

Physiology of the Heart

Conduction System

Cardiac Cellular Electrophysiology

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This presentation includes only the most important terms and facts. Its content by itself is not a sufficient source of information required to pass the Physiology exam.



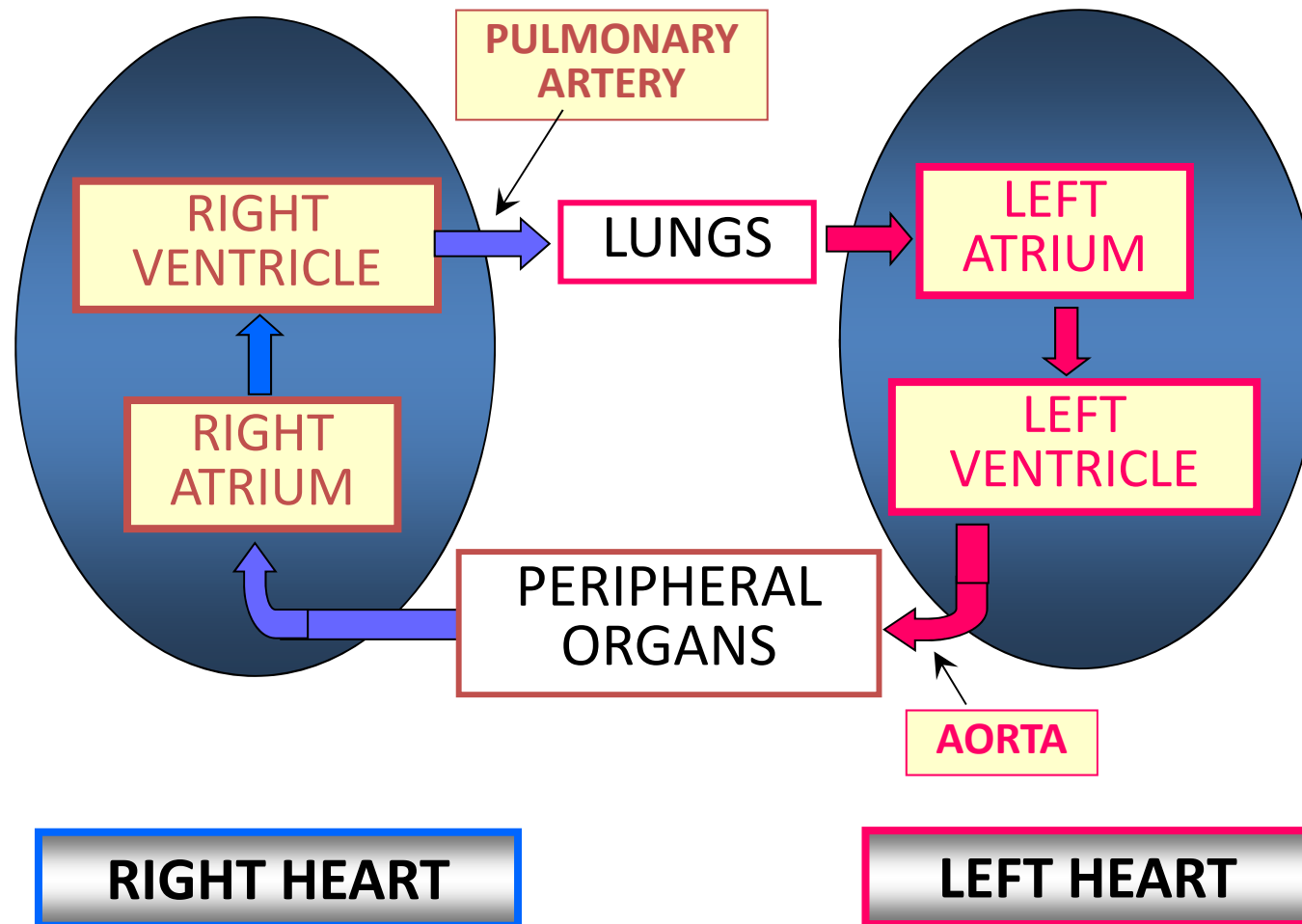
ORGANIZATION OF CARDIOVASCULAR SYSTEM

Roles of the Cardiovascular System

- **primary role** - distribution of dissolved gases and other nutrients
- **several secondary roles, for example:**
 - fast chemical signalling to the cells (circulating hormones and neurotransmitters)
 - thermoregulation (delivery of heat from the core to the surface of the body)
 - immune reaction
- **roles of the heart:**
 - primary role - pumping of blood
 - endocrine organ (natriuretic peptides)

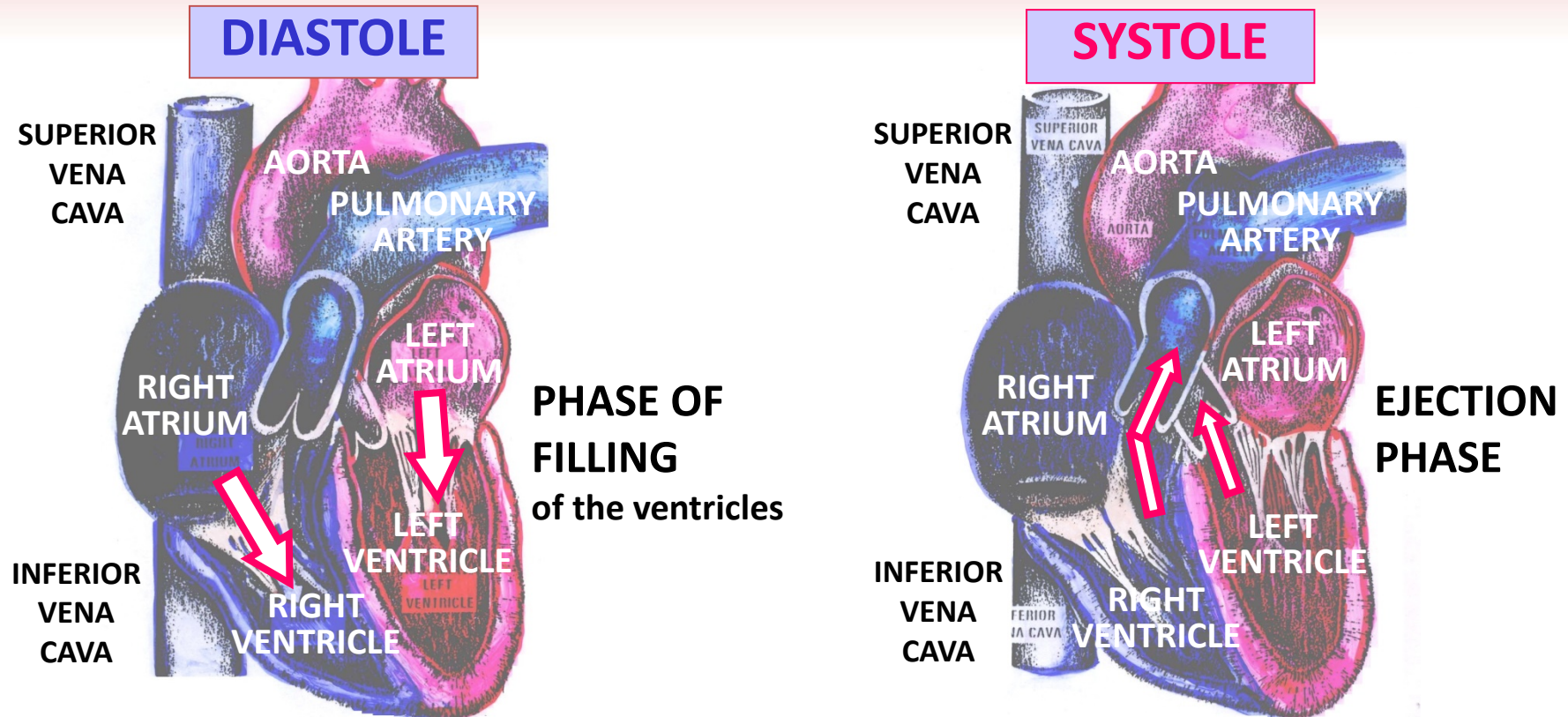
ORGANIZATION OF CARDIOVASCULAR SYSTEM

TWO PUMPS INTERCONNECTED IN SERIES



ORGANIZATION OF CARDIOVASCULAR SYSTEM

Two Main Phases of the Cardiac Cycle



ONE WAY VALVES	DIASTOLE	SYSTOLE
ATRIOVENTRICULAR (mitral and tricuspid)	open	closed
SEMILUNAR (aortal and pulmonary)	closed	open

