ELECTRICAL ACTIVITY OF THE HEART

Dr. Ahmad Ali

Lecture in Zoology

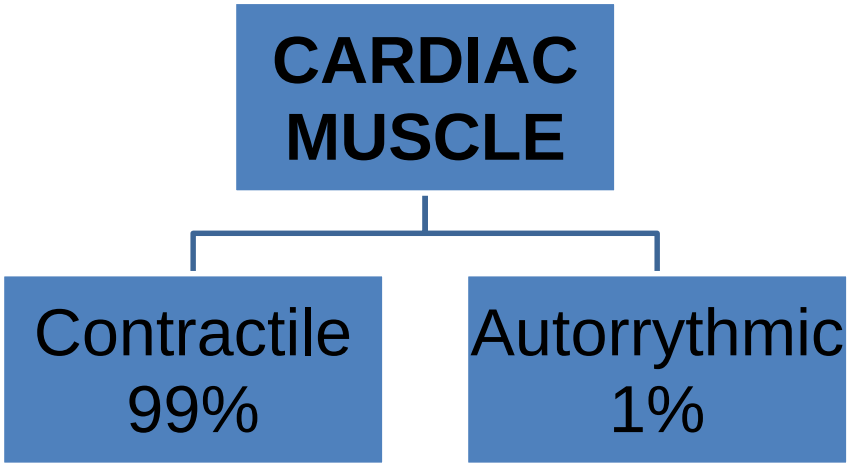
The Islamia University of Bahawalpur

Cardiac cells contract without Nervous Stimulation.

- Cardiac muscle, like skeletal muscle & neurons, is an excitable tissue with the ability to generate action potential.
- Most cardiac muscle is contractile (99%), but about 1% of the myocardial cells are specialized to generate action potentials spontaneously. These cells are responsible for a unique property of the heart: ***its ability to contract without any outside signal.***
- The heart can contract without an outside signal because the signal for contraction is ***myogenic, originating within the heart itself.***
- The heart contracts, or beats, rhythmically as a result of action potentials that it generates by itself, a property called **auto rhythmicity** (*auto* means "self").
- The signal for myocardial contraction comes NOT from the nervous system but from specialized myocardial cells also called **auto rhythmic cells,** also called **pacemaker cells.**

THE MYOCARDIUM

- Two specialized types of cardiac muscle cells:
- Each of these 2 types of cells has a distinctive action potential.



