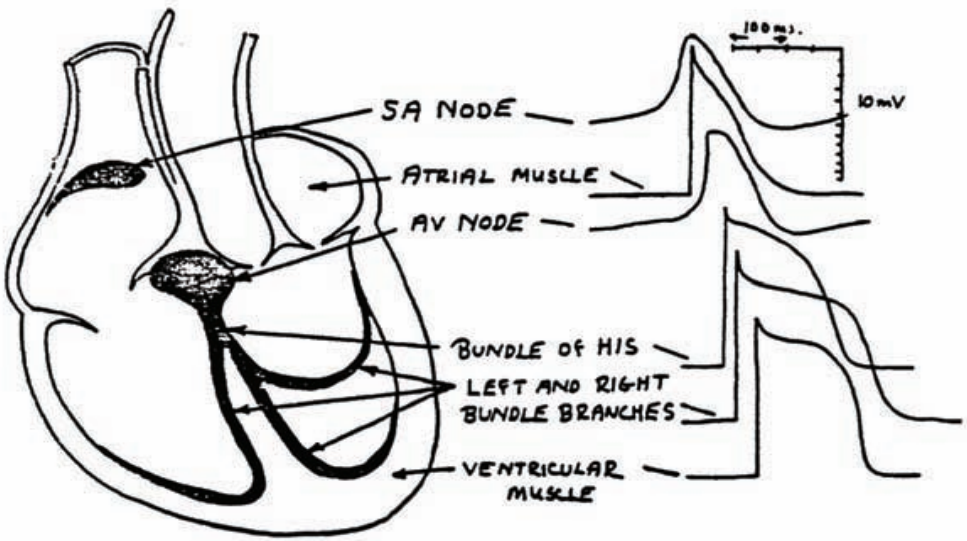



Figure by MIT OpenCourseWare.

# Cardiac Electrical Activity




Courtesy of Dr. Roger Mark. HST.542J Quantitative Physiology: Organ Transport Systems, Spring 2004. (Massachusetts Institute of Technology: MIT OpenCourseWare). http://ocw.mit.edu (accessed June 17, 2008). Figure adapted from Phillips RE, Feeney MK, 1980 The Cardiac Rhythms. Saunders, Philadelphia and from Hoffman BF, Cranefiel PF 1960 Electrophysiology of the Heart. McGraw Hill, New York.

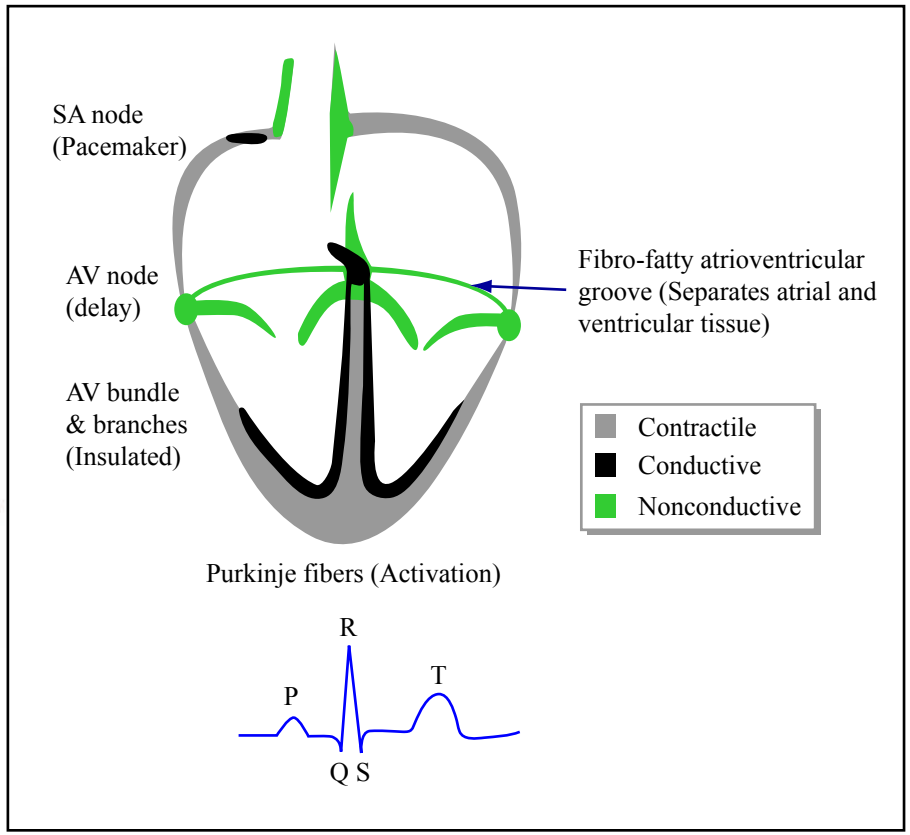
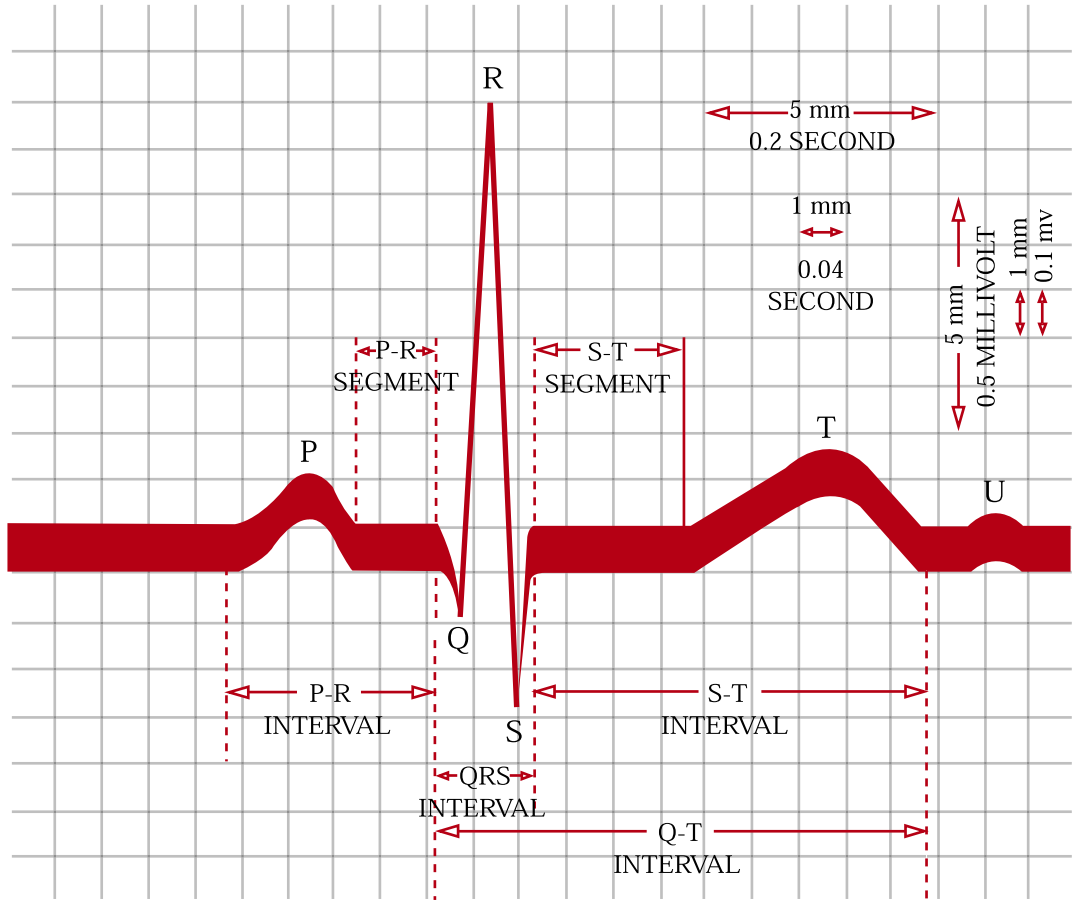



Figure by MIT OpenCourseWare.

# Normal features of the electrocardiogram.




Recording Conventions, Waveform Nomenclature, and Normal Values for the Electrocardiogram.

Figure by MIT OpenCourseWare. After p. 50 in Netter, Frank H. A Compilation of Paintings on the Normal and Pathologic Anatomy and Physiology, Embryology, and Diseases of the Heart, edited by Fredrick F. Yonkman. Vol. 5 of The Ciba Collection of Medical Illustrations. Summit, N.J.: Ciba Pharmaceutical Company, 1969.

# Normal sinus rhythm

**Figure 15 - Normal Sinus Rhythm—Rate 85**

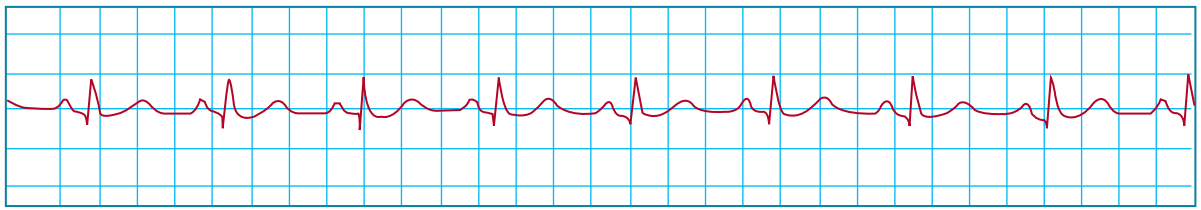


Figure by MIT OpenCourseWare.

# What has changed?

**Figure 16 - Sinus Tachycardia—Rate 122**

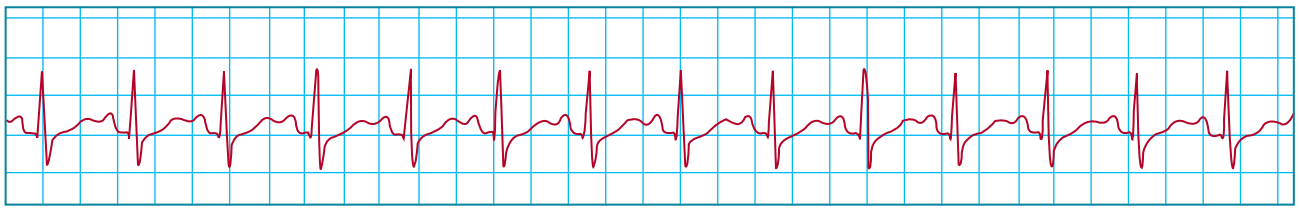


Figure by MIT OpenCourseWare.

# Sinus bradycardia

**Figure 17 - Sinus Bradycardia—Rate 48**

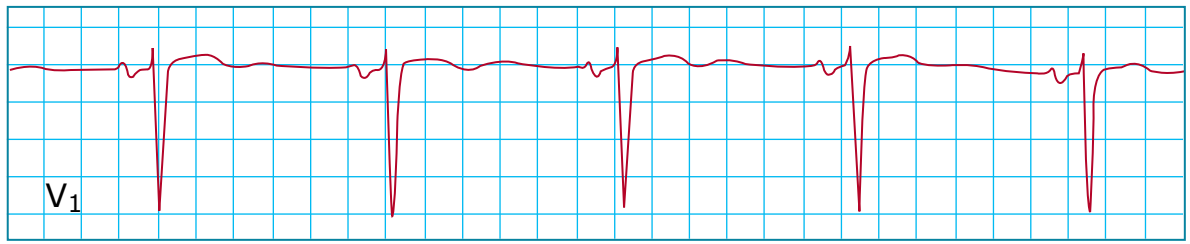
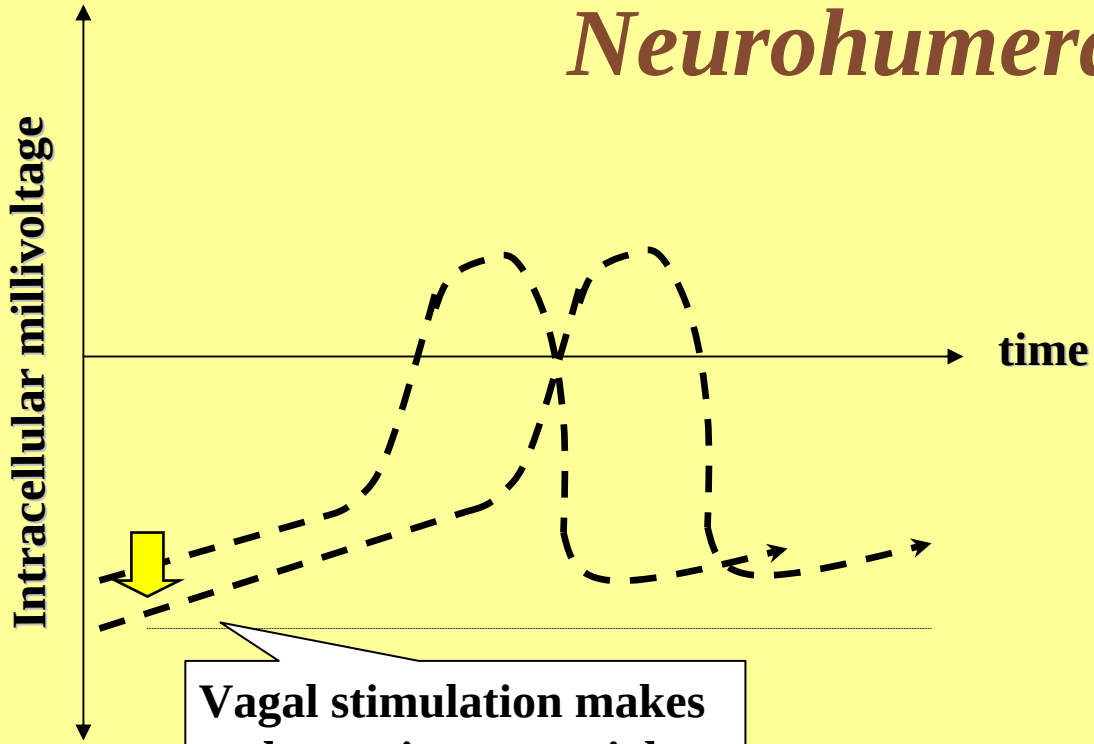
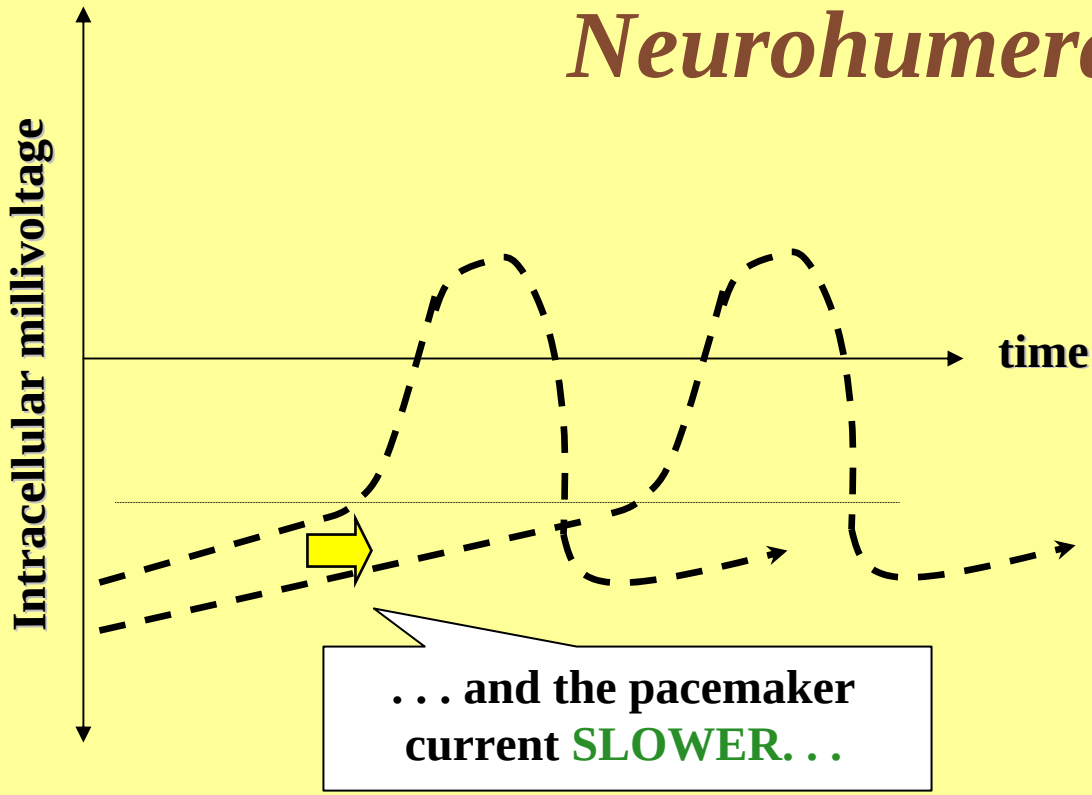