ORGANIZATION OF CARDIOVASCULAR SYSTEM

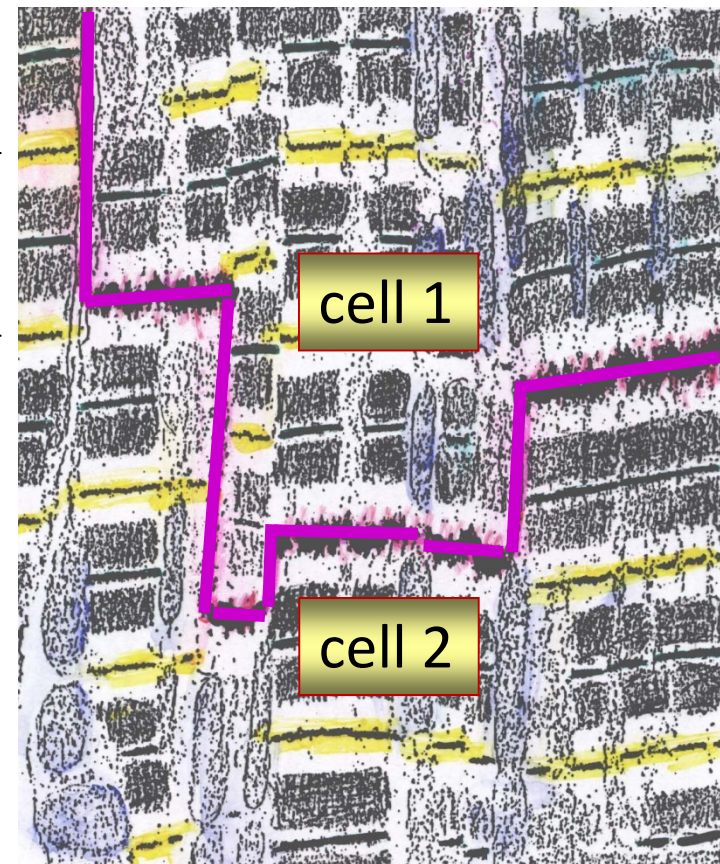
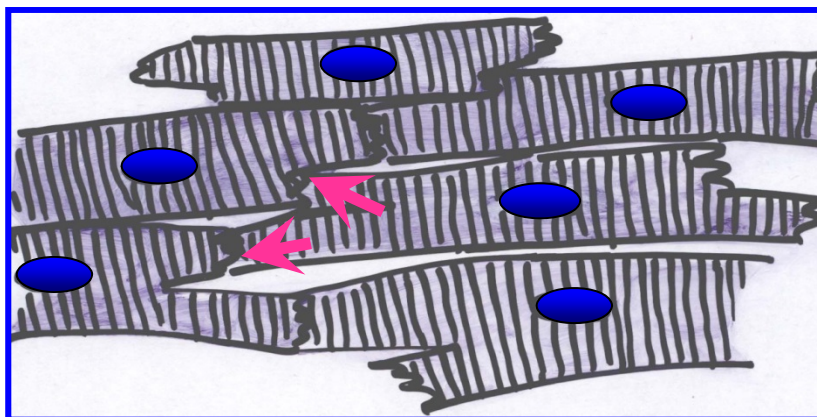
Two Major Types of Cardiac Cells

- **cardiomyocytes of the working myocardium** - specialized for contraction (atrial and ventricular myocytes)

FUNCTIONAL SYNCYTIUM

- mechanical connections
- electrical connections - **gap junctions**

sarcomere



ORGANIZATION OF CARDIOVASCULAR SYSTEM

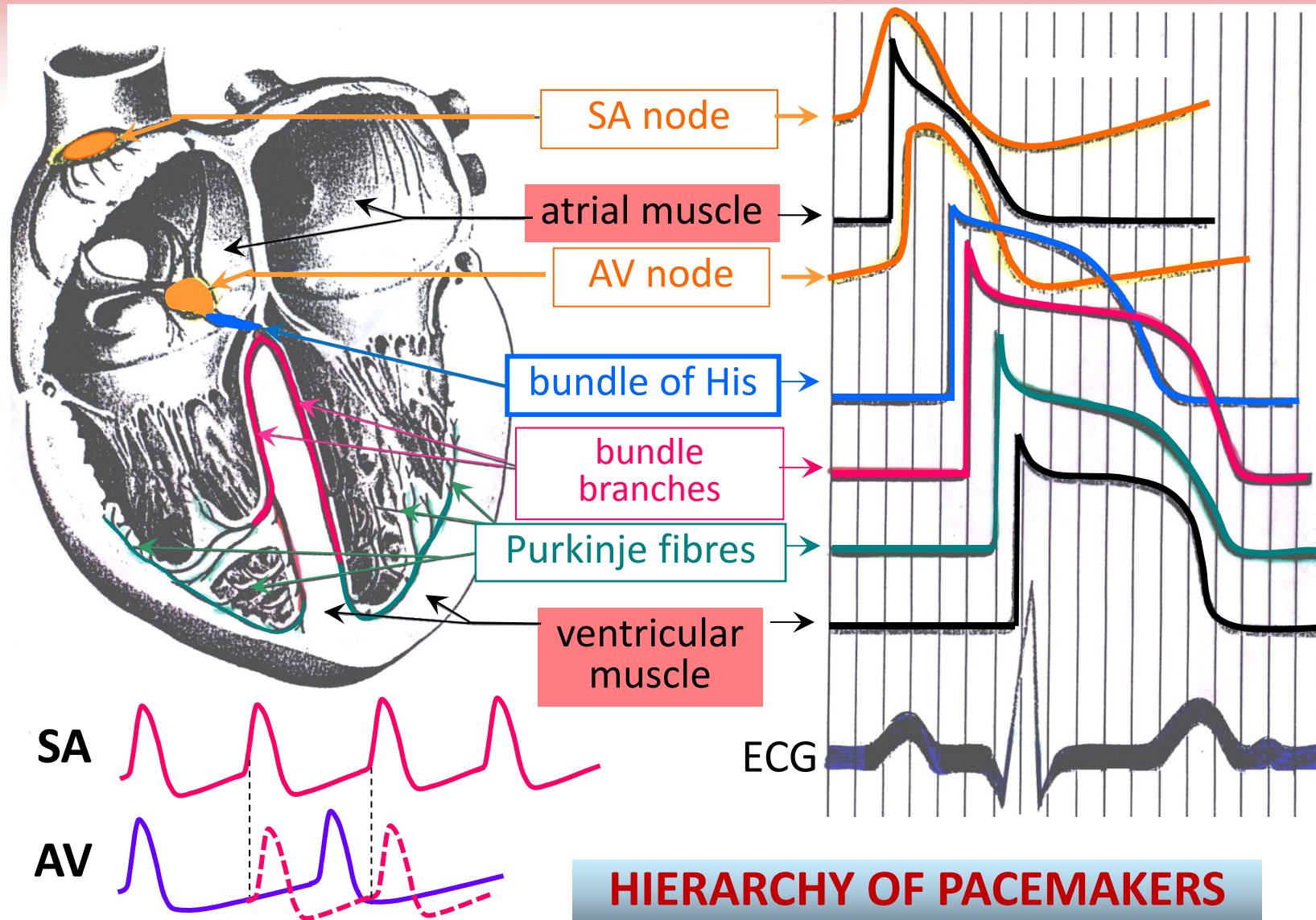
Two Major Types of Cardiac Cells

- **cardiomyocytes of the working myocardium** - specialized for contraction (atrial and ventricular myocytes)
- **cardiomyocytes of the cardiac conduction system** - specialized for:
 - automatic excitation (pacemaker activity)
 - conduction of excitation

The cardiac conduction system ensures:

- 1) generation of automatic electrical activity of the heart (pacemaker activity) that initiates its mechanical activity
- 2) optimal timing of the mechanical activity of the heart as a pump

CARDIAC CONDUCTION SYSTEM



HIERARCHY OF PACEMAKERS

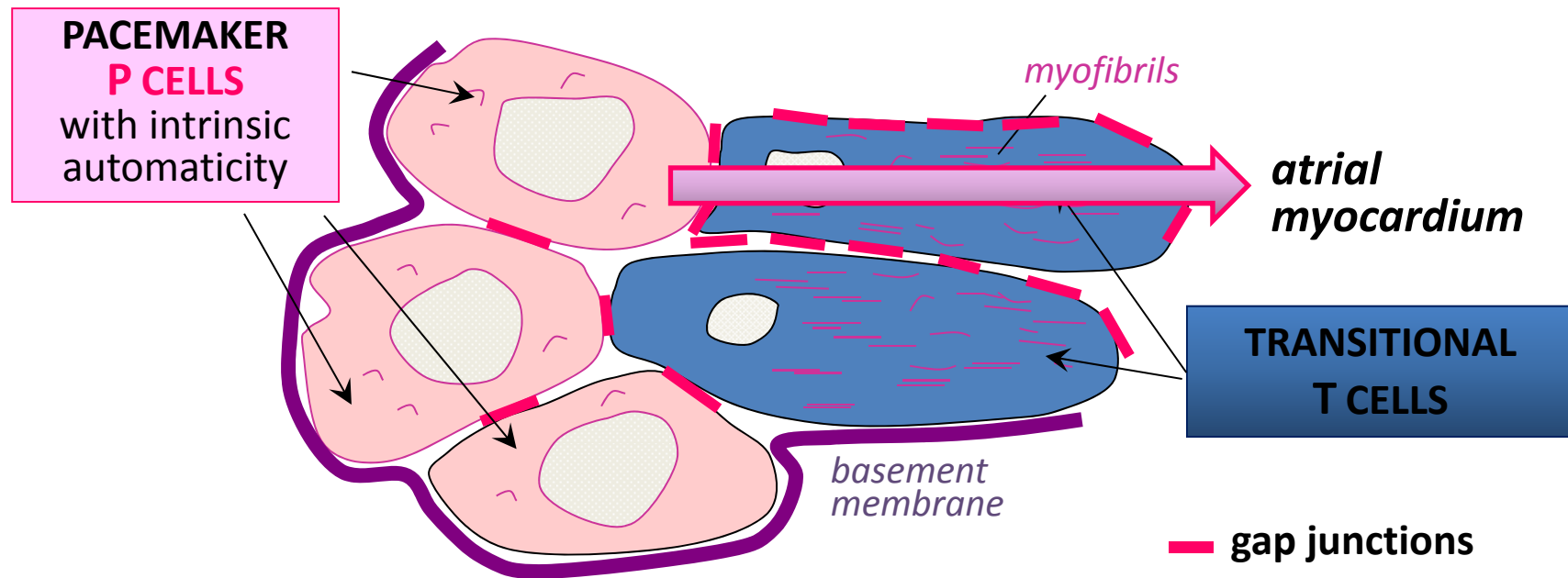
CARDIAC CONDUCTION SYSTEM

- **SINOATRIAL (SA) NODE**
PRIMARY pacemaker (60-100 impulses/min)