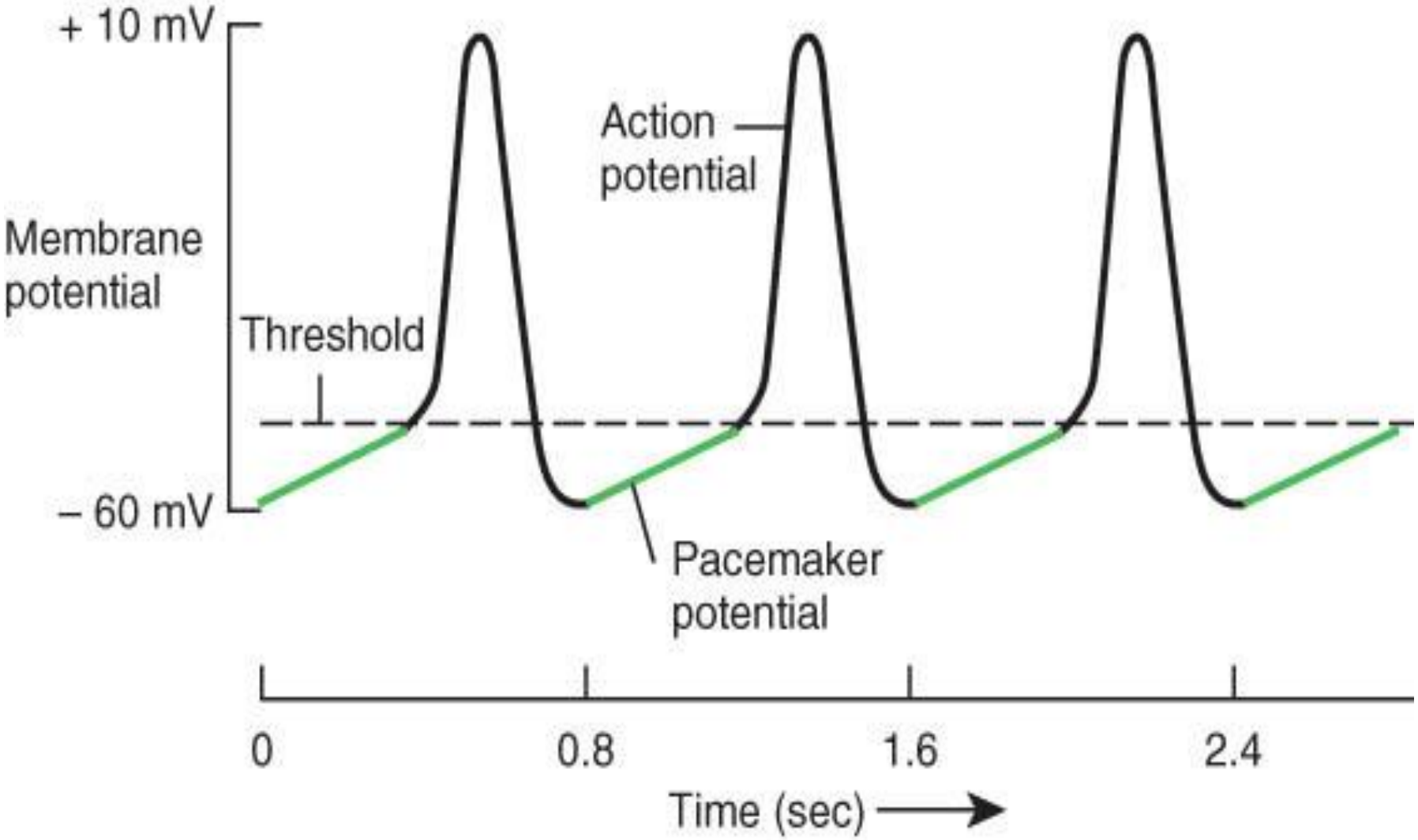
Electrical Activity of the Heart

- Myocardial **Auto rhythmic cells (1%)** –
- These cells are smaller and contain few contractile fibers or organelles.
- Because they do not have organized sarcomeres, they do not contribute to the contractile force of the heart.

- Myocardial **Contractile cells (99%)** –
- Contractile cells which include most of the heart muscle
  - Atrial muscle
  - Ventricular muscle
    - These cells contract and are also known as the **Working Myocardium.**

Action Potential of the Auto-rythmic cardiac cells

- The auto rhythmic cells **do not** have a stable resting membrane potential like the nerve and the skeletal muscles.
- Instead they have an unstable membrane potential that starts at – 60mv and slowly drifts upwards towards threshold.
- Because the membrane potential never rests at a constant value, it is called a ***Pacemaker Potential*** rather than a resting membrane potential.



(b) Pacemaker potentials and action potentials in autorhythmic fibers of SA node

What causes the membrane potentials of these cells to be unstable?

- Auto rhythmic cells contain channels different from other excitable cells.
- When cell membrane potential is at -60mv, channels are permeable to both Na and K.
- This leads to **Na influx** and K efflux.
- The net influx of positive charges slowly depolarizes the auto rhythmic cells. This leads to opening of **Calcium channels**.
- This moves the cell more towards threshold. When threshold is reached, many Calcium channels open leading to the Depolarization phase.