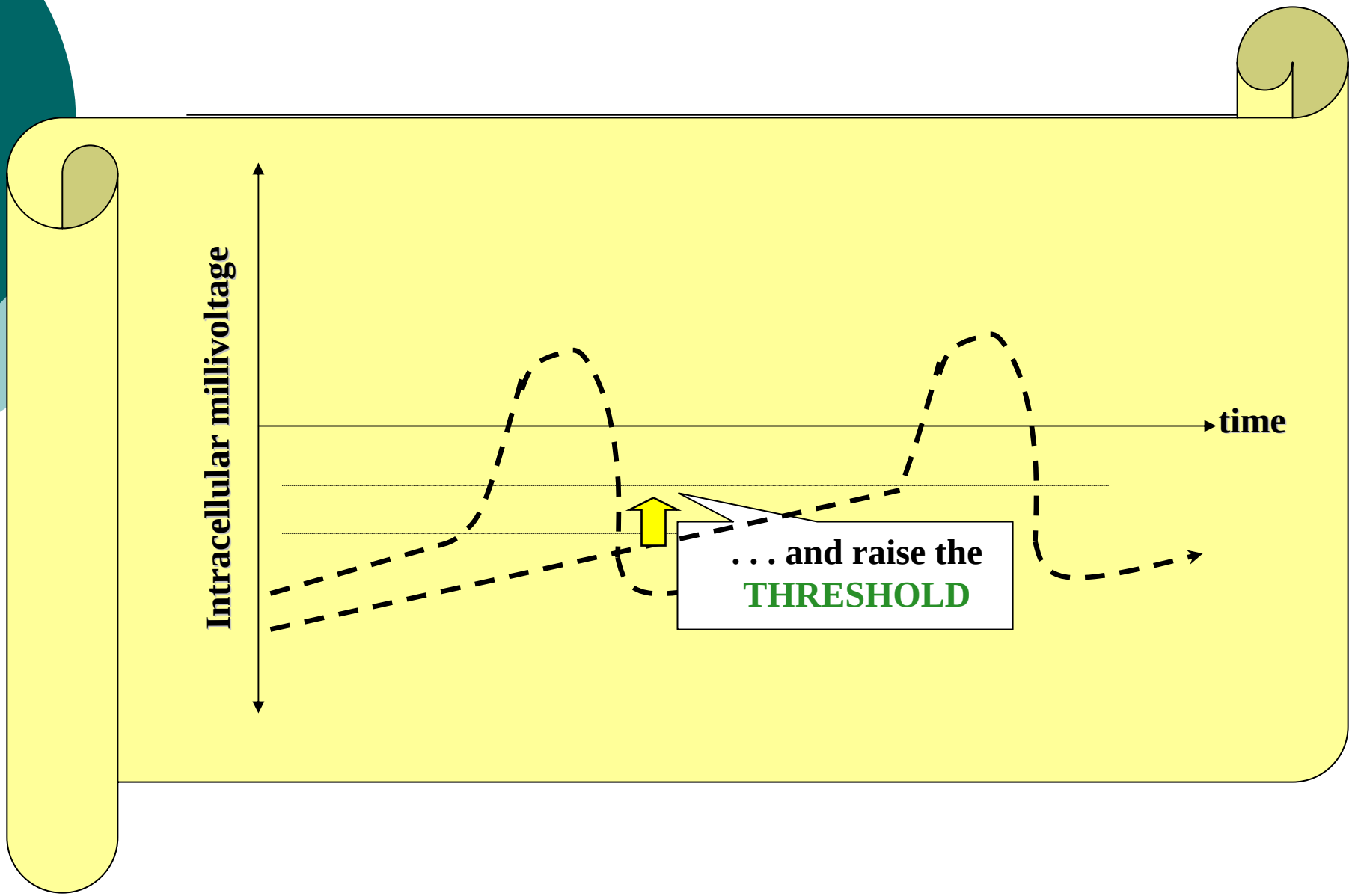

Figure by MIT OpenCourseWare.