CARDIAC CONDUCTION SYSTEM

SA node

TWO TYPES of the SA-nodal cells



SICK SINUS SYNDROME

- *pacemaker P cells are impaired, activity is slowed or stopped*
- *transmission of excitation from P cells to the atrial cells is reduced or interrupted*

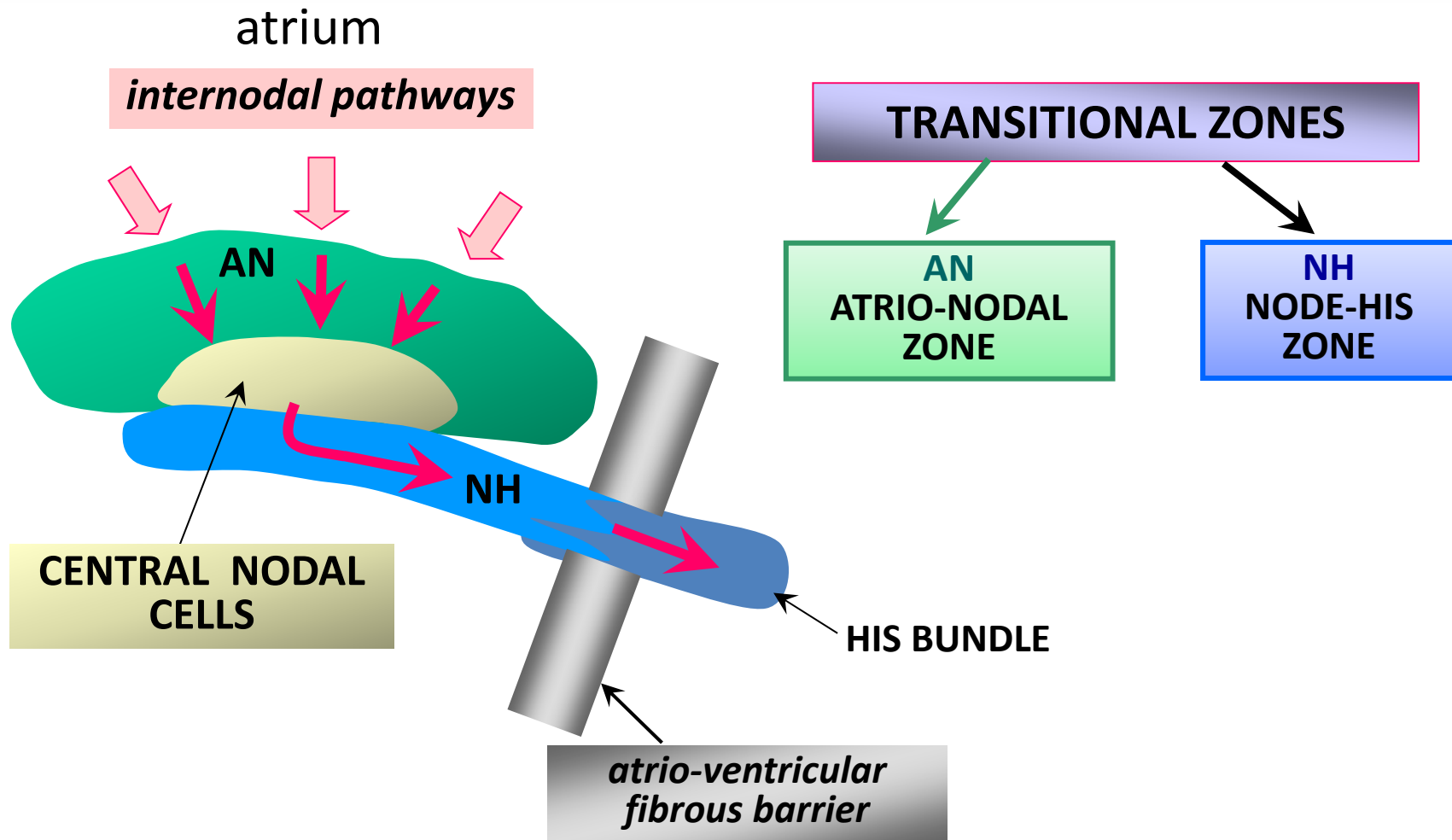
CARDIAC CONDUCTION SYSTEM

- **SINOATRIAL (SA) NODE**
PRIMARY pacemaker (60-100 impulses/min)
- **INTERNODAL PREFERENTIAL PATHWAYS**
- **ATRIOVENTRICULAR (AV) NODE**
SECONDARY pacemaker (40-55 impulses/min)

CARDIAC CONDUCTION SYSTEM

AV node

THREE TYPES of the AV-nodal cells



CARDIAC CONDUCTION SYSTEM

AV node

- **SOLE PATHWAY** FOR PROPAGATION OF EXCITATION FROM ATRIA TO VENTRICLES (NH zone merges into the bundle of His)
- **DELAY** IN PROPAGATION OF EXCITATION, ~100 ms (important for adequate timing of atrial and ventricular contractions)
- **SUBSTITUTIVE (SECONDARY) PACEMAKER** (40-55 impulses/min; importance in the case of sick sinus syndrome)
- **FILTER OF SUPRAVENTRICULAR TACHYARRHYTHMIAS**
atrial excitations are transmitted to the ventricles only up to the limited frequency 180-200 excitations/min (the heart function as a pump is preserved)

CARDIAC CONDUCTION SYSTEM

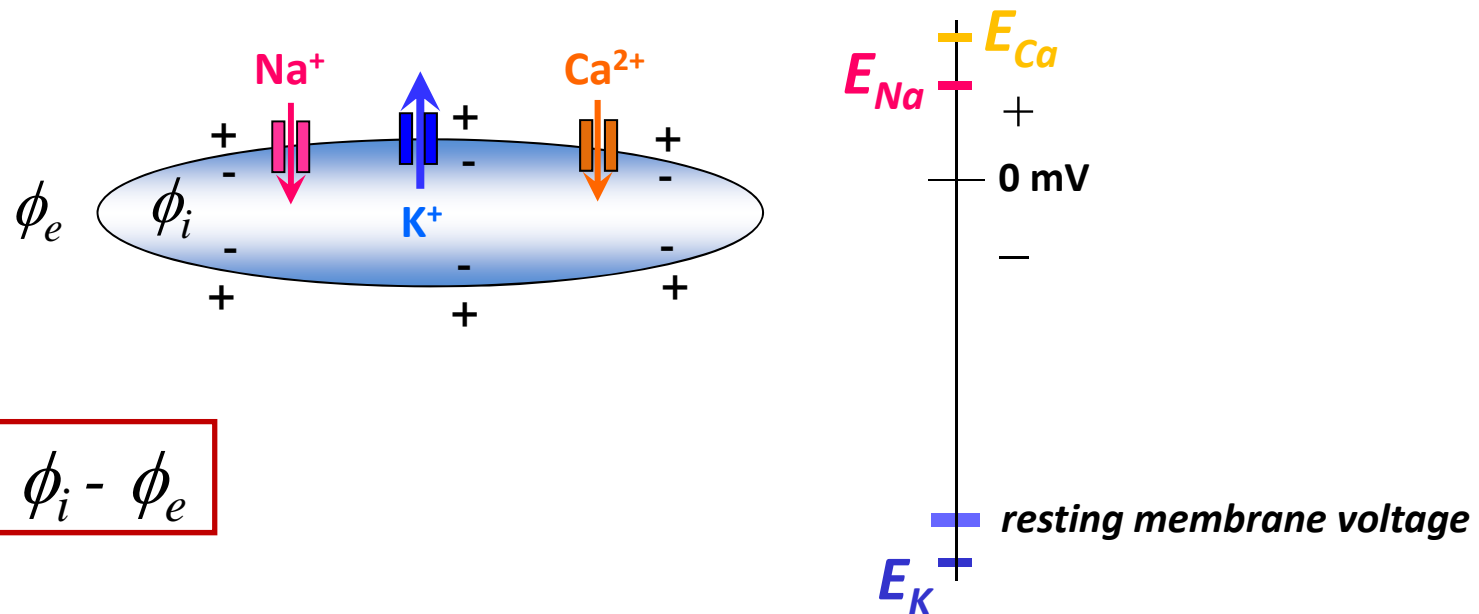
- **SINOATRIAL (SA) NODE**
PRIMARY pacemaker (60-100 impulses/min) **0.05 m/s**
- **INTERNODAL PREFERENTIAL PATHWAYS** **1 m/s**
- **ATRIOVENTRICULAR (AV) NODE**
SECONDARY pacemaker (40-55 impulses/min) **0.05 m/s**
- **BUNDLE OF HIS** **1 m/s**
- **BUNDLE BRANCHES (LEFT AND RIGHT)** **1 m/s**
- **PURKINJE FIBRES**
TERCIARY pacemaker (25-40 impulses/min) **4 m/s**