IONIC BASIS OF ACTION POTENTIAL OF AUTORRYTHMIC CELLS

Phase 1: Pacemaker Potential:

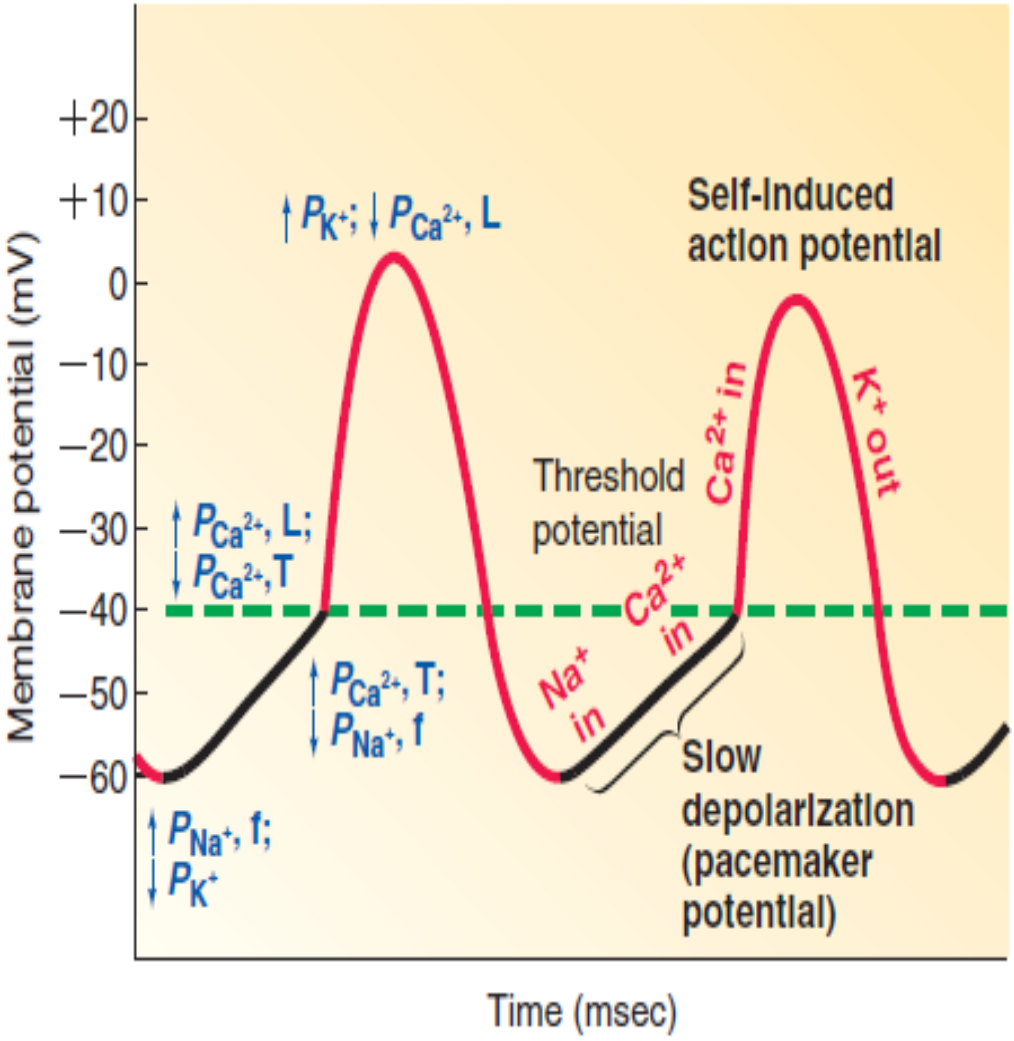
- Opening of voltage-gated Sodium channels called Funny channels (I_f or f channels).
- Closure of voltage-gated Potassium channels.
- Opening of Voltage-gated Transient-type Calcium (T-type Ca^{2+} channels) channels .

Phase 2: The Rising Phase or Depolarization:

- Opening of Long-lasting voltage-gated Calcium channels (L-type Ca^{2+} channels).
- Large influx of Calcium.