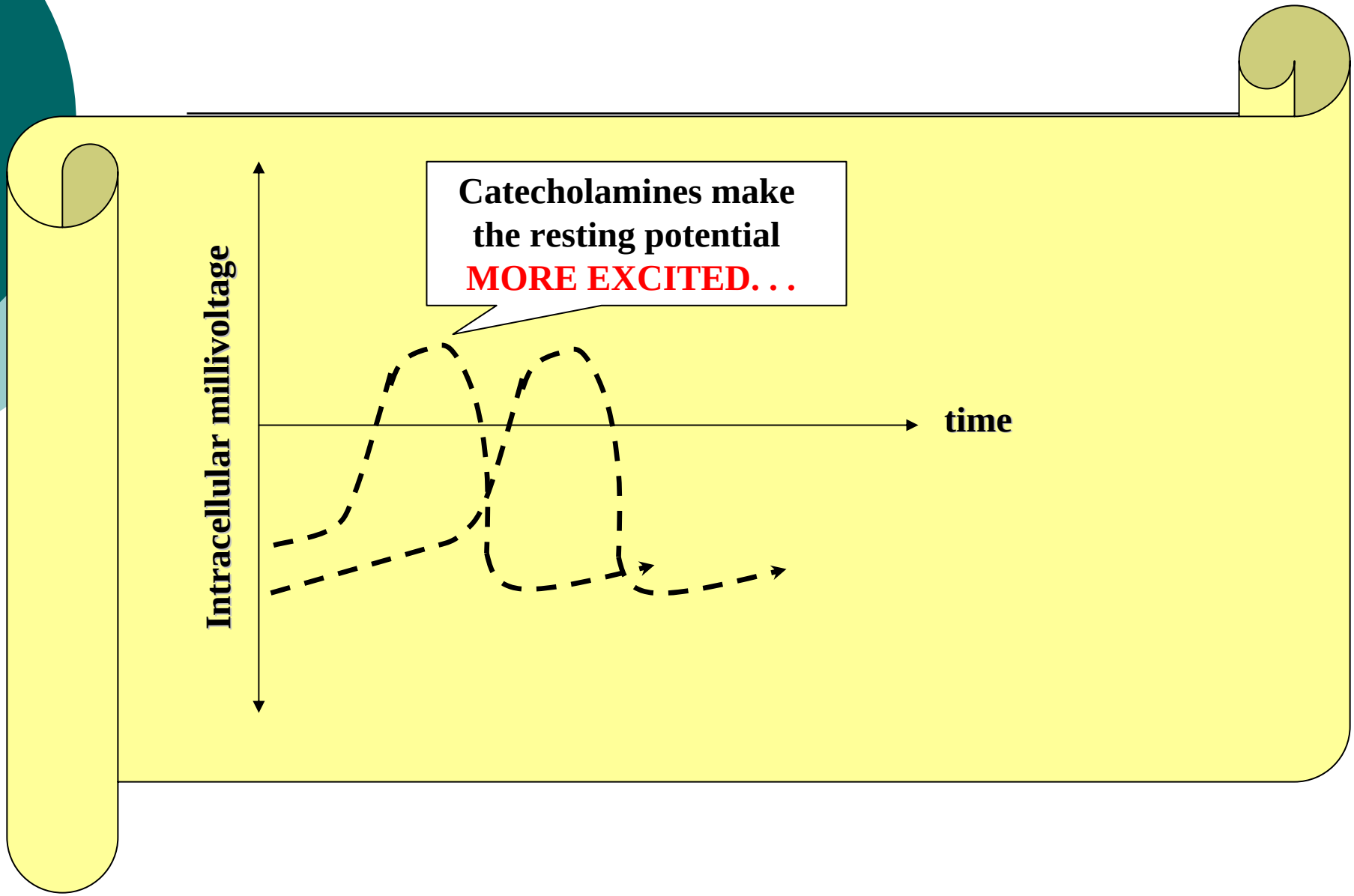
# *Neurohumeral factors*

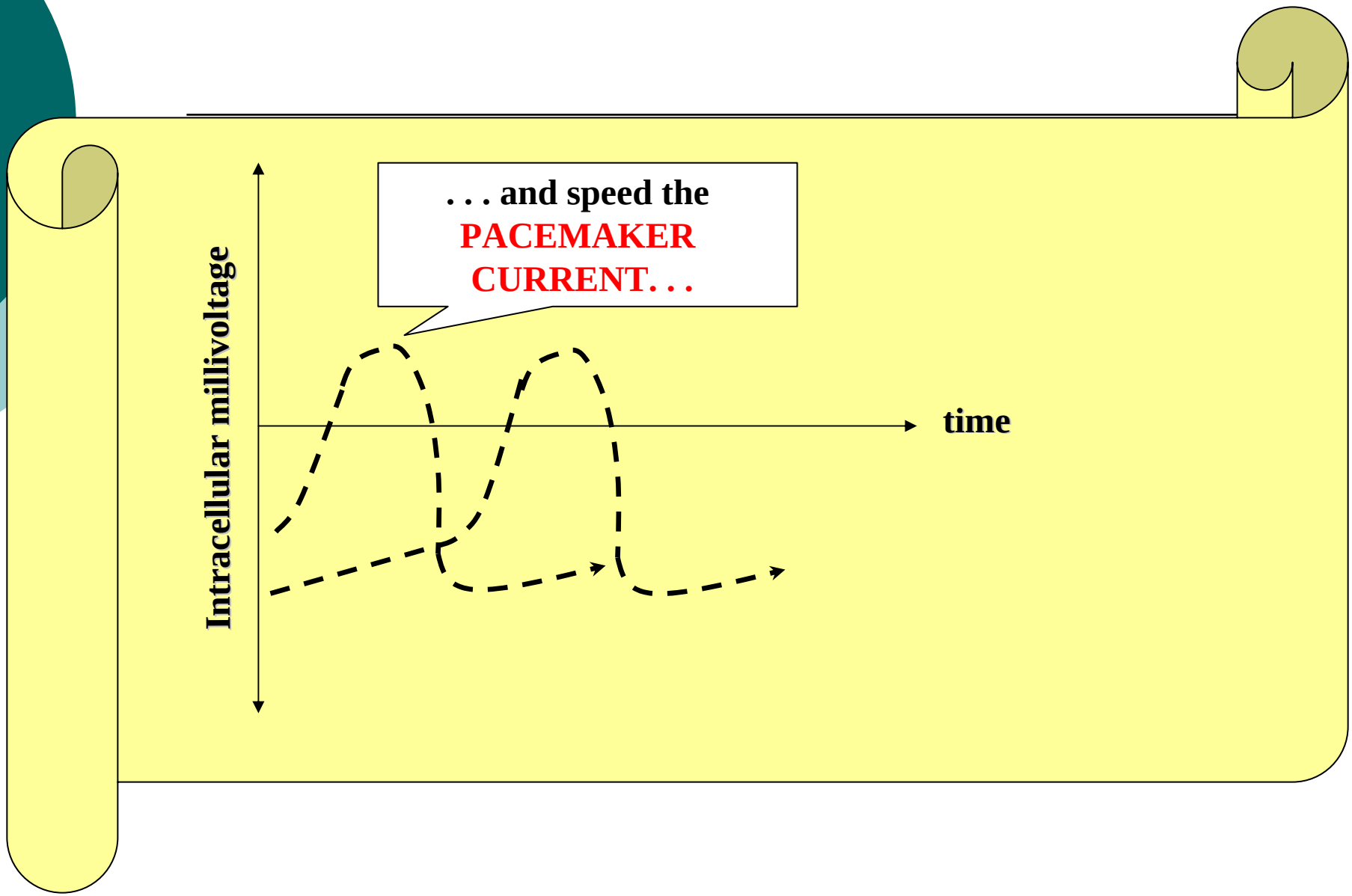


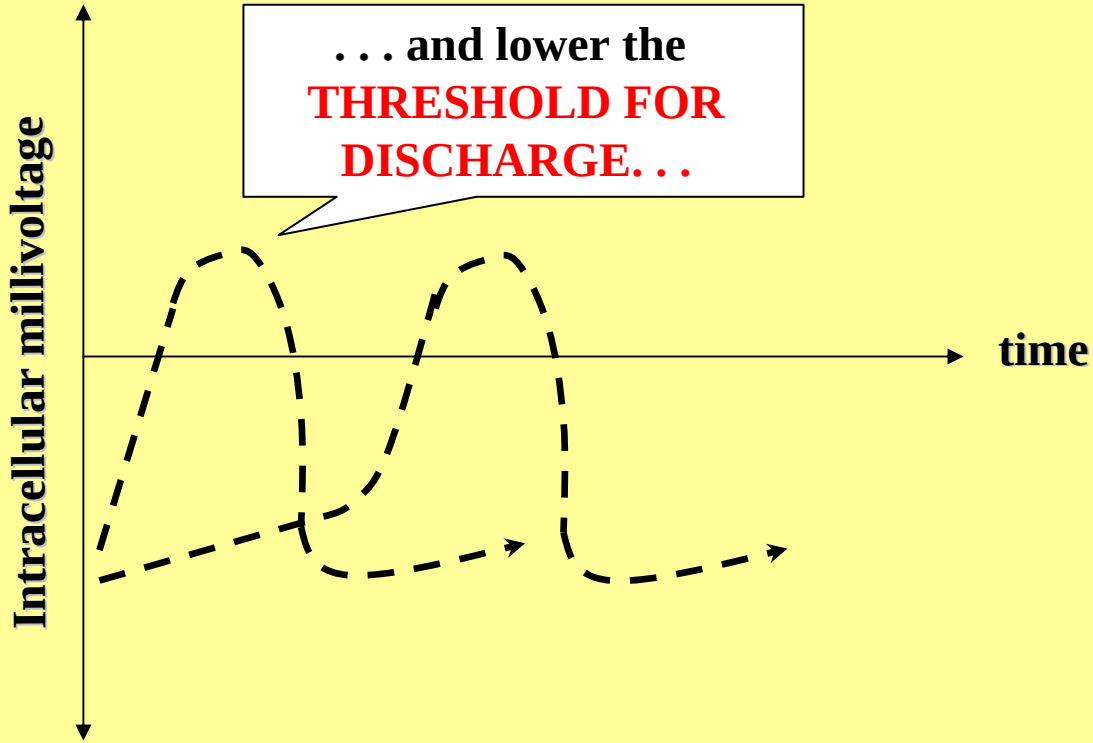
# *Neurohumeral factors*

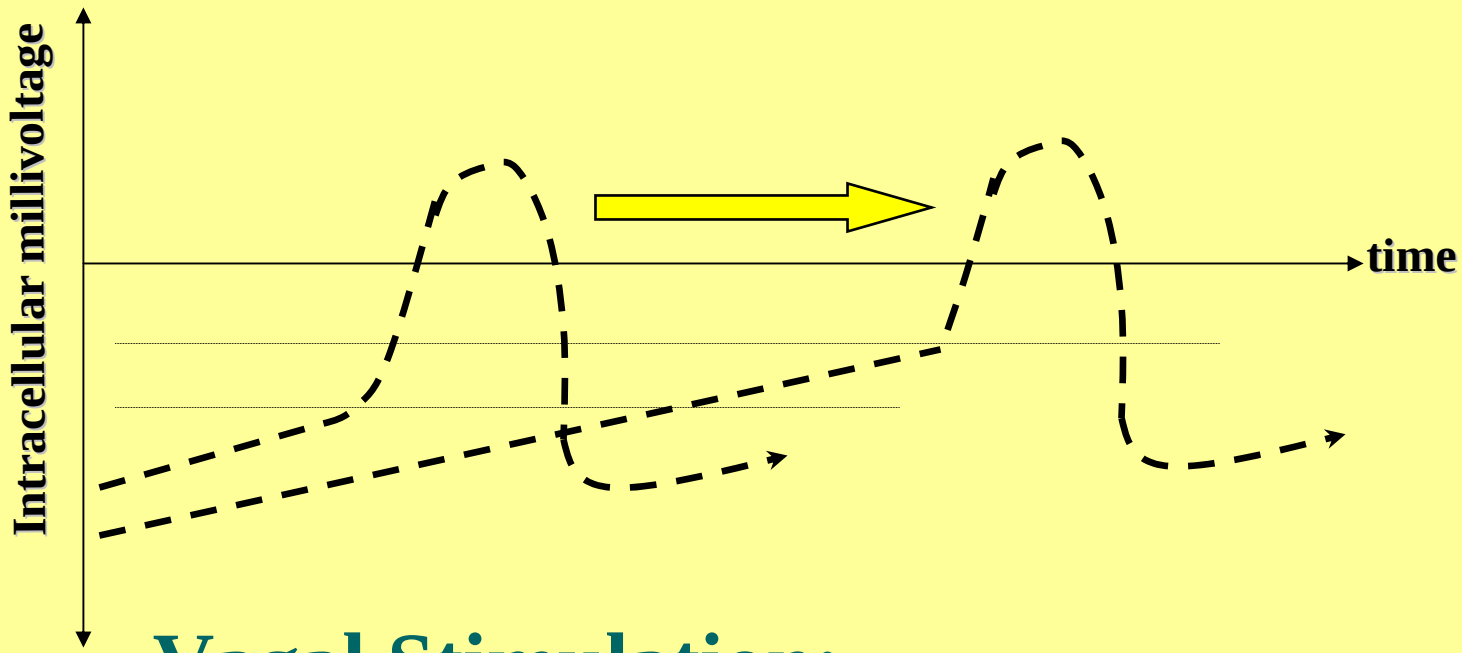




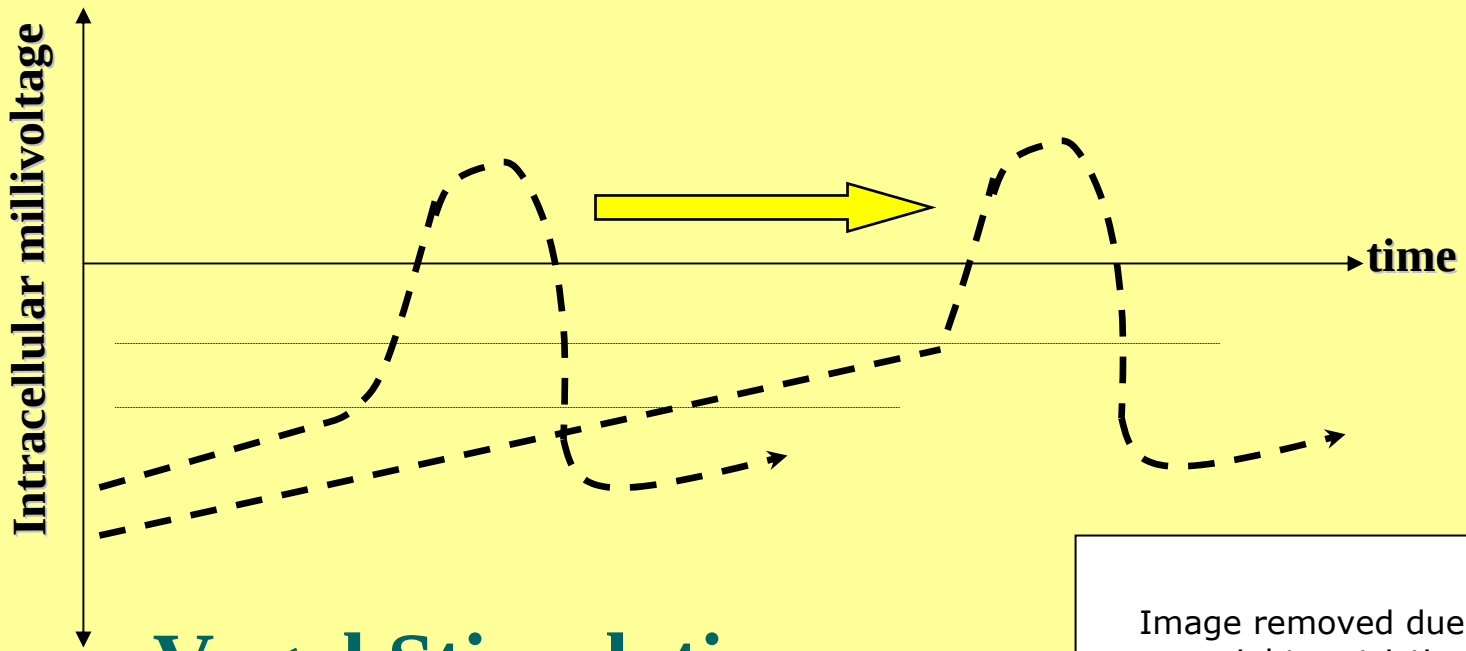








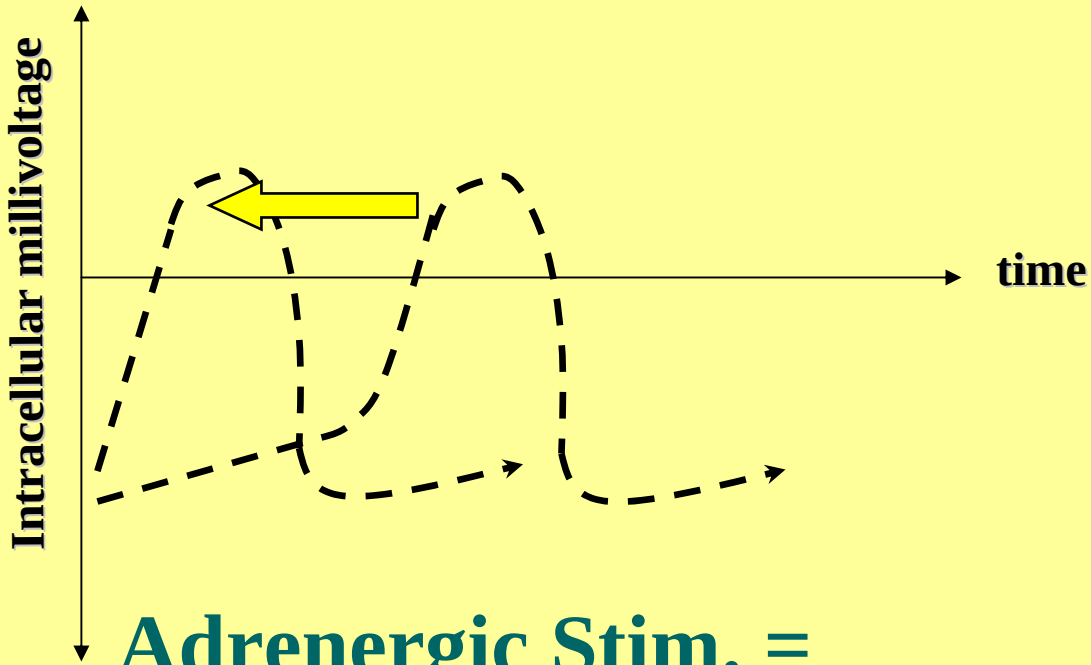

# Vagal Stimulation:



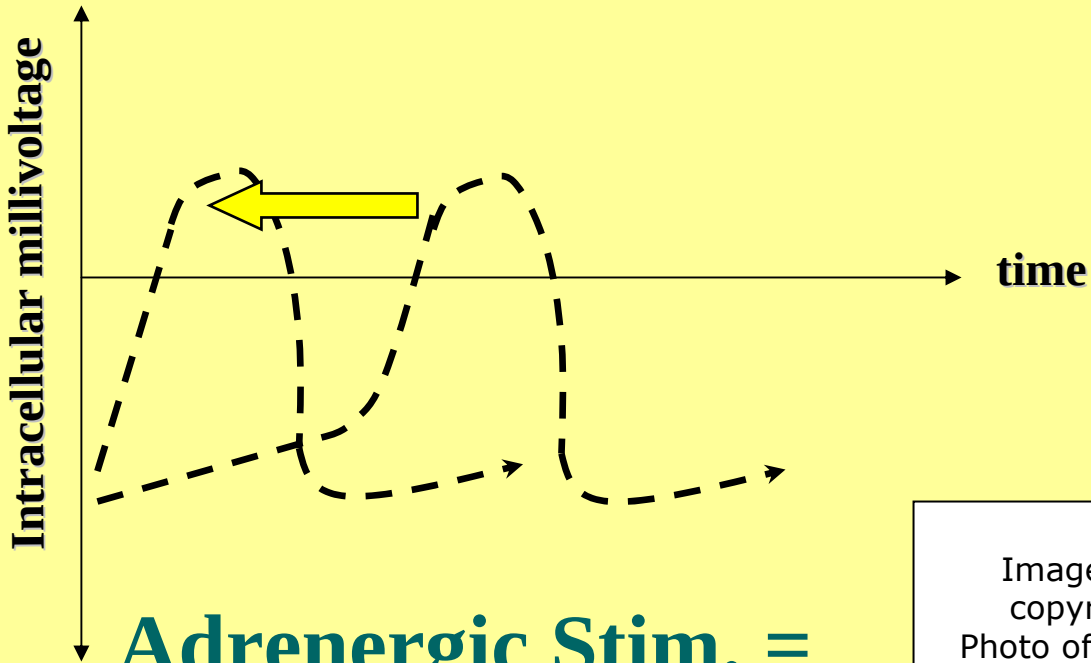

# Vagal Stimulation:

# Ricardo Montelban Effect

Image removed due to copyright restrictions. Photo of actor Ricardo Montelban.




**Adrenergic Stim. =**




**Adrenergic Stim. =**

**Potsy Effect**

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Photo of characters from TV show "Happy Days," including Potsy.

# Sinus arrhythmia

**Figure 18 - Sinus Arrhythmia**

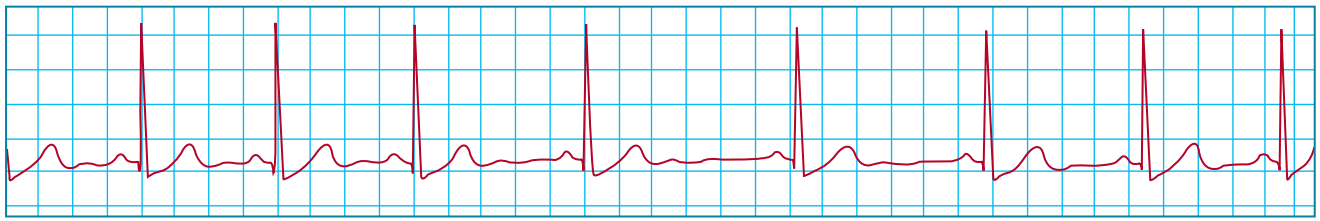


Figure by MIT OpenCourseWare.

# Atrial premature contractions (see arrowheads)

**Figure 25 - Atrial Premature Contractions**

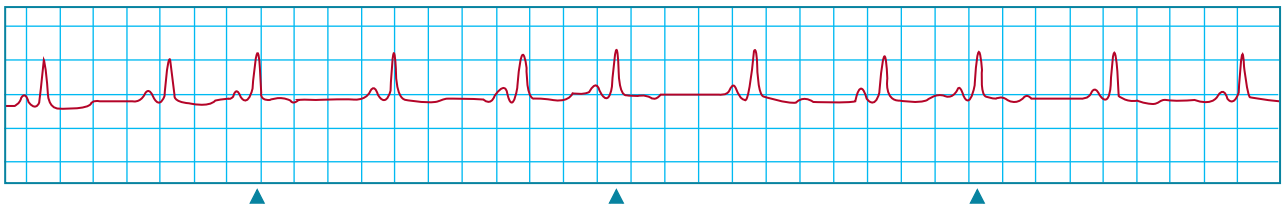


Figure by MIT OpenCourseWare.