Conduction velocity in atrial and ventricular muscle: 1 m/s

CARDIAC CELLULAR ELECTROPHYSIOLOGY

Ionic Channels

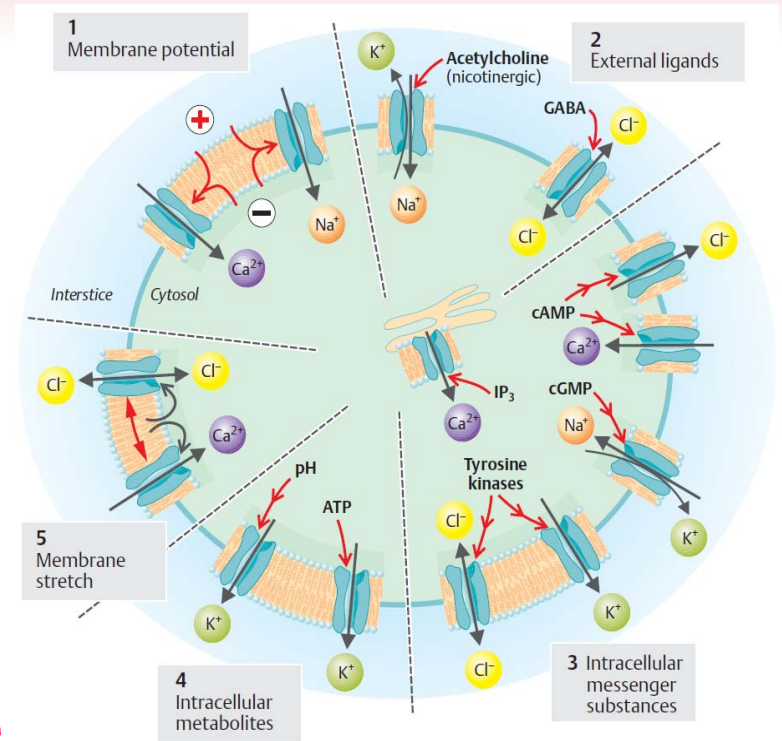
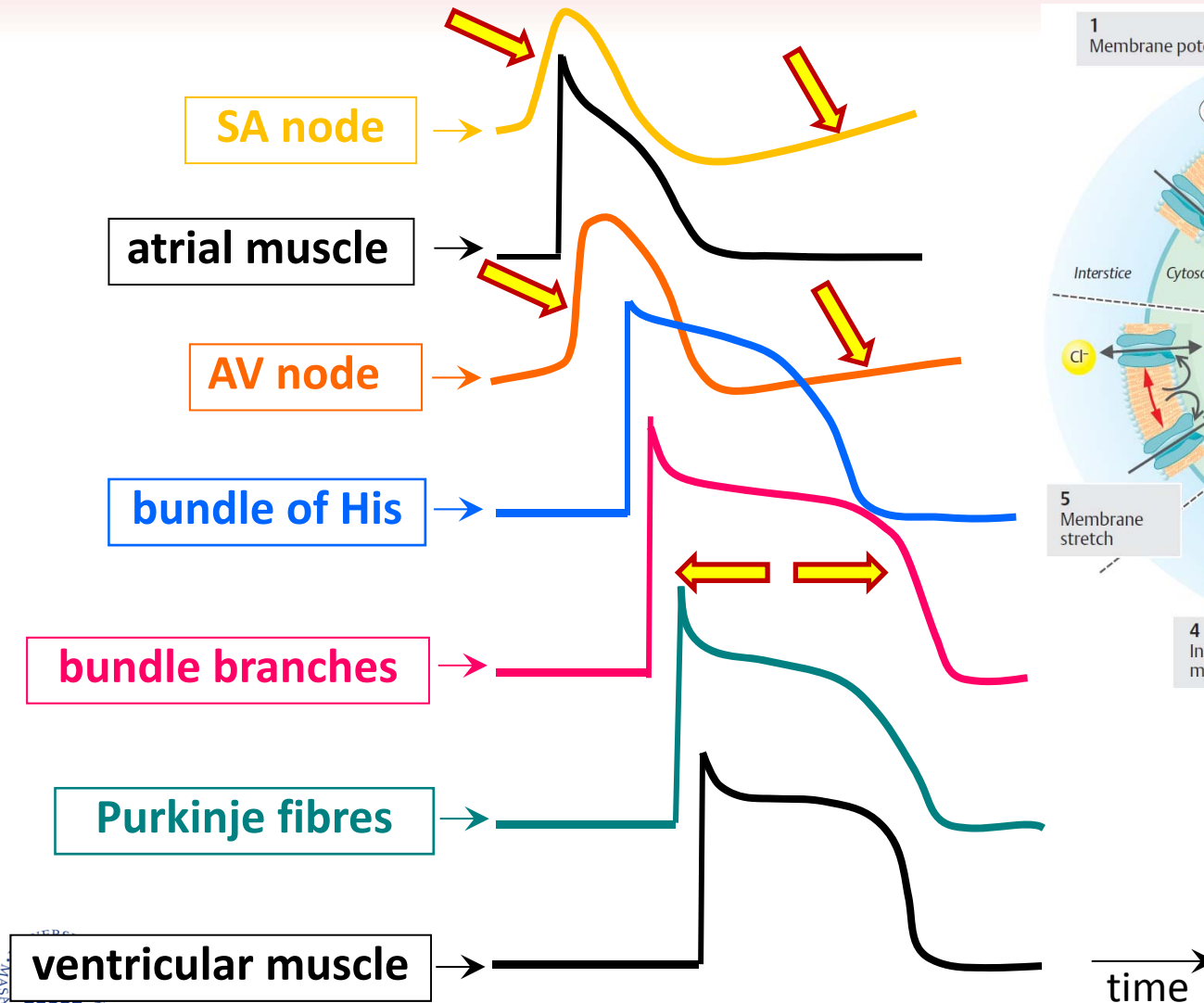
Movement of ions through the open channels
down their electrochemical (concentration + electrical) gradients



$$V_m = \phi_i - \phi_e$$

CARDIAC CELLULAR ELECTROPHYSIOLOGY

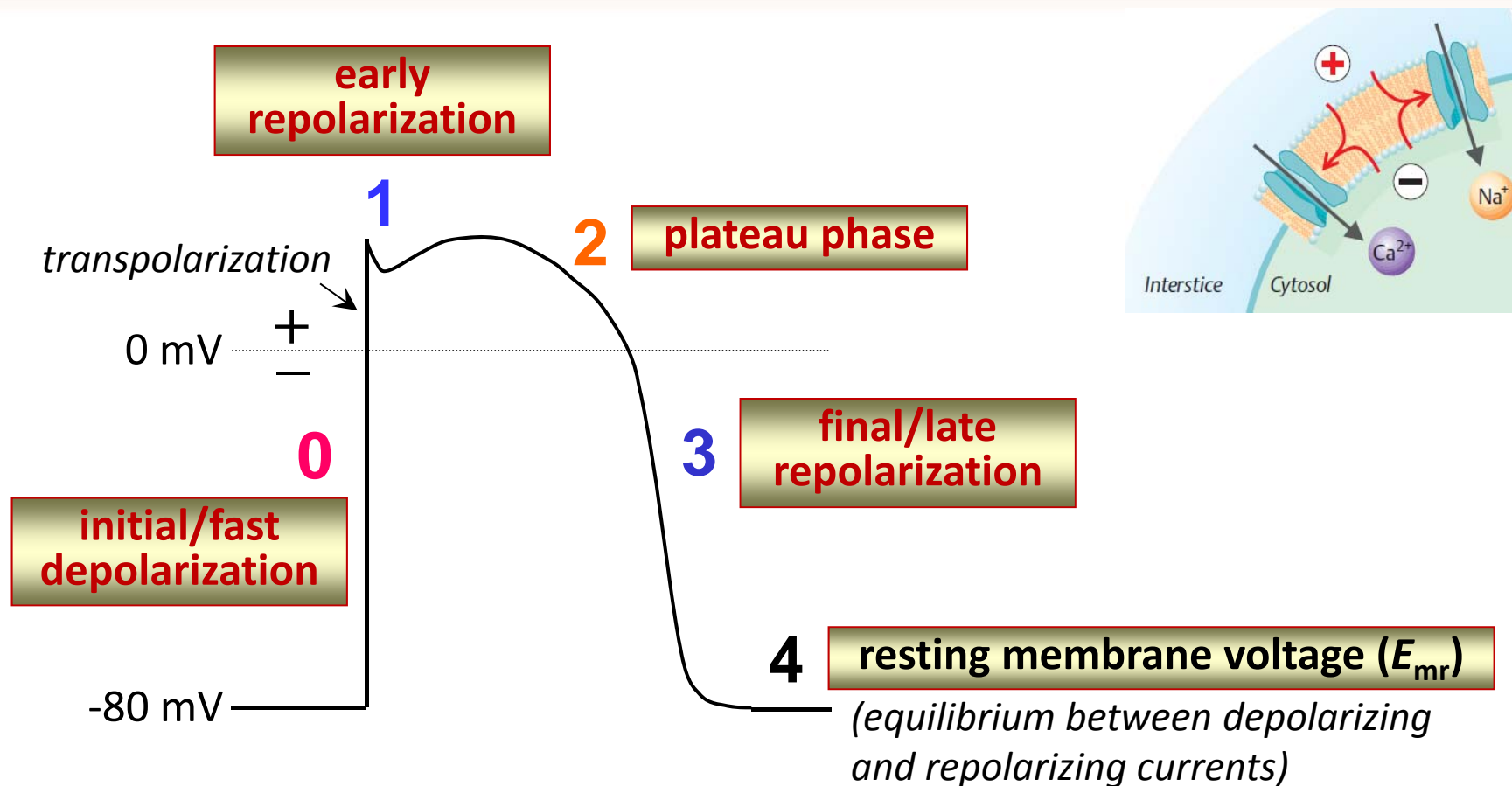
Ionic Currents Underlying Action Potential Configuration