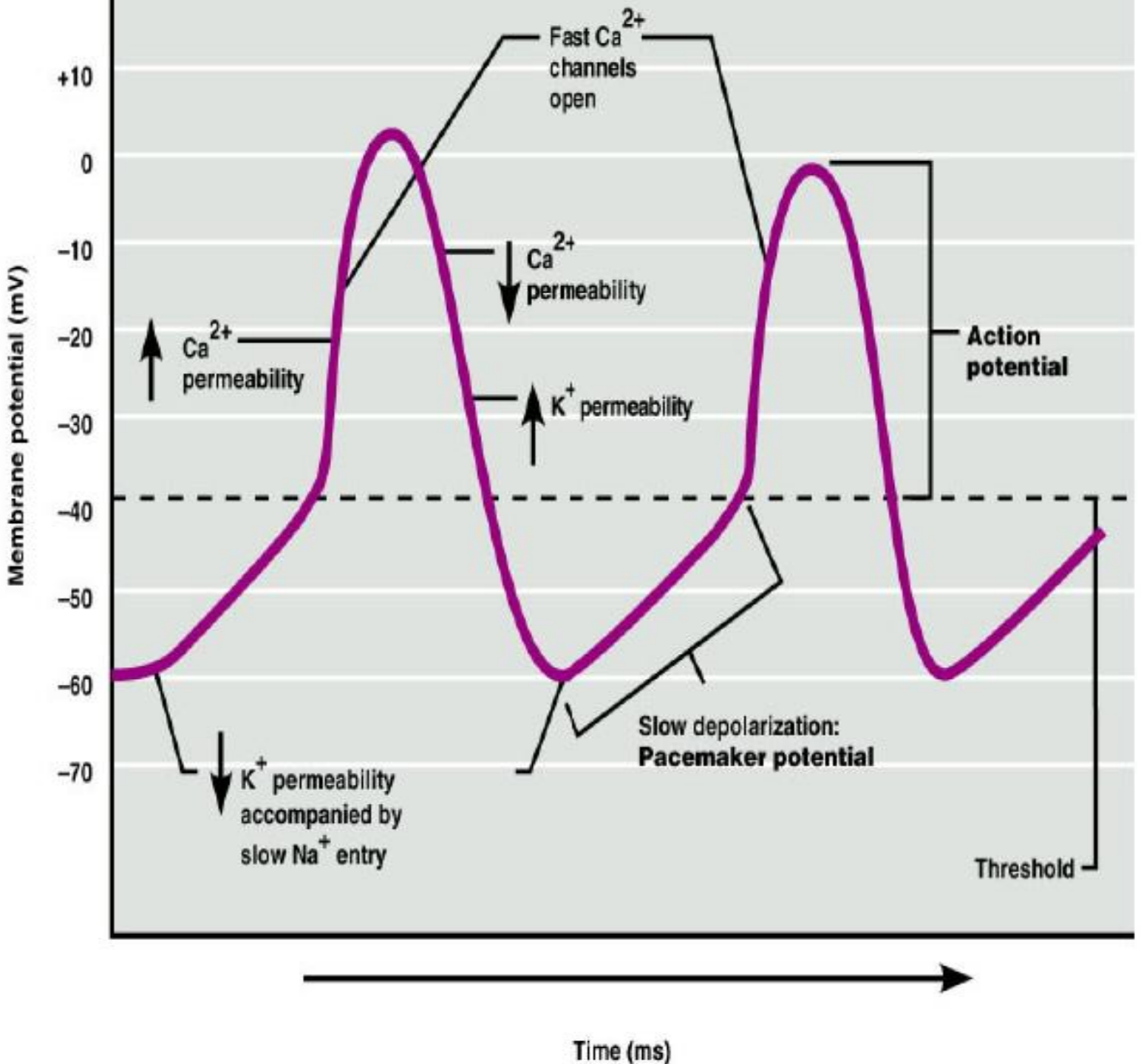
Phase 3: The Falling Phase or Repolarization:

- Opening of voltage-gated Potassium channels
- Closing of L-type Ca channels.
- Potassium Efflux.