# Arrhythmias

- Not firing when you should
- Firing when you shouldn't
- All of the above (Reentrance)

# Firing when you shouldn't

- Usually just a spark; rarely sufficient for an explosion
- "Leakiness" leads to pacemaker-like current
- Early after-depolarization
- Late after-depolarization

# What's going on here?

**Figure 36 - Ventricular Premature Contractions**

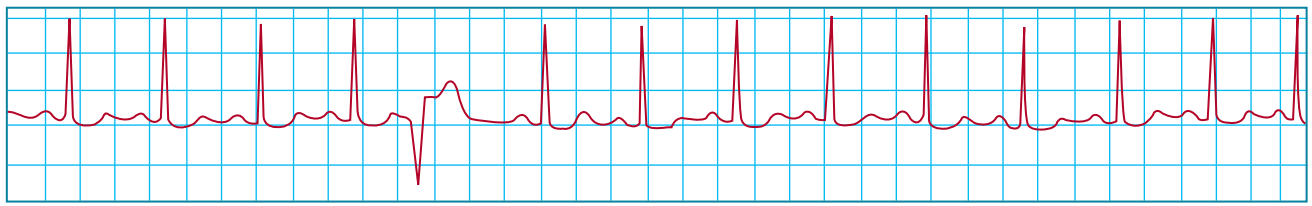
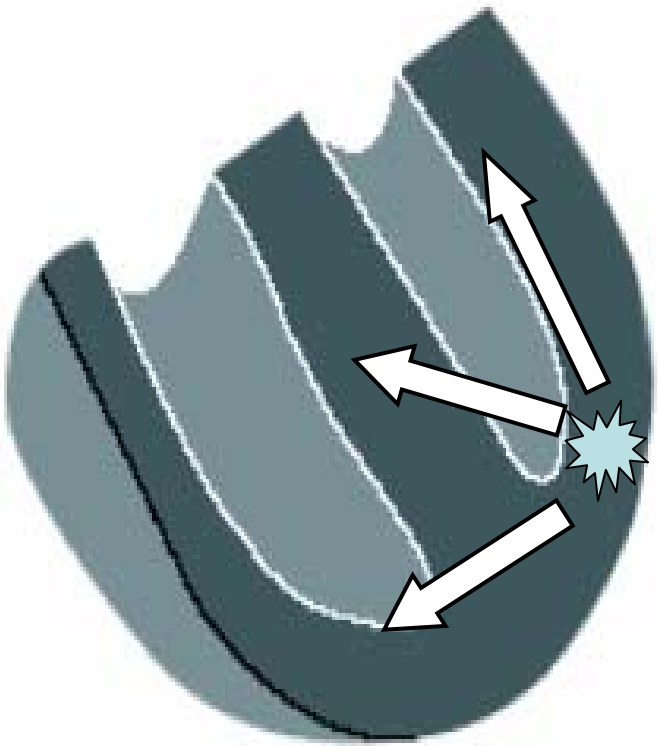
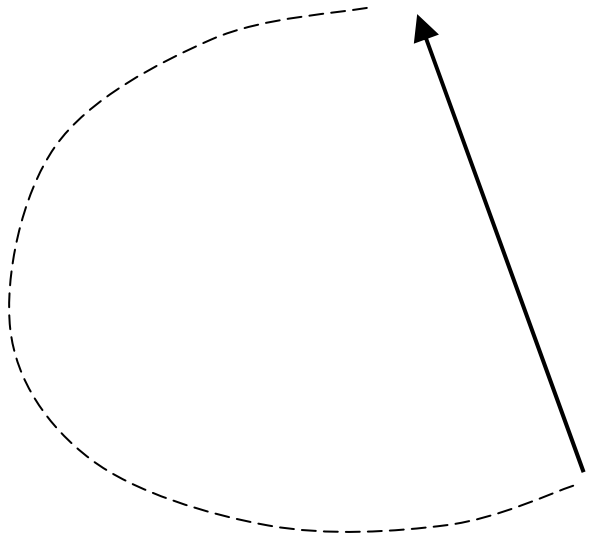


Figure by MIT OpenCourseWare.

# Wave-front Trajectory in a Ventricular Premature Contraction.





# Is this the same thing?

**Figure 24 - Ventricular Escape Beat**

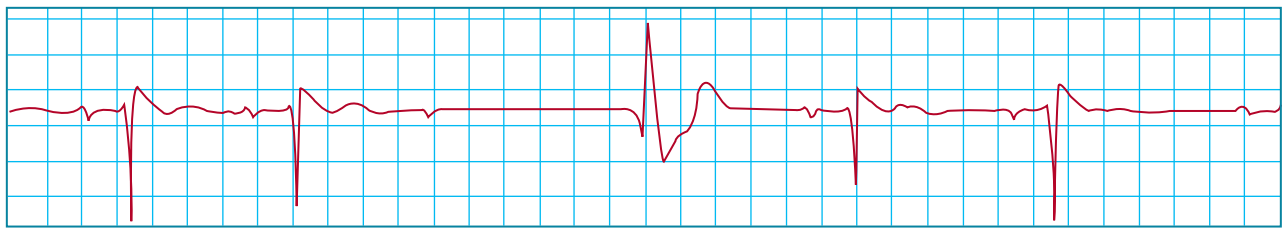


Figure by MIT OpenCourseWare.

# What's going on here?

**Figure 50 - Complete A-V Block with Junctional Escape Rhythm**

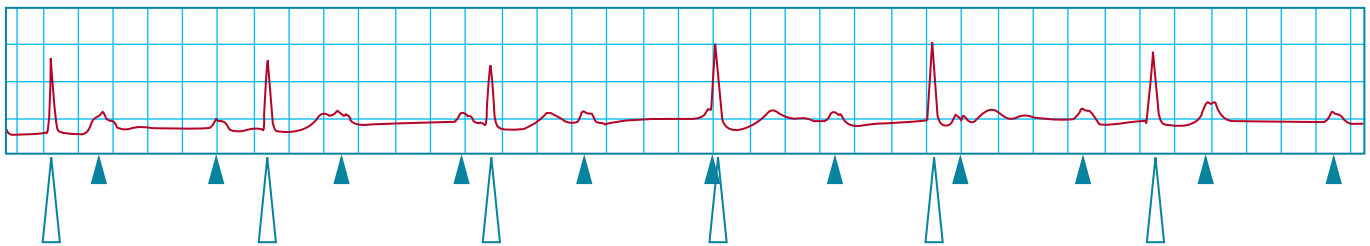


Figure by MIT OpenCourseWare.

# What's going on here?

**Figure 35 - Atrial Fibrillation (2 examples)**

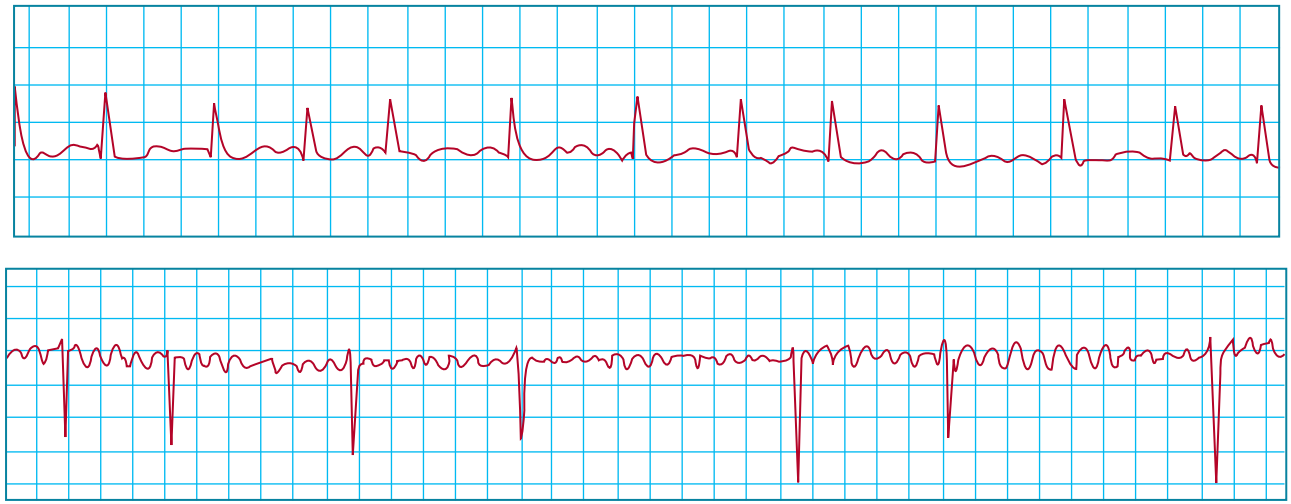


Figure by MIT OpenCourseWare.

# Non-sustained ventricular tachycardia (3 episodes)

**Figure 43 - Short Bursts of Ventricular Tachycardia**

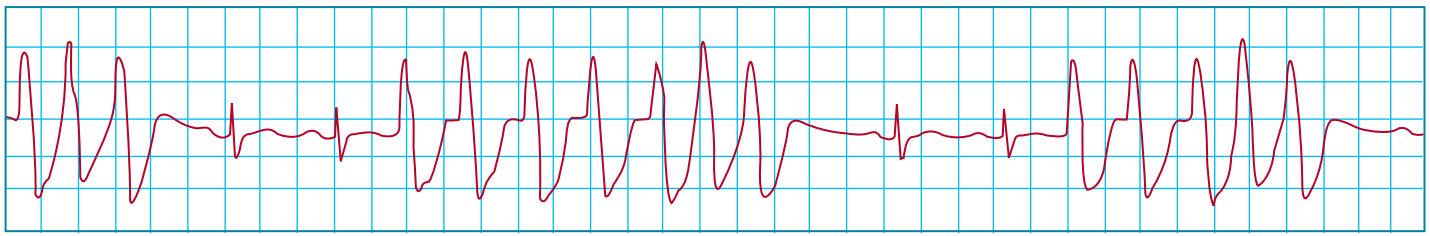
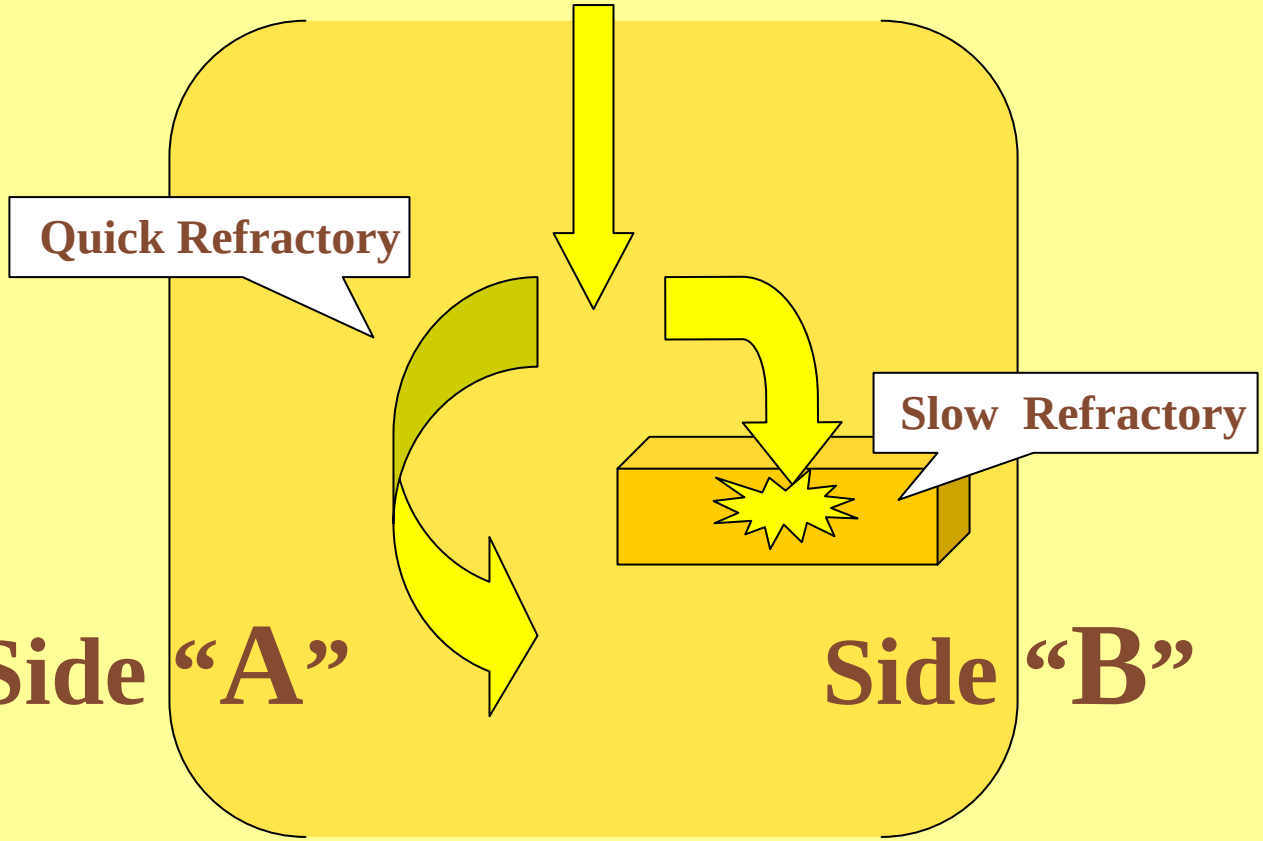


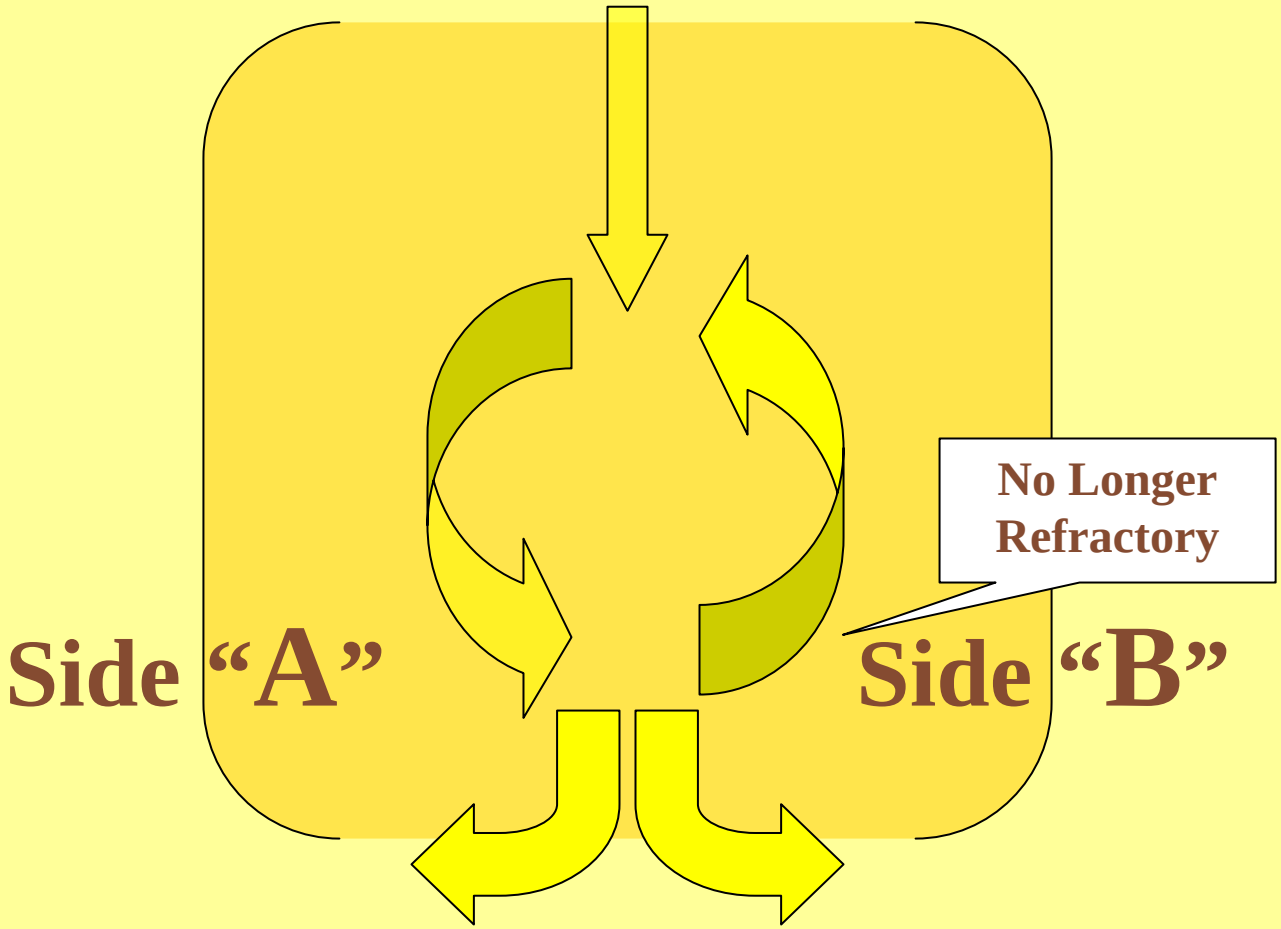
Figure by MIT OpenCourseWare.