Despopoulos, Color Atlas of Physiology © 2003

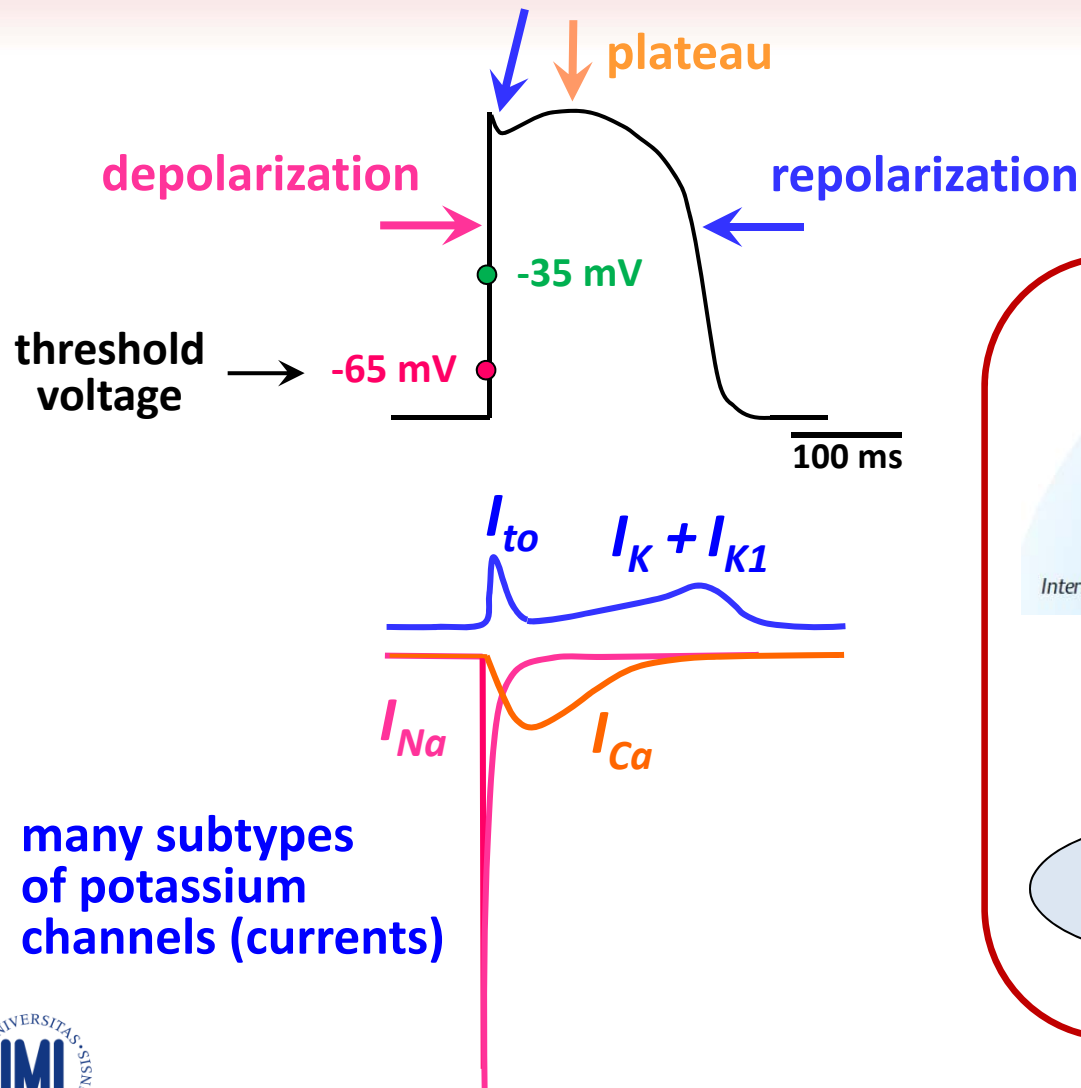
CARDIAC CELLULAR ELECTROPHYSIOLOGY

Ionic Currents Underlying Action Potential Configuration

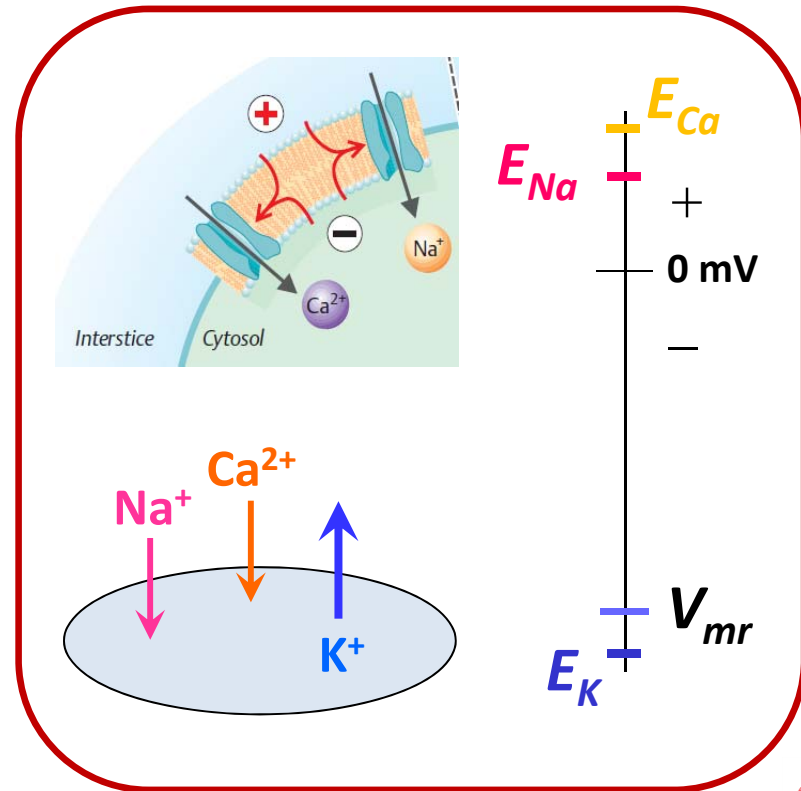


CARDIAC CELLULAR ELECTROPHYSIOLOGY

Ionic Currents Underlying Action Potential Configuration

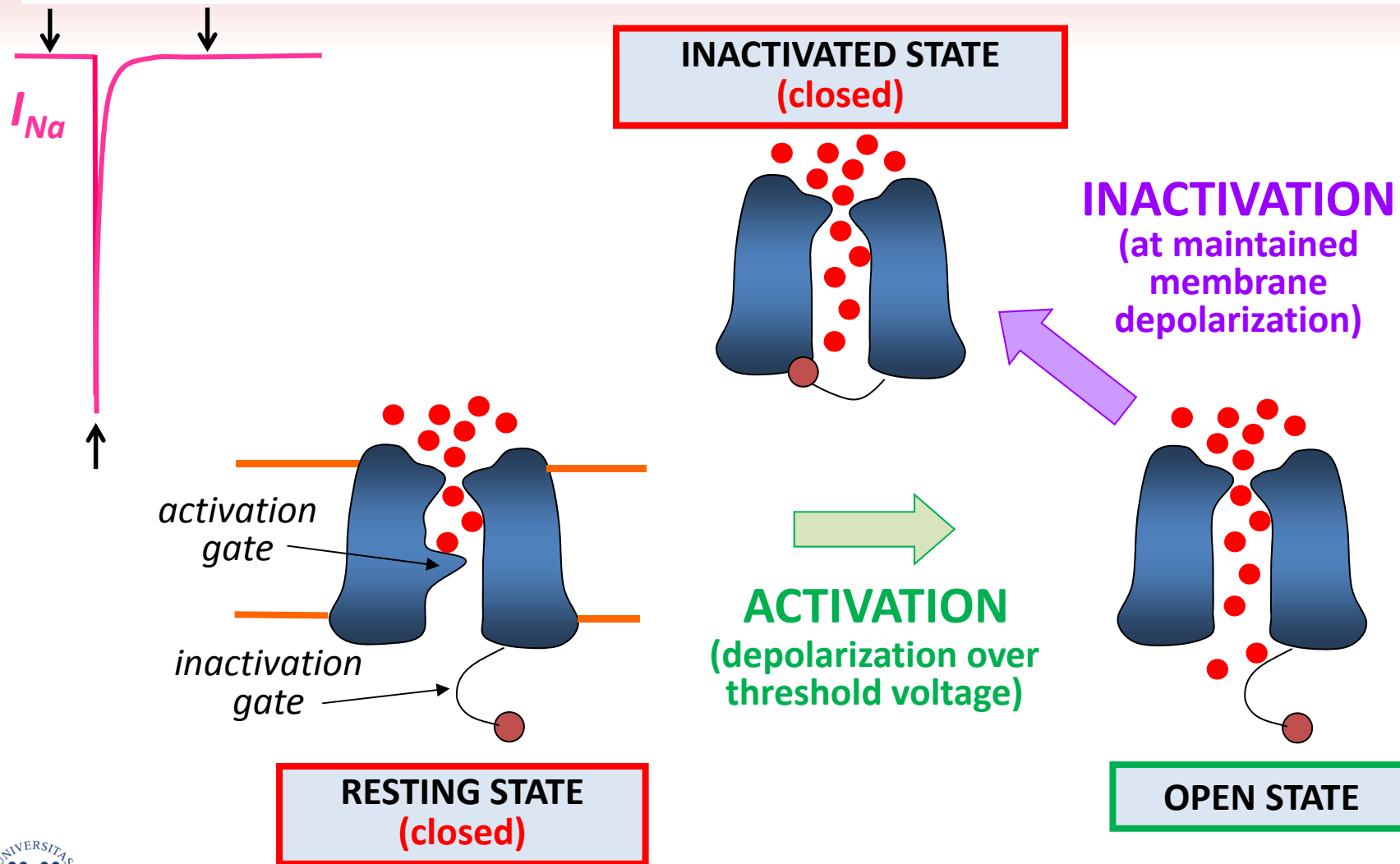


many subtypes of potassium channels (currents)