# Re-entry




## KeyWords:
## Heterogeneous, Circus, Self-Perpetuating

# Re-entry

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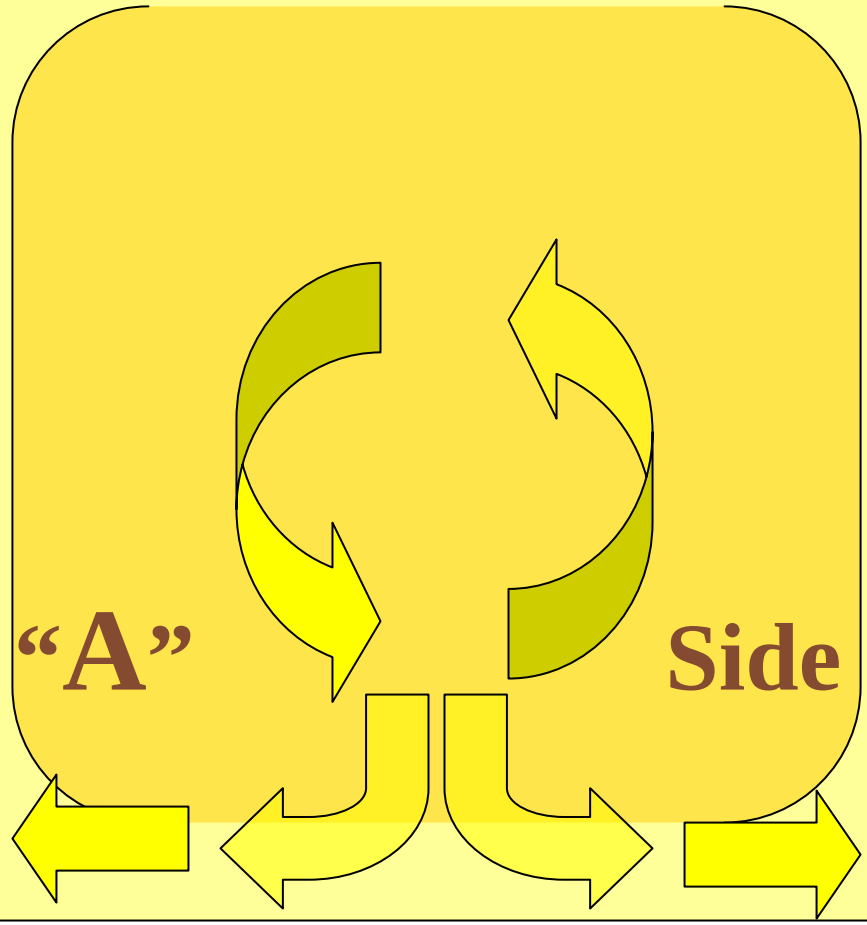


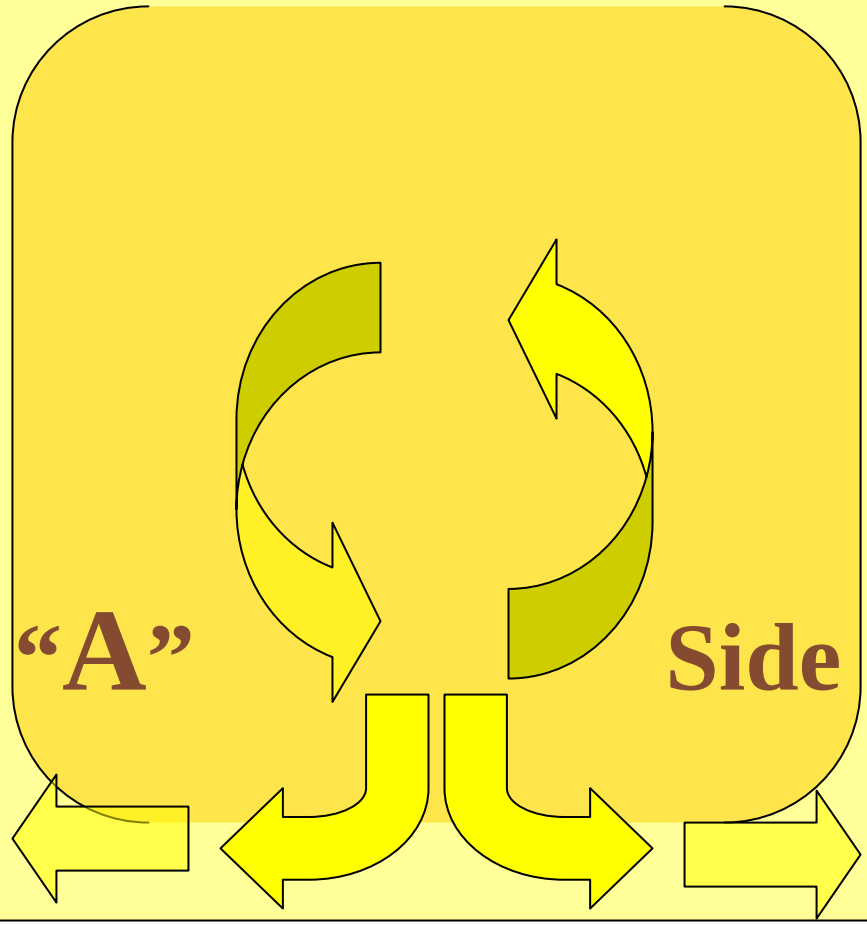
Side “A”

Side “B”

## KeyWords:

## Heterogeneous, Circus, Self-Perpetuating

# Re-entry



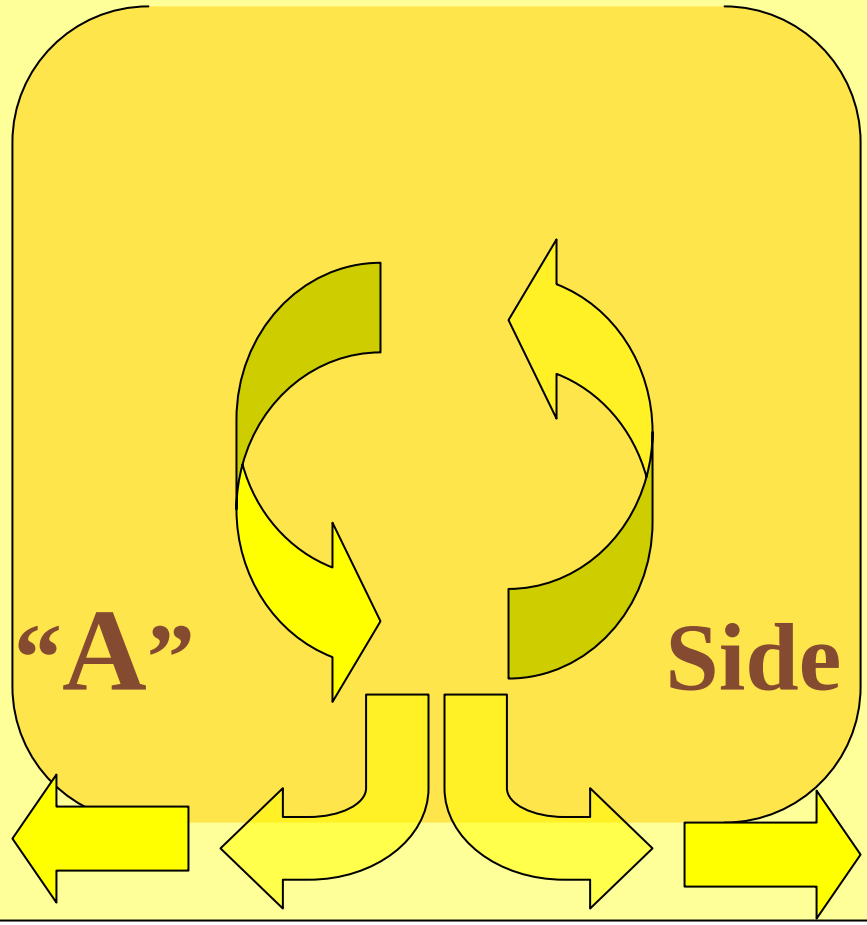
Side “A”

Side “B”

## KeyWords:

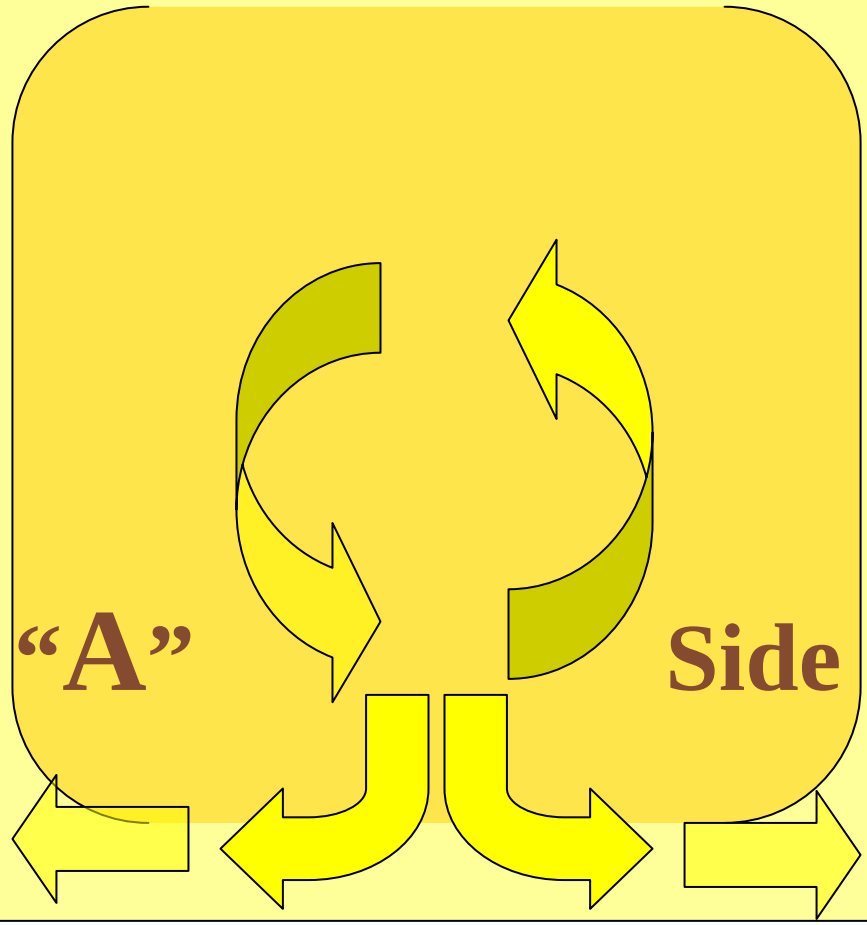
## Heterogeneous, Circus, Self-Perpetuating

# Re-entry




## KeyWords:
## Heterogeneous, Circus, Self-Perpetuating

# Re-entry



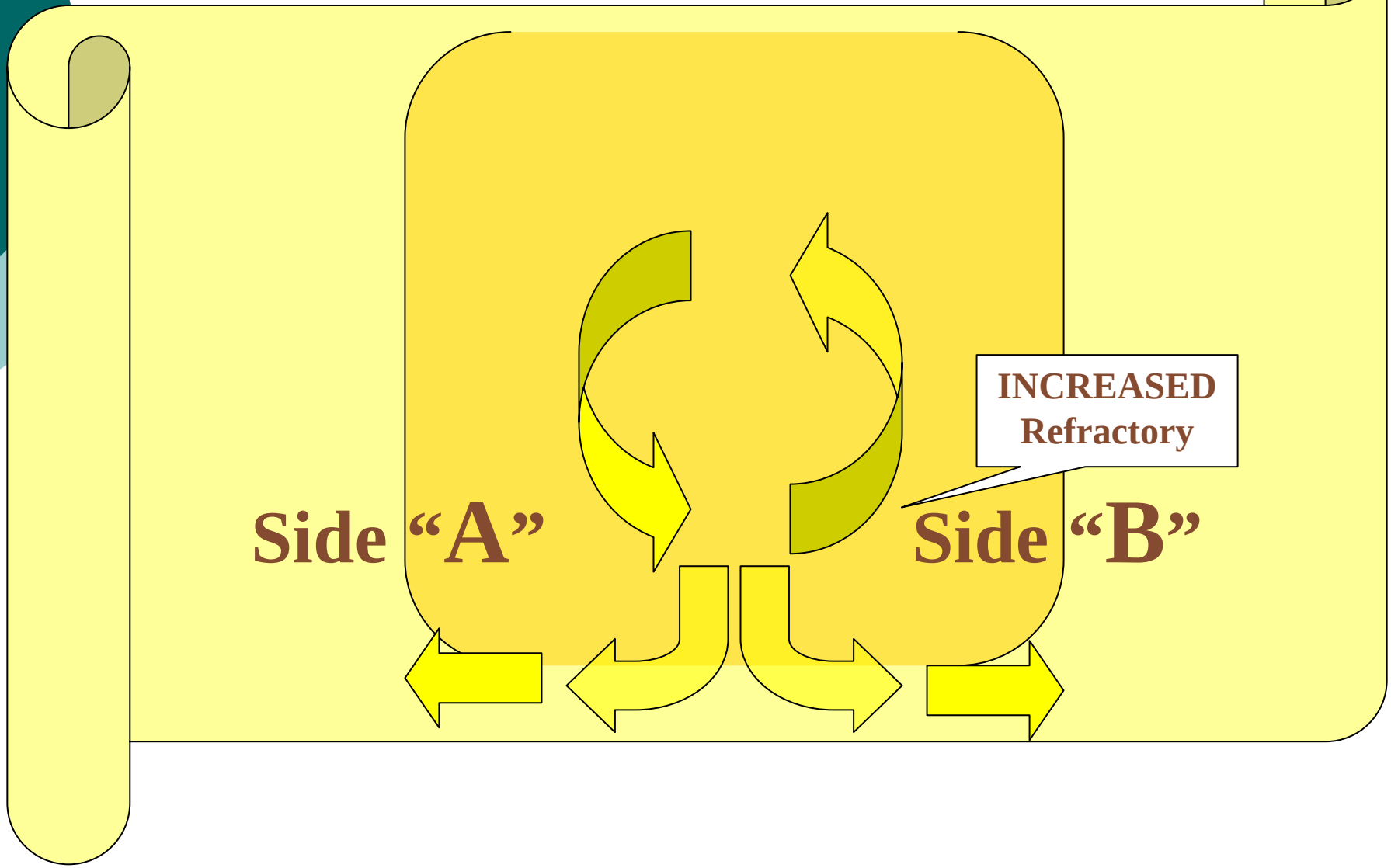
Side “A”

Side “B”

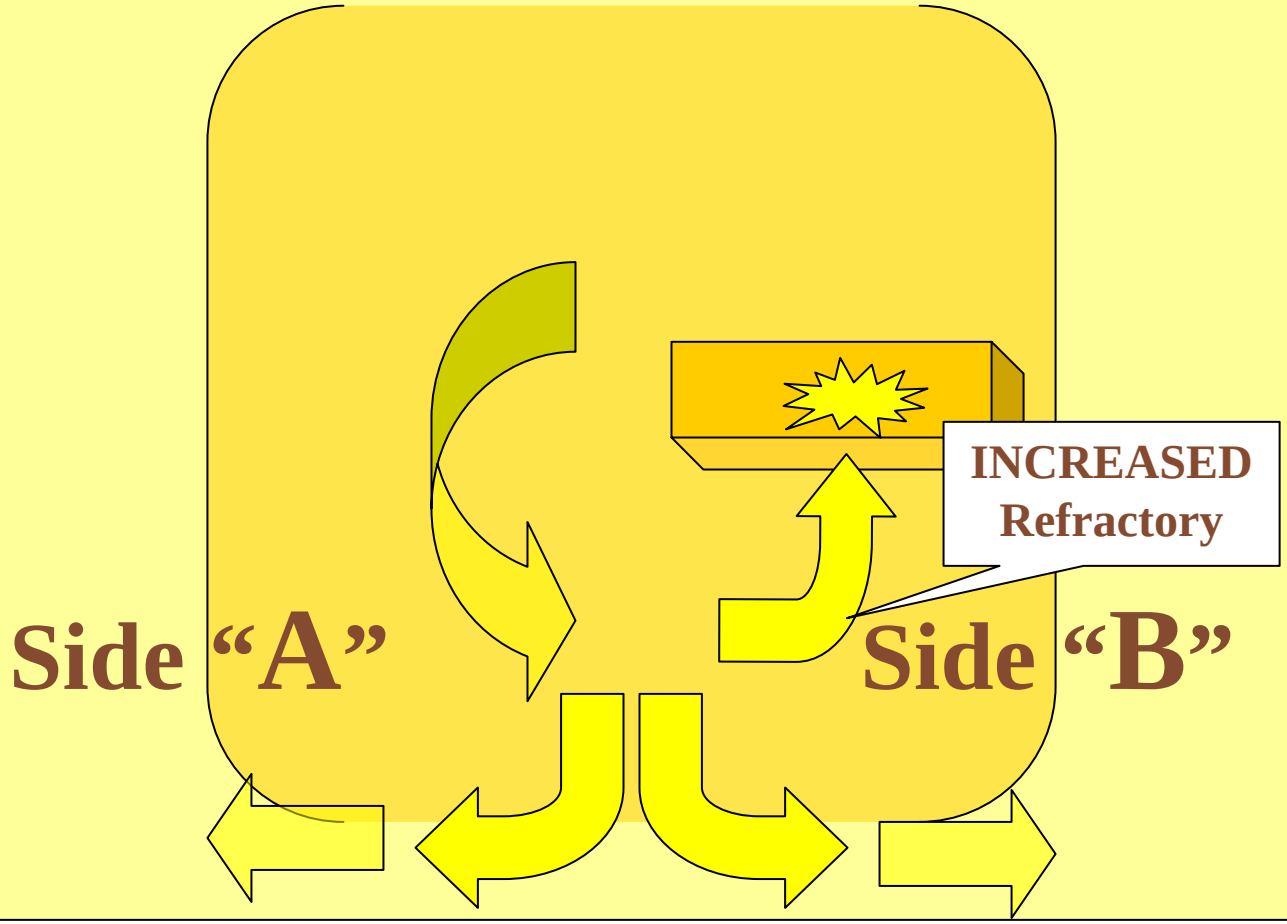
## KeyWords:

## Heterogeneous, Circus, Self-Perpetuating

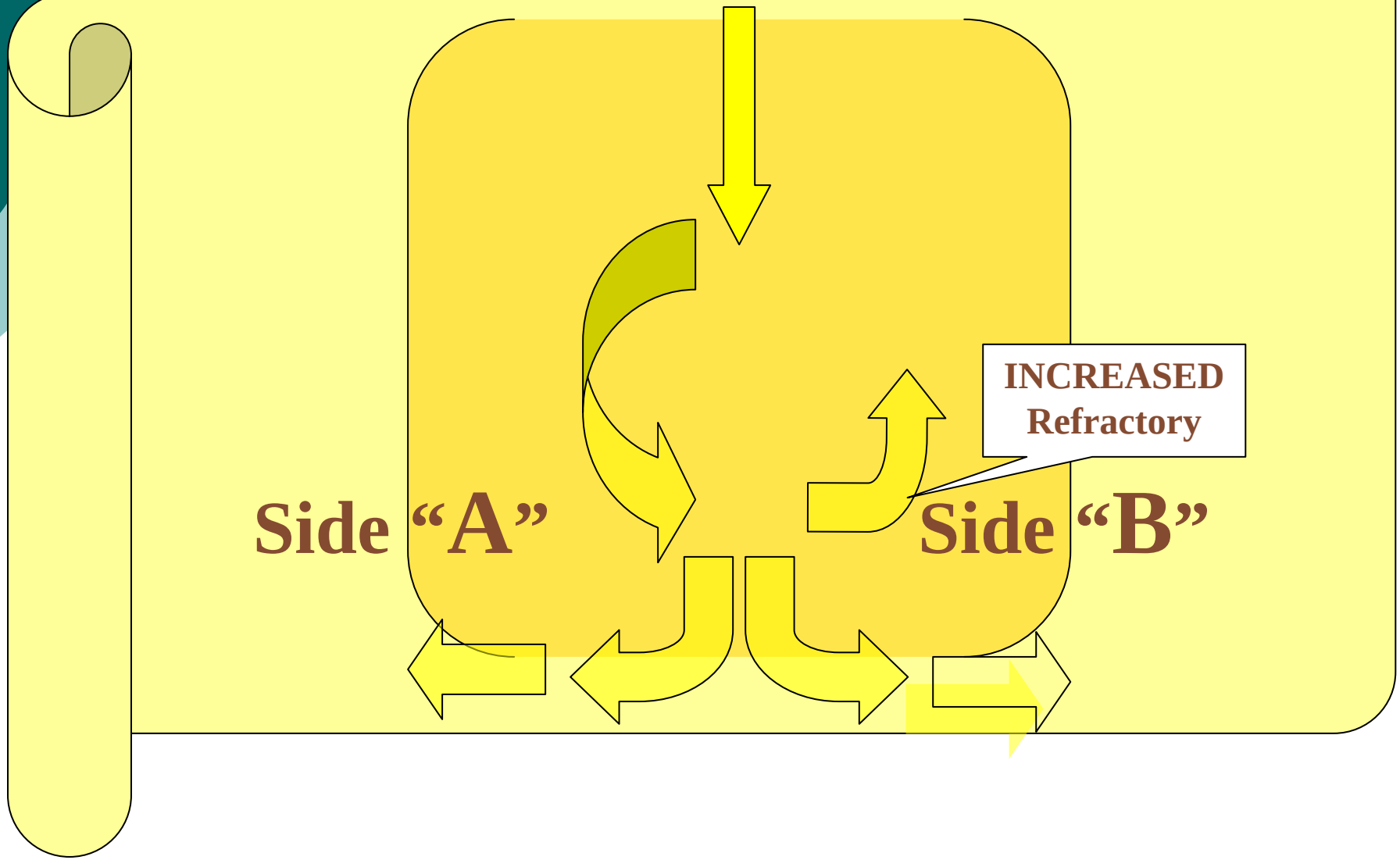
# Timing is Everything



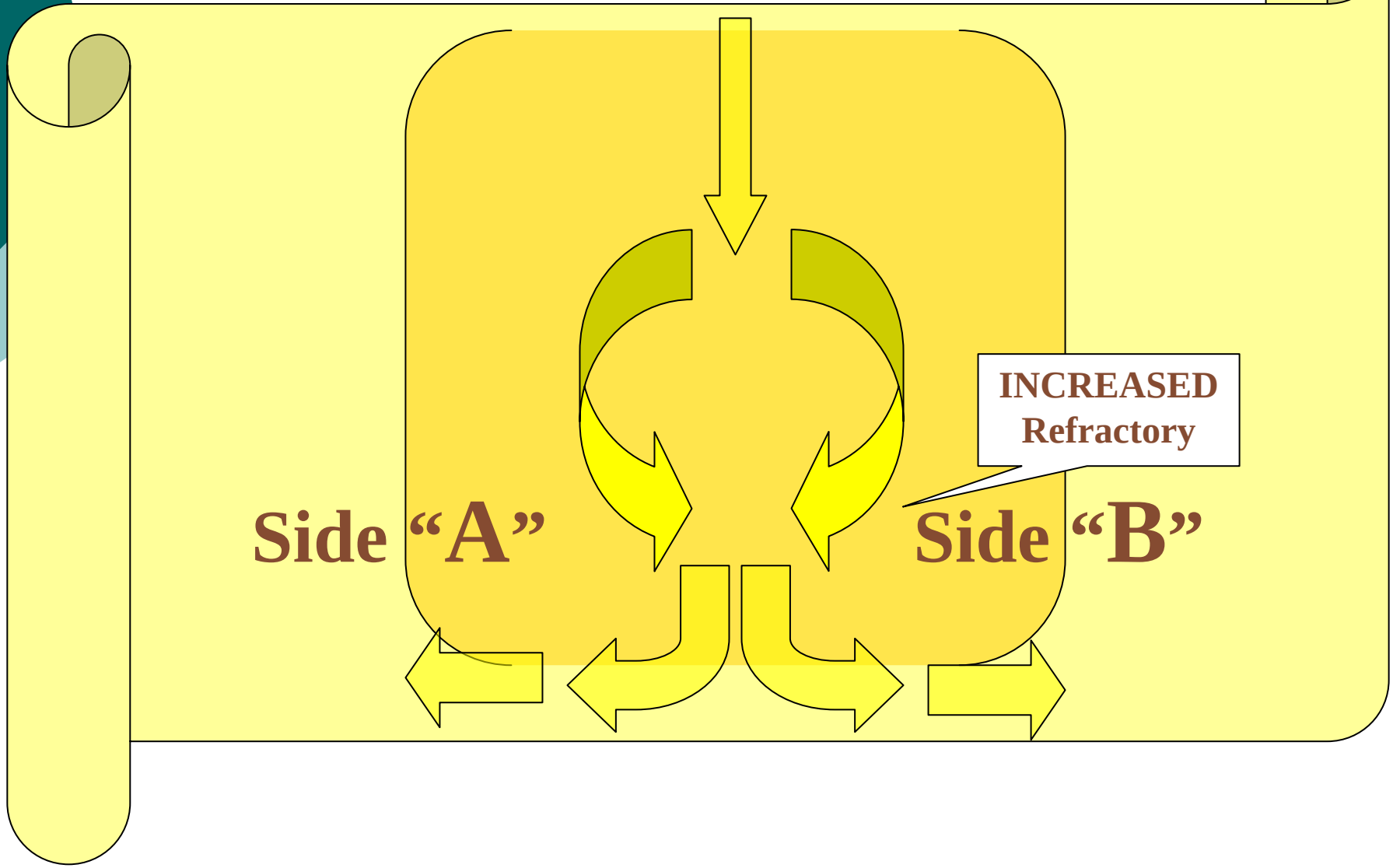
# Timing is Everything



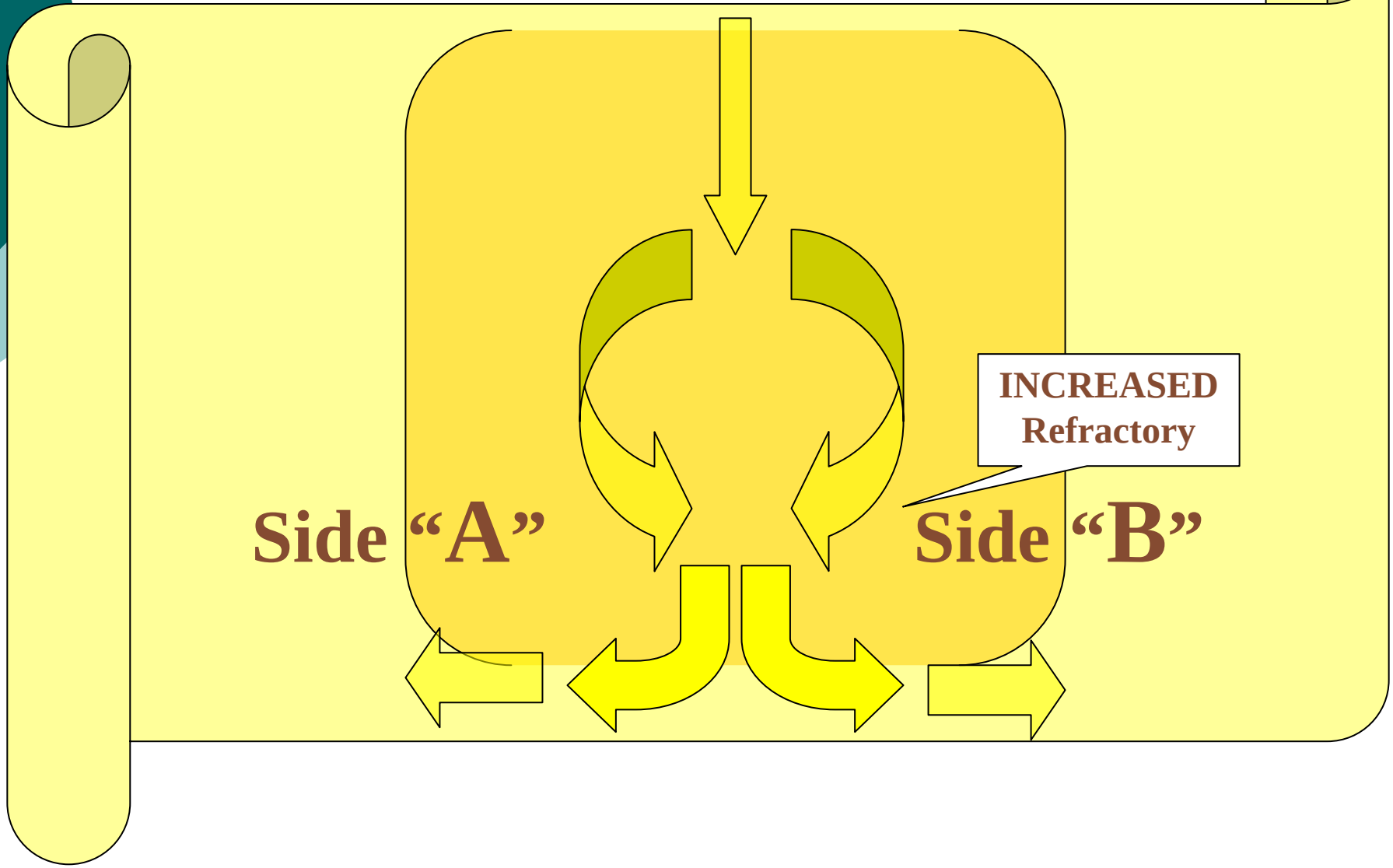
# Timing is Everything



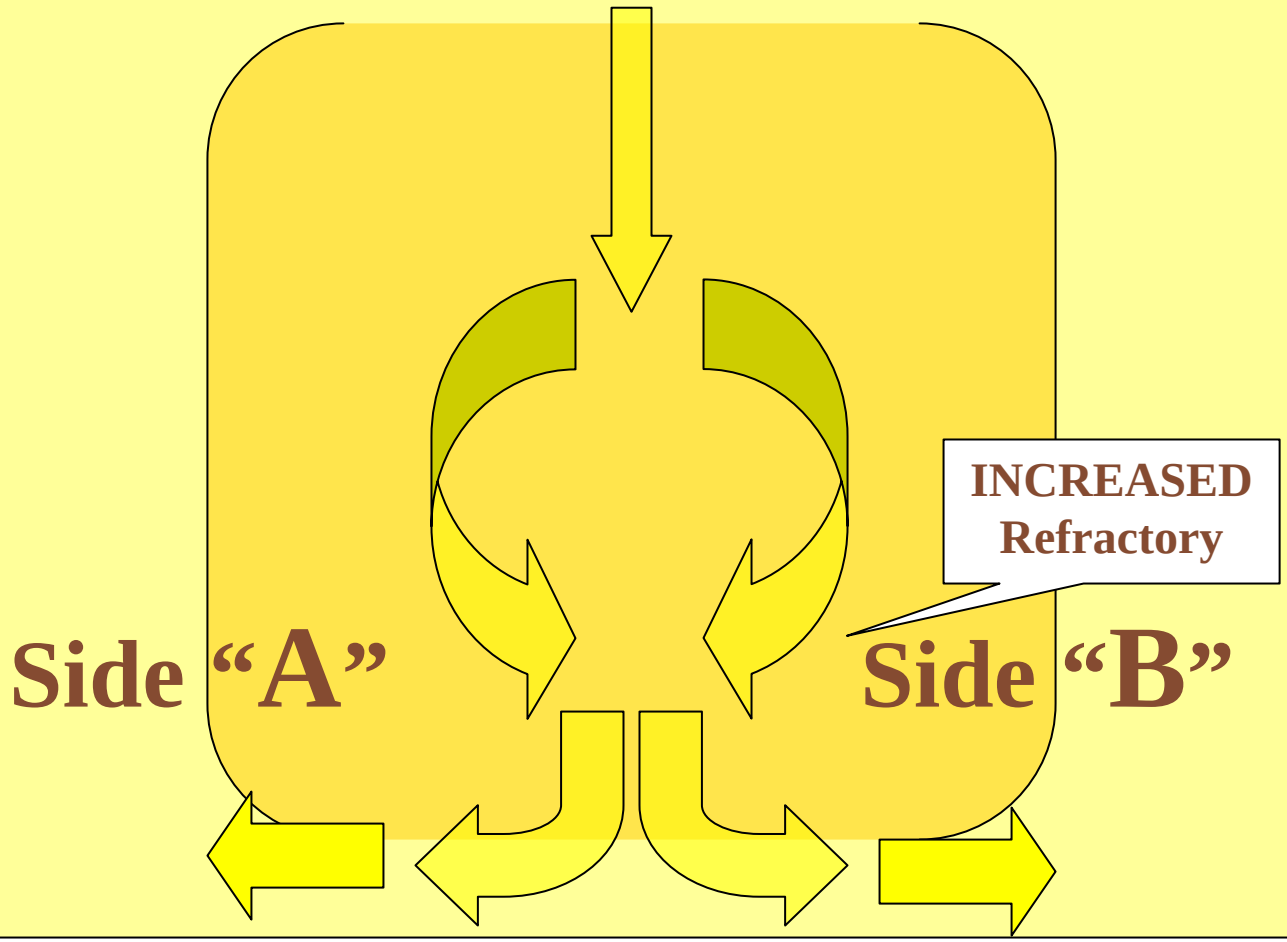
# Timing is Everything



# Timing is Everything



# Timing is Everything



# Ventricular Fibrillation

**Figure 45 - Three Examples of Ventricular Fibrillation**

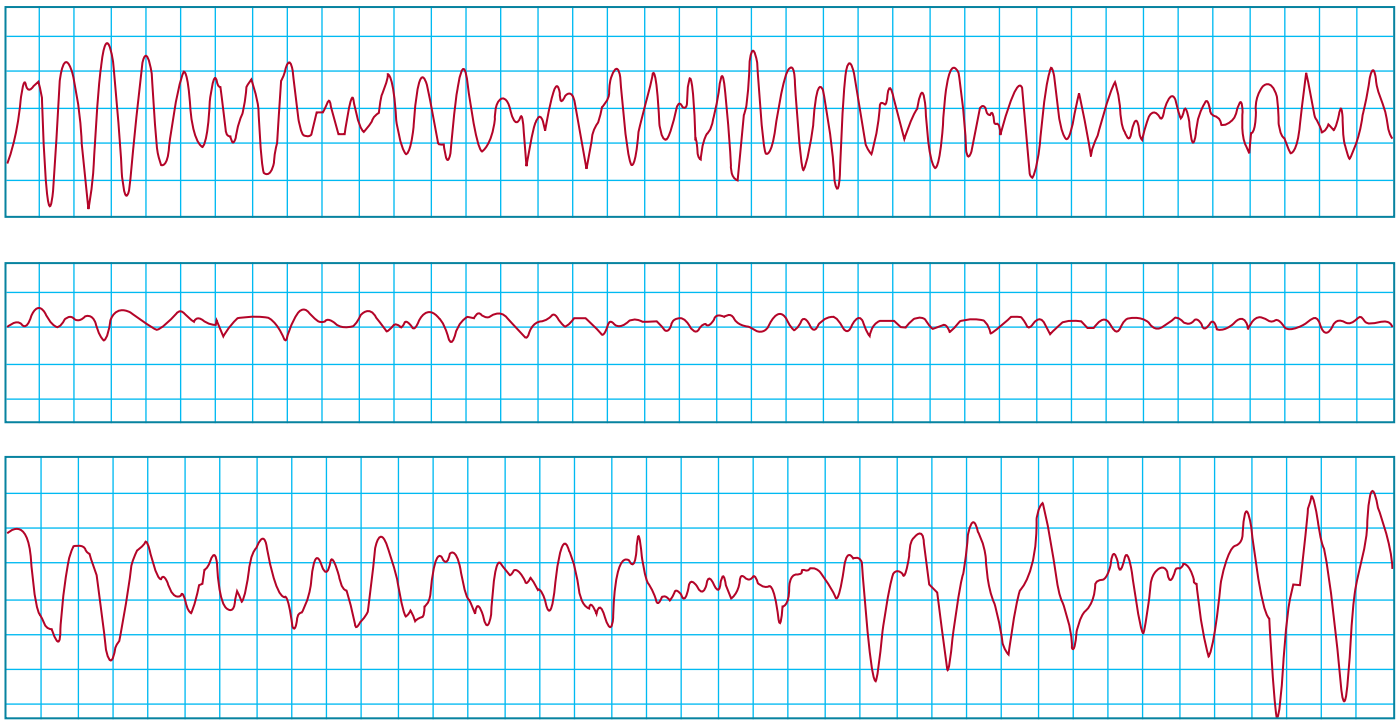
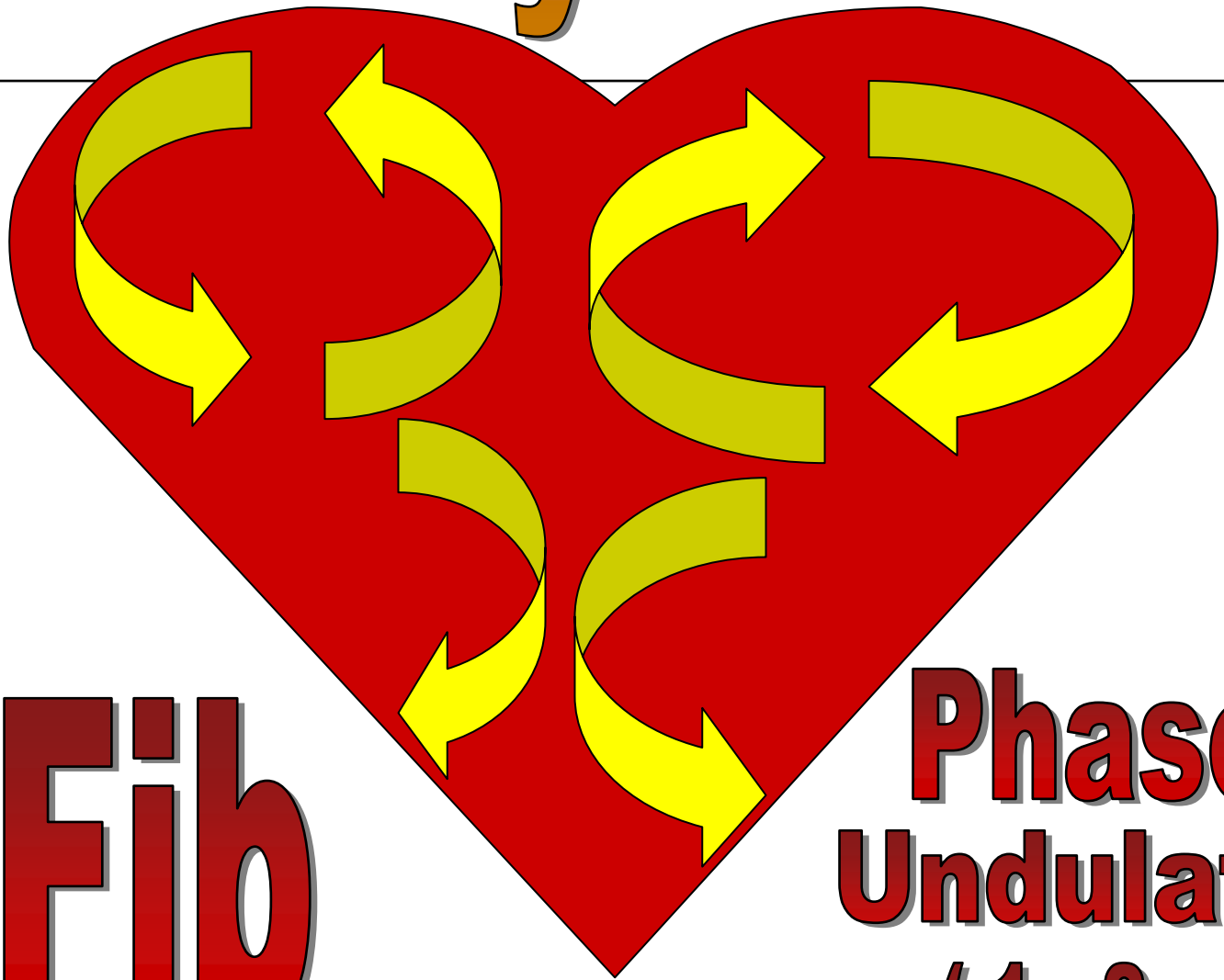


Figure by MIT OpenCourseWare.

# Re-Entry-A-Go-Go:



## V-Fib

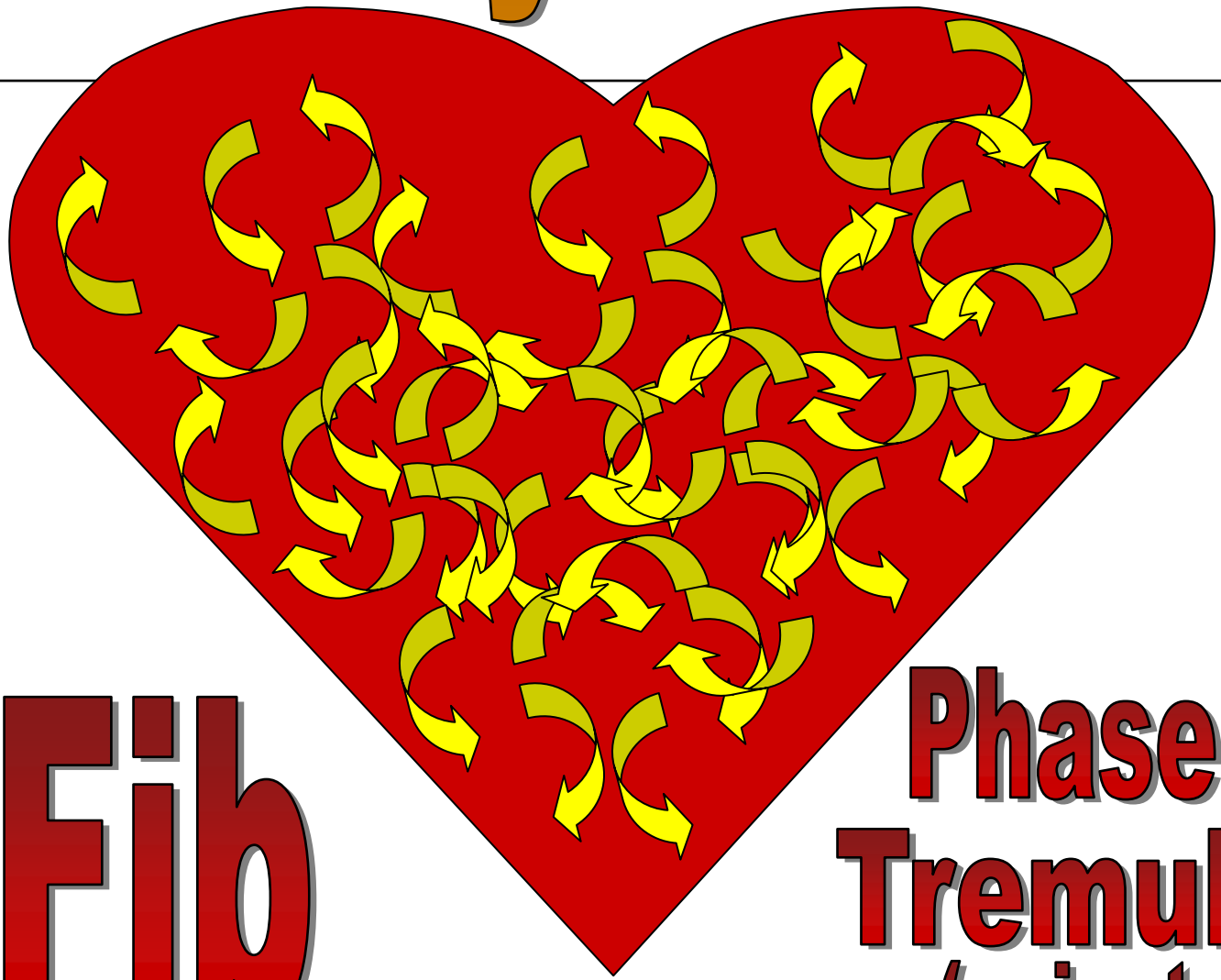
## Phase I
## Undulatory
## ( 1 - 2 sec)