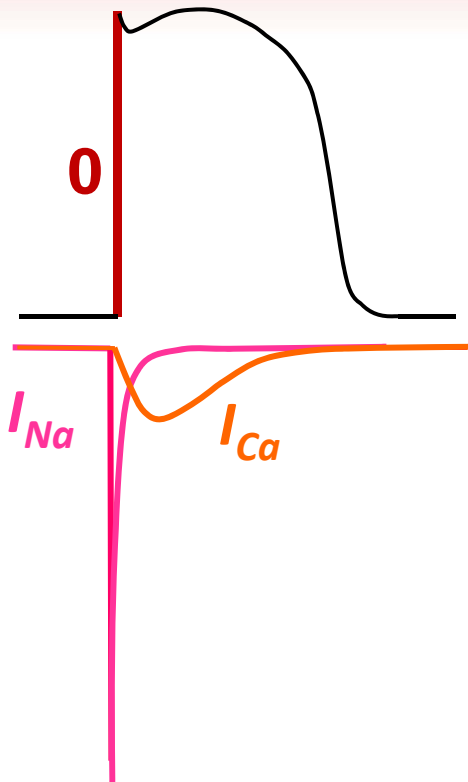
CARDIAC CELLULAR ELECTROPHYSIOLOGY

Ionic Currents Underlying Action Potential Configuration



CARDIAC CELLULAR ELECTROPHYSIOLOGY

Mechanism of the initial fast depolarization (phase 0)



regenerative (self restoring) process

produced by POSITIVE FEEDBACK
between MEMBRANE VOLTAGE and
CONDUCTANCE of MEMBRANE
CHANNELS (g_{Na} , g_{Ca})

working myocardium - I_{Na}

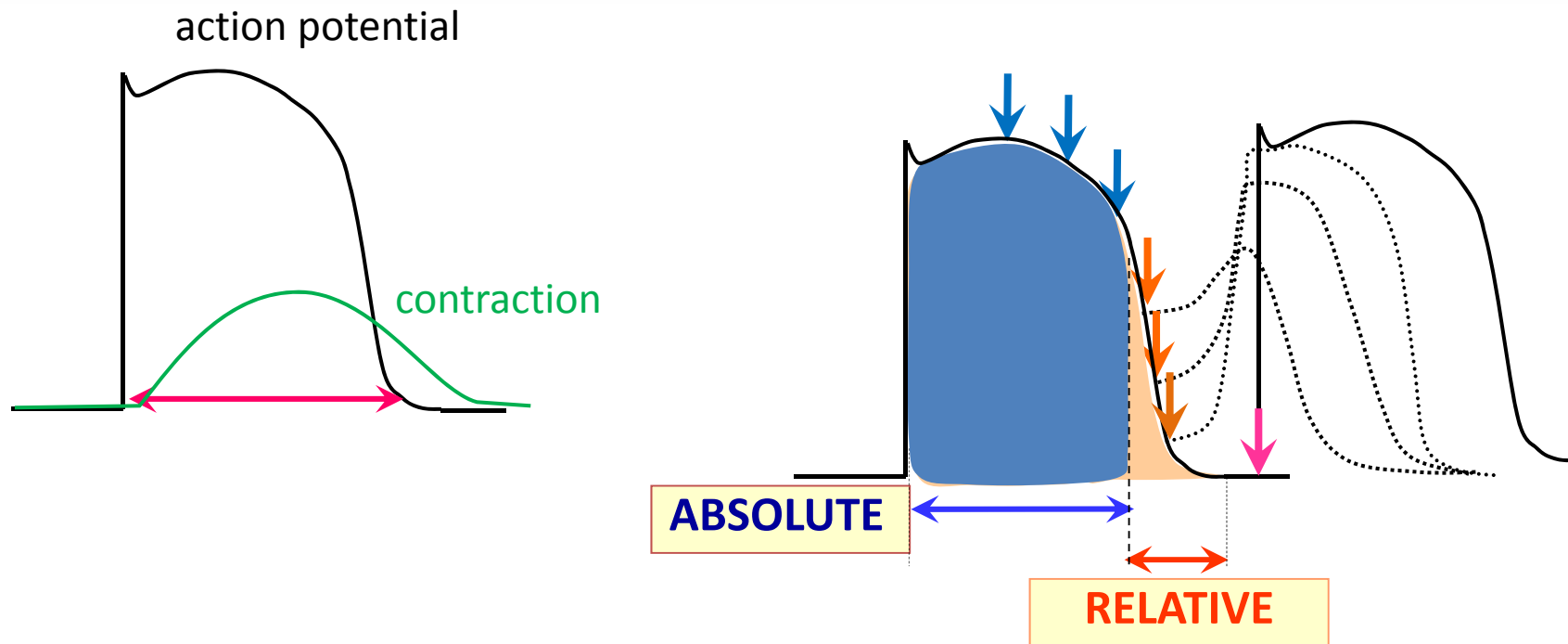
depolarizing currents

↑ depolarization ⇒ **↑ conductance of Na^+ (Ca^{2+}) channels** ⇒ **↑ I_{Na} (I_{Ca})**

*(directly proportionate to the fraction of
 Na^+ (Ca^{2+}) channels in the open state)*

CARDIAC CELLULAR ELECTROPHYSIOLOGY

Refractory Period – Suppression of Excitability

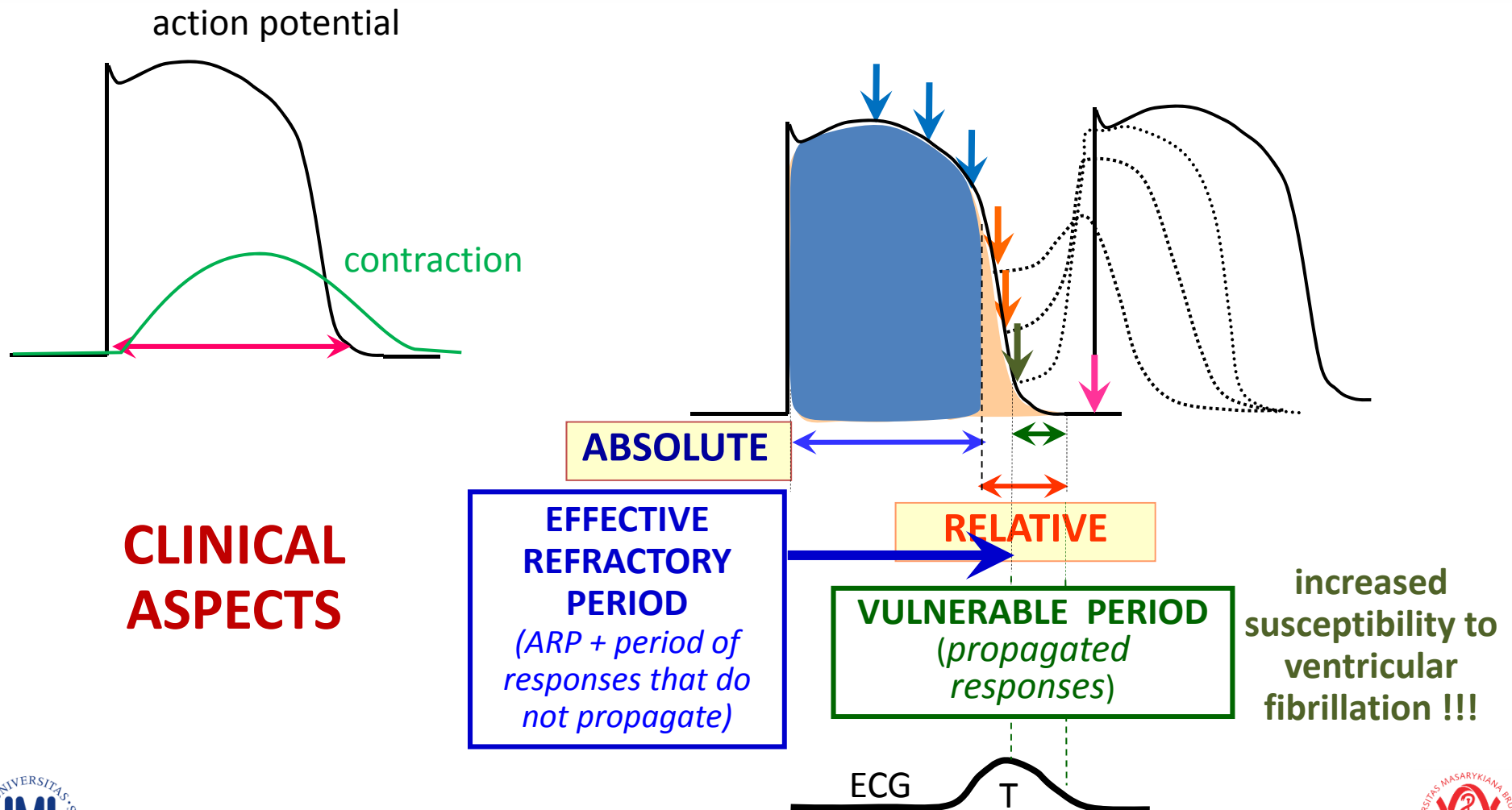


protection of the heart against:

- retrograde propagation of excitation (reentry)
- tetanic contraction at higher heart rate