# Re-Entry-A-Go-Go:

## V-Fib

## Phase II Convulsive (10 - 30 sec)

# Re-Entry-A-Go-Go:



## V-Fib

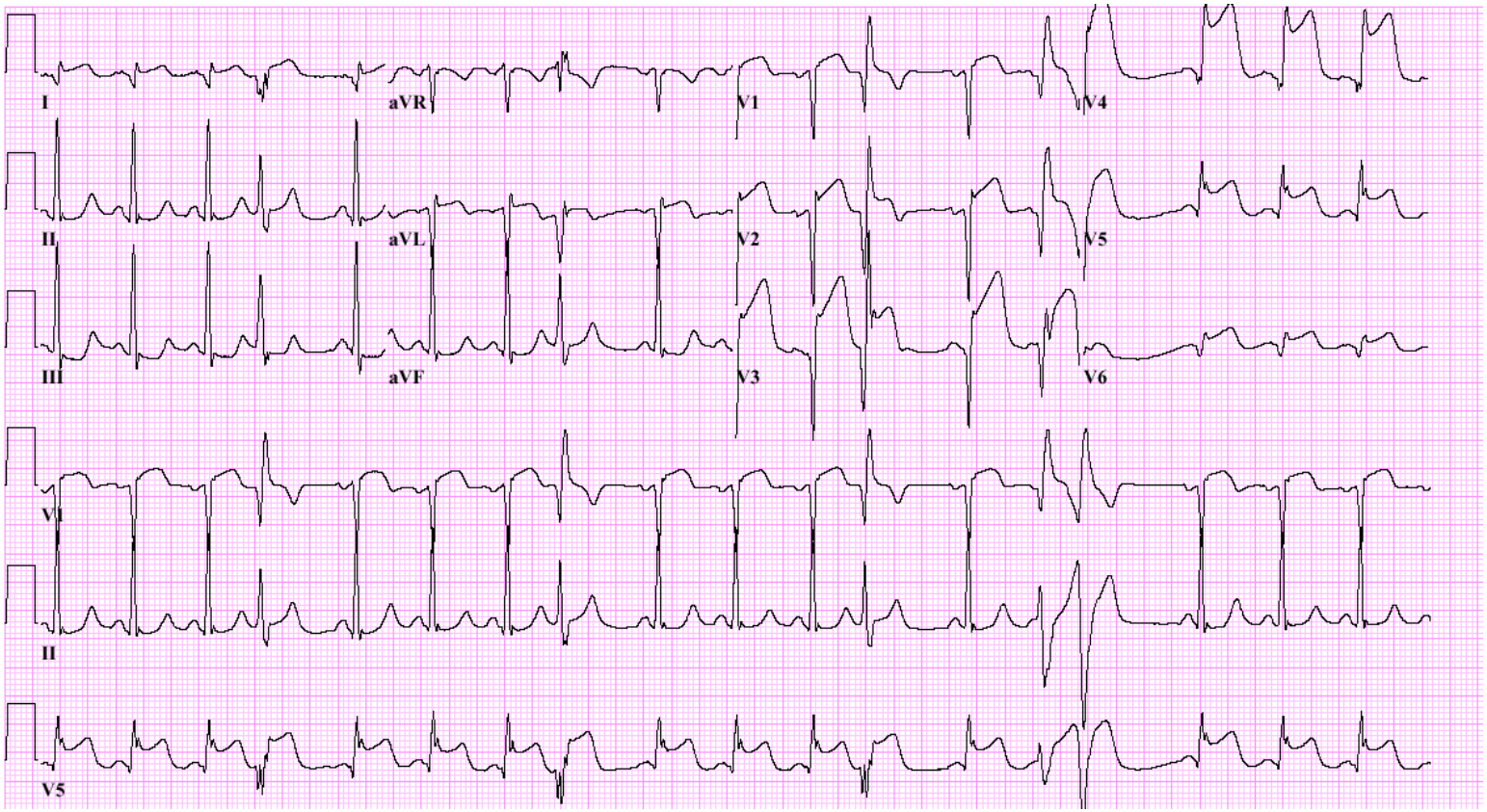
## Phase III Tremulous ( minutes )

# Re-Entry-A-Go-Go:

## V-Fib

## Phase II Convulsive (10 - 30 sec)

# Heart attack



# Frontal Plane Limb Leads

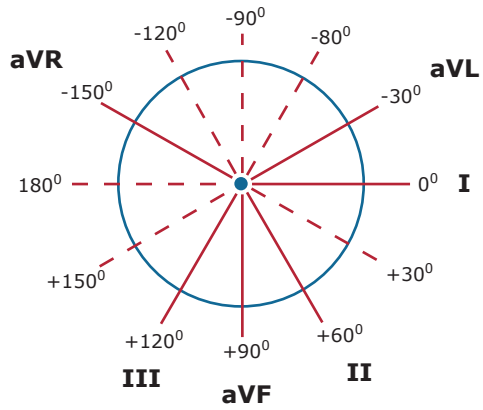



Figure by MIT OpenCourseWare.

The location of these leads is as follows:

$V_1$: on the fourth intercostal space at the right sternal margin

$V_2$: on the fourth intercostal space at the left sternal margin

$V_3$: midway between leads V2 and V4

$V_4$: on the fifth intercostal space at the midclavicular line

$V_5$: on the anterior axillary line at the horizontal level of lead V4

$V_6$: on the midaxillary line at the horizontal level of lead V4

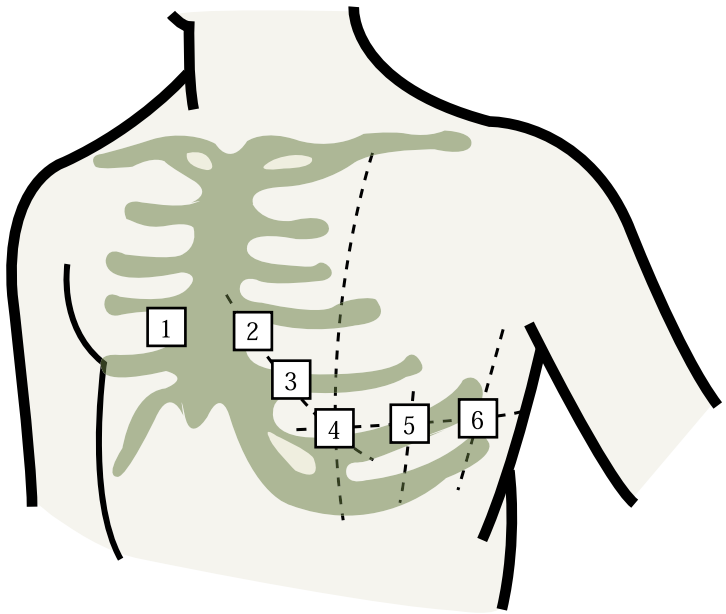
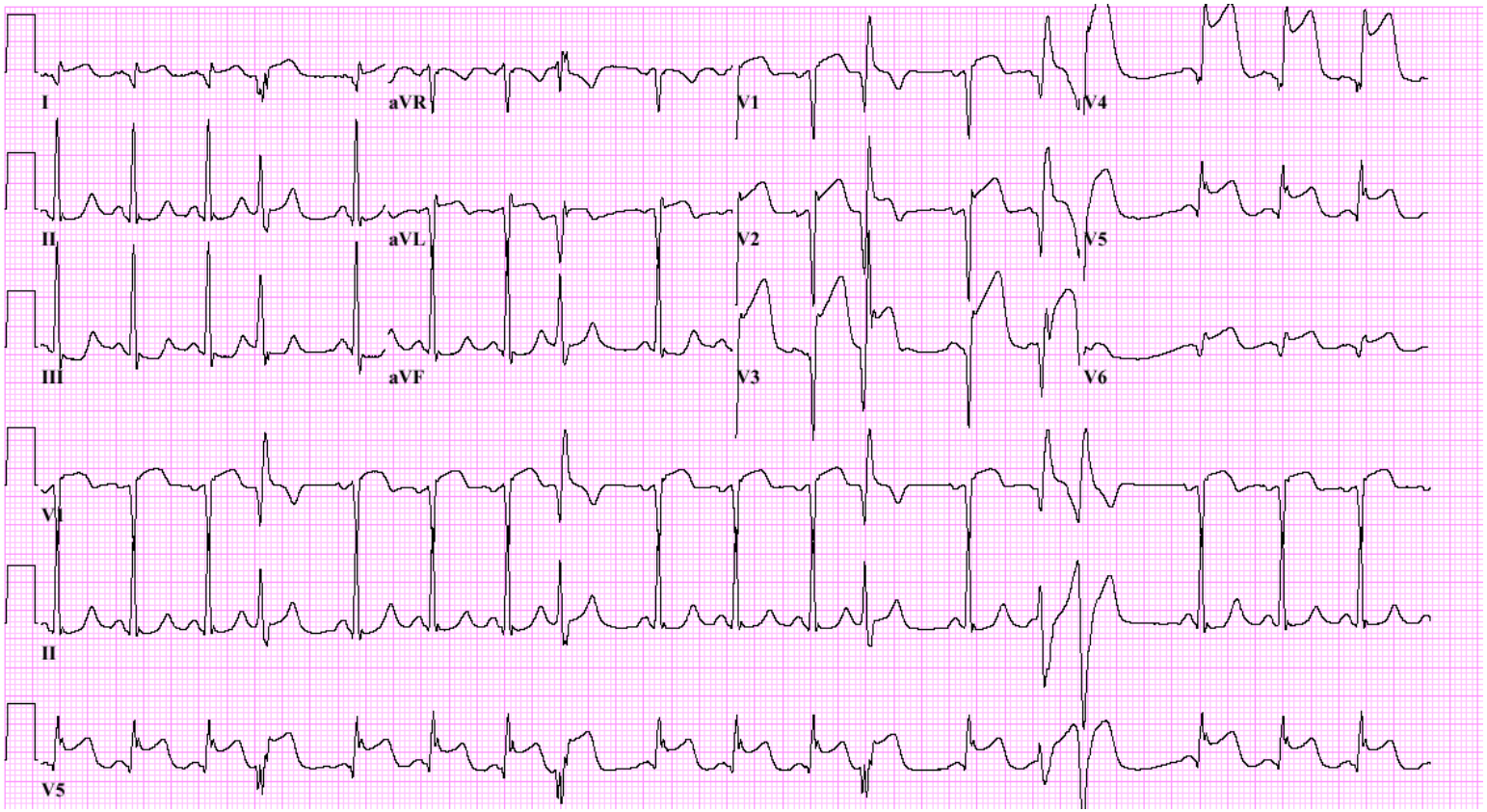
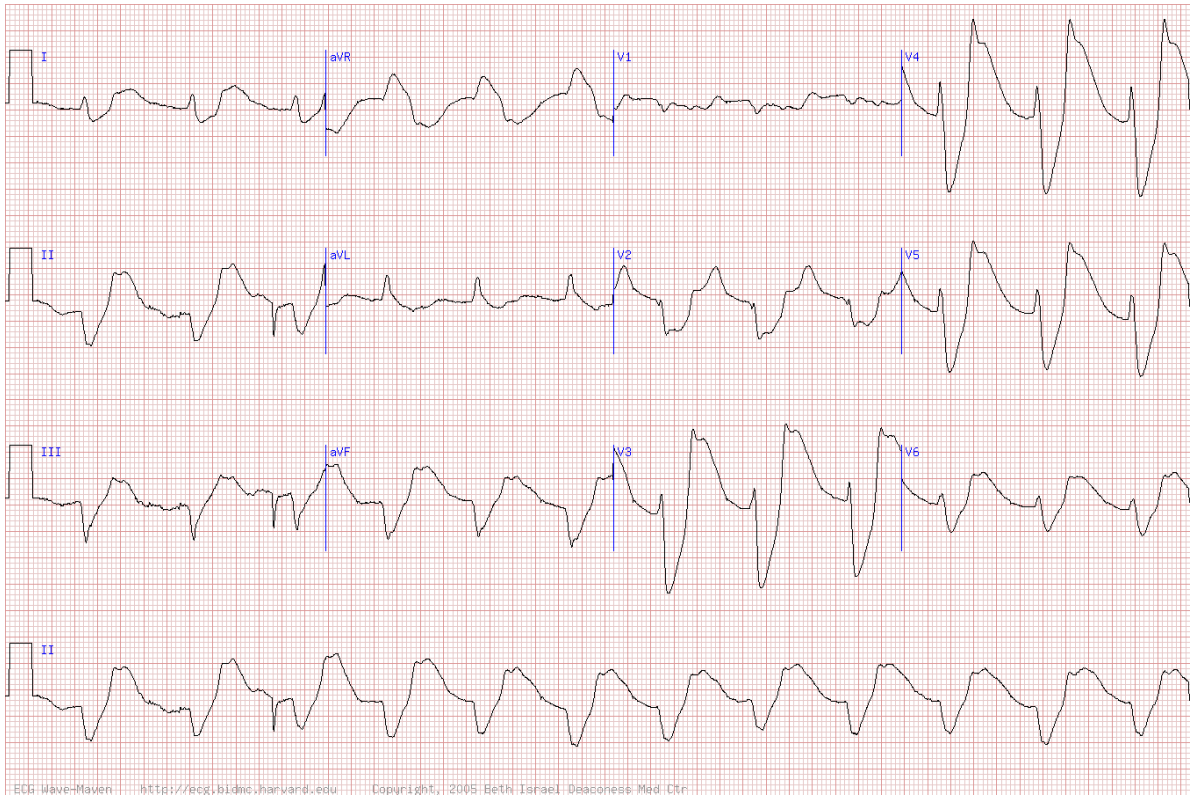



Figure by MIT OpenCourseWare.

# Heart attack



# Hyperkalemia




Courtesy of Ary Goldberger, M.D. Used with permission.
Source: Nathanson L A, McClennen S, Safran C, Goldberger AL. ECG Wave-Maven: Self-Assessment Program for Students and Clinicians. http://ecg.bidmc.harvard.edu. Case #164.

See ECG Wave-Maven (http://ecg.bidmc.harvard.edu/maven/mavenmain.asp) for many other examples of how metabolic conditions can affect the ECG.

# Understanding the ECG: A Cautionary Note

- Basic cell electrophysiology, wavefront propagation model, dipole model:
  Powerful, but incomplete
- There will always be electrophysiologic phenomena which will not conform with these explanatory models
- Examples:
  - metabolic disturbances
  - anti-arrhythmic medications
  - need for 12-lead ECG to record a 3-D phenomenon

# Questions?