CARDIAC CELLULAR ELECTROPHYSIOLOGY

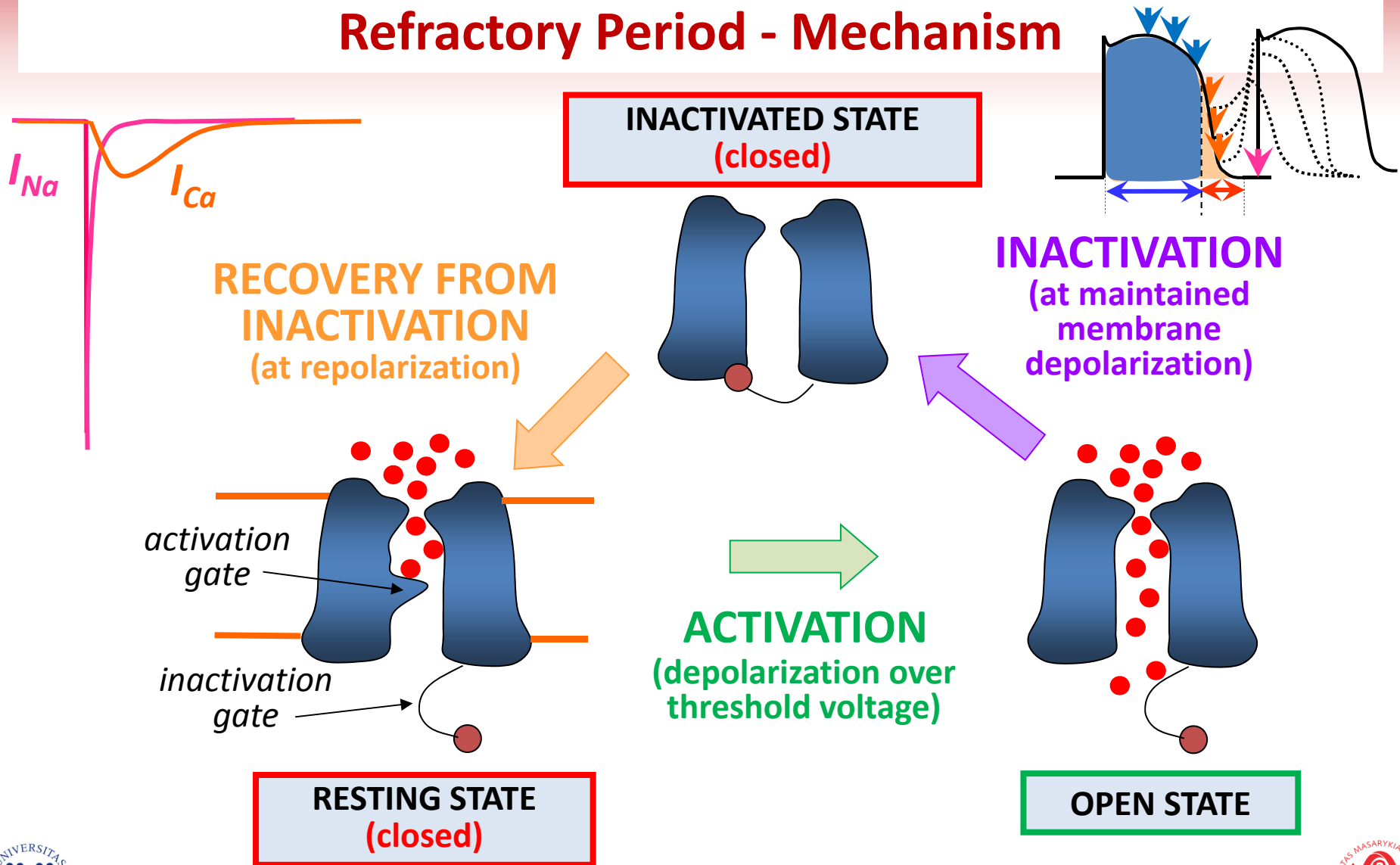
Refractory Period – Suppression of Excitability



CLINICAL ASPECTS

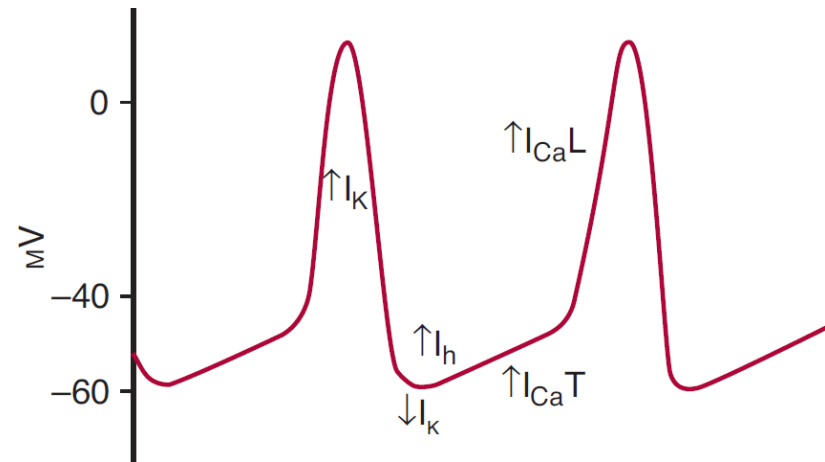
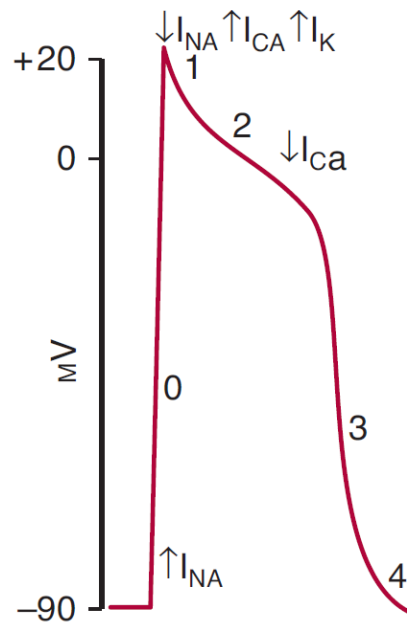
CARDIAC CELLULAR ELECTROPHYSIOLOGY

Refractory Period - Mechanism



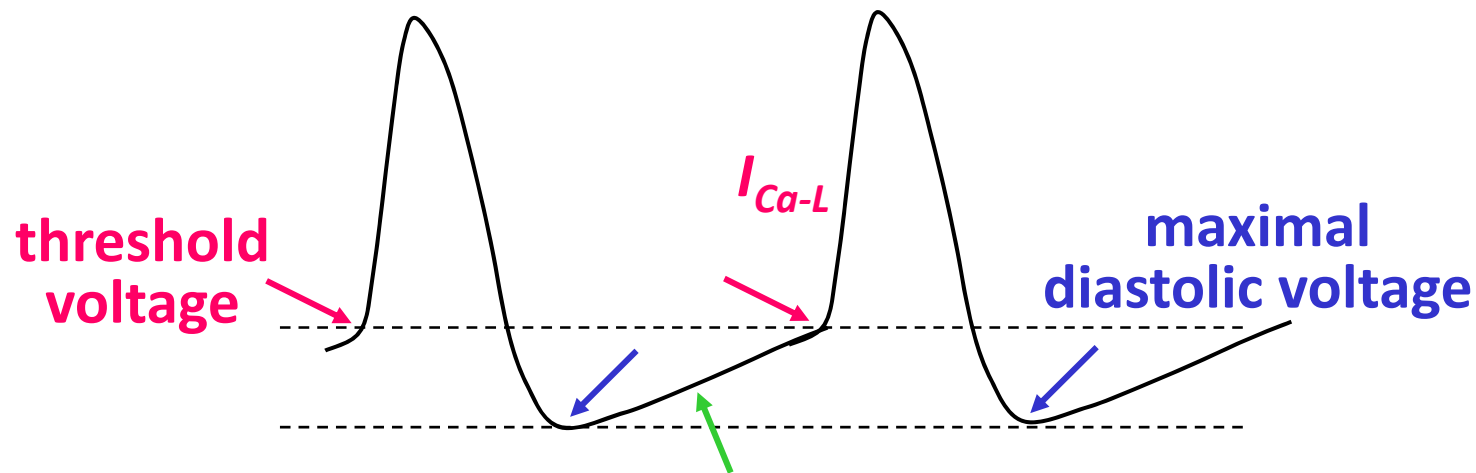
CARDIAC CELLULAR ELECTROPHYSIOLOGY

Pacemaker Activity - Mechanism



CARDIAC CELLULAR ELECTROPHYSIOLOGY

Pacemaker Activity - Mechanism

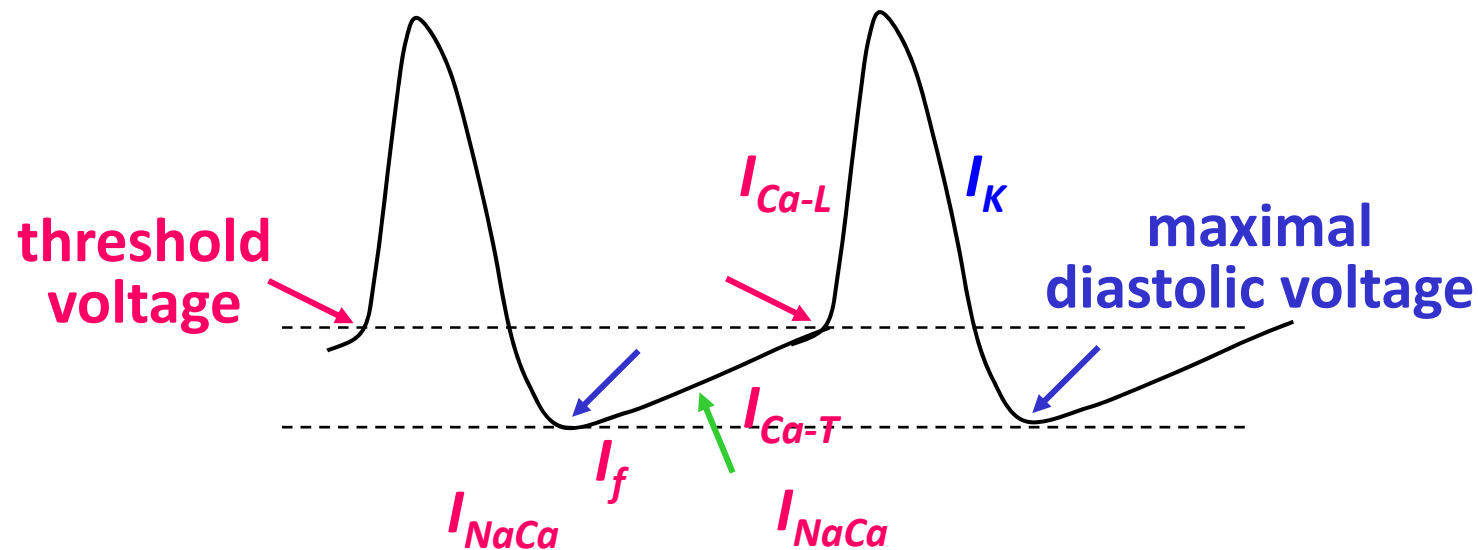


FACTORS DETERMINING THE HEART RATE:

- 1) maximal diastolic voltage
- 2) steepness of diastolic depolarization
- 3) threshold voltage for activation of I_{Ca-L}

CARDIAC CELLULAR ELECTROPHYSIOLOGY

Pacemaker Activity - Mechanism

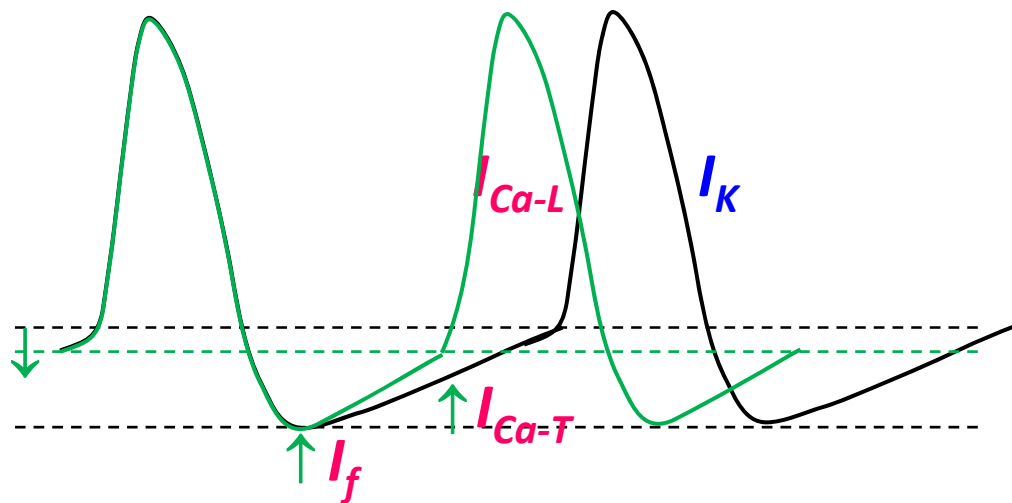


COMPLEX PROCESS resulting from an INTERPLAY between

- **REPOLARIZING CURRENTS**, namely I_K (including $I_{K,Ach}$)
- **DEPOLARIZING CURRENTS**, namely I_f , I_{Ca-T} , and I_{NaCa}

CARDIAC CELLULAR ELECTROPHYSIOLOGY

Pacemaker Activity - Mechanism

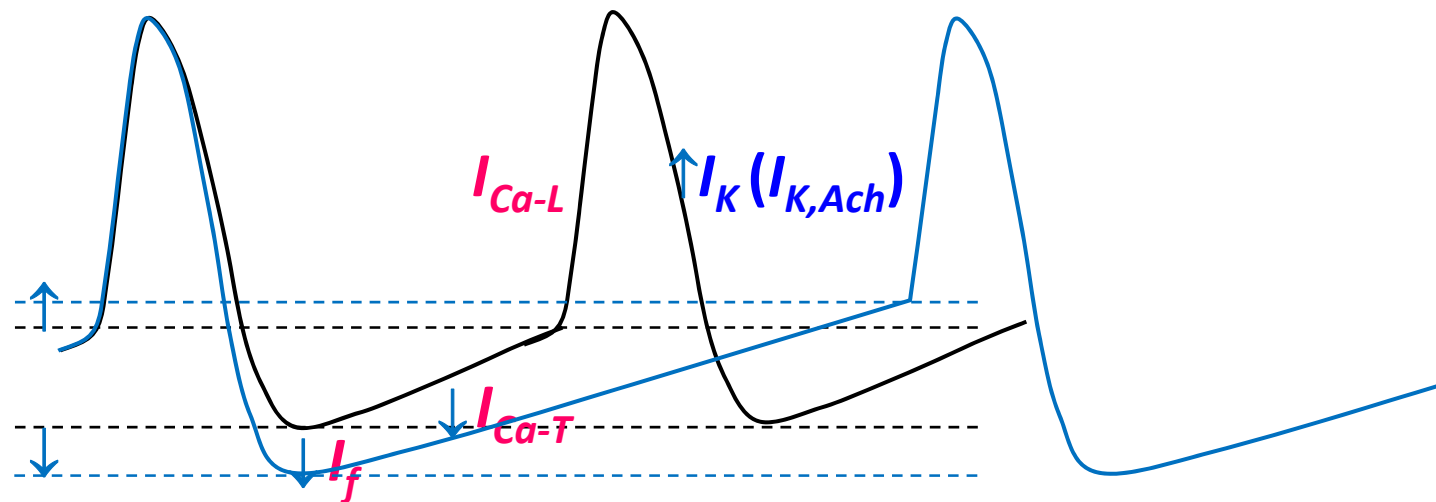


SYMPATHETIC STIMULATION

- \uparrow cAMP \longrightarrow \uparrow I_f and I_{Ca-T} \longrightarrow \uparrow rate of diastolic depolarization
 \longrightarrow \downarrow threshold voltage for activation of I_{Ca-L}
(\uparrow excitability)

CARDIAC CELLULAR ELECTROPHYSIOLOGY

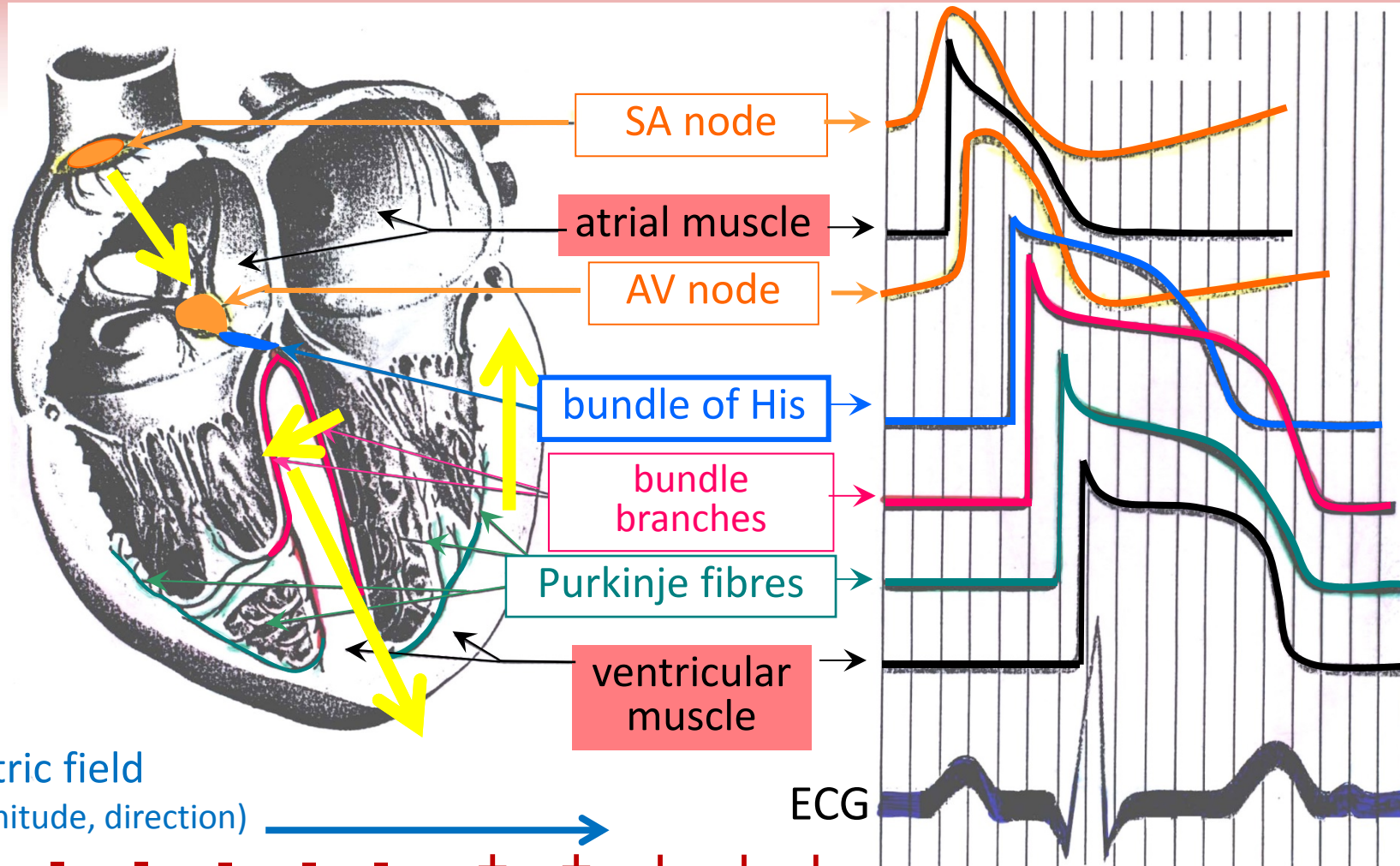
Pacemaker Activity - Mechanism



PARASYMPATHETIC STIMULATION

- \downarrow cAMP \longrightarrow \downarrow I_f and I_{Ca-T} \longrightarrow \downarrow rate of diastolic depolarization
 \longrightarrow \uparrow threshold voltage for activation of I_{Ca-L}
(\downarrow excitability)
- activation of $I_{K,Ach}$ \longrightarrow \downarrow maximal diastolic voltage

SPREADING OF EXCITATION IN THE HEART



electric field
(magnitude, direction)