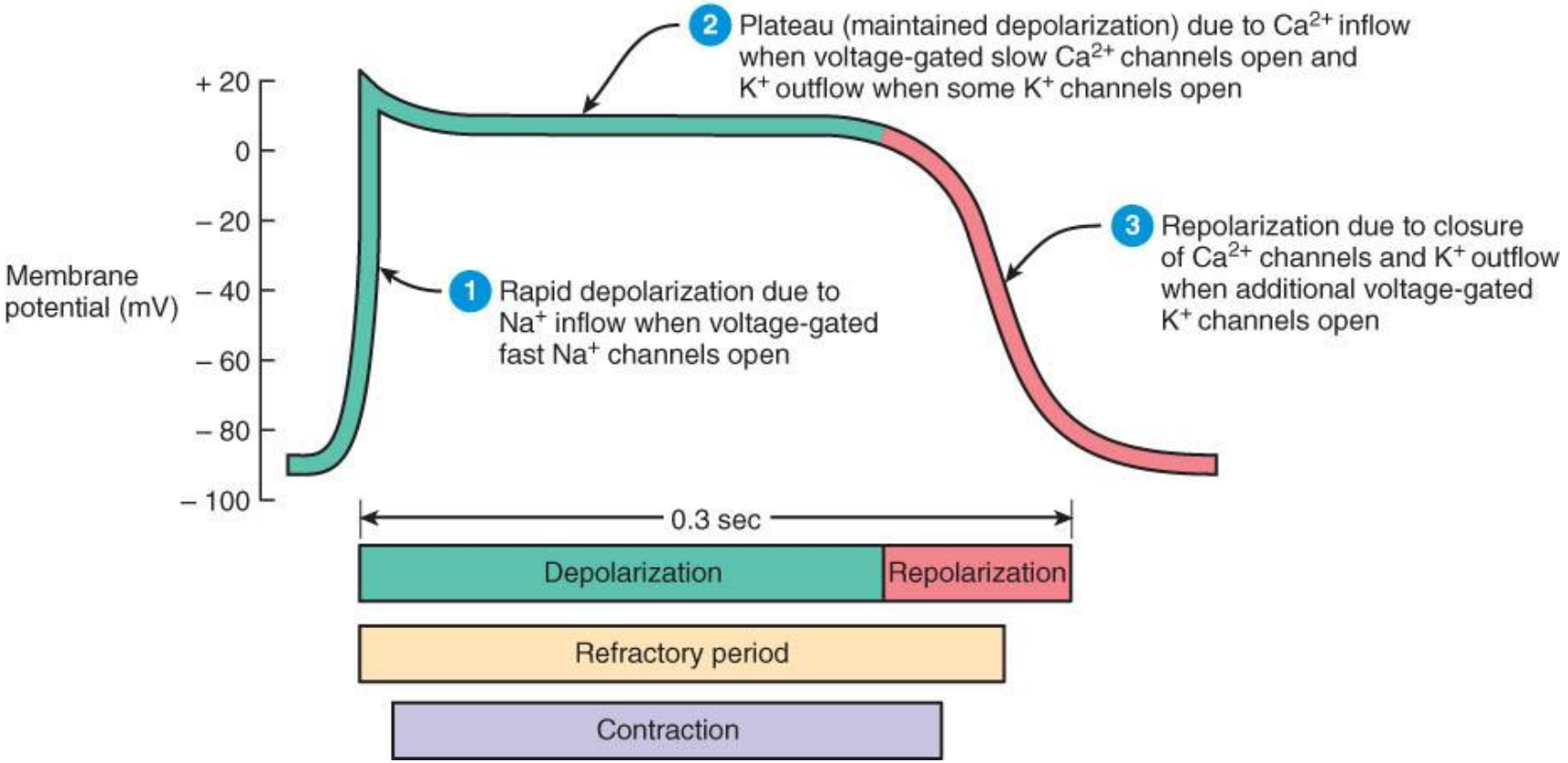
KEY

f = Funny channels
T = Transient-type channels
L = Long-lasting channels


Fast Ca^{2+} channels open
+10
0
−10
−20
−30
−40
−50
−60
−70
Membrane potential (mV)
Ca^{2+} permeability
Ca^{2+} permeability
K^+ permeability
Action potential
K^+ permeability accompanied by slow Na^+ entry
Slow depolarization: Pacemaker potential
Threshold
Time (ms)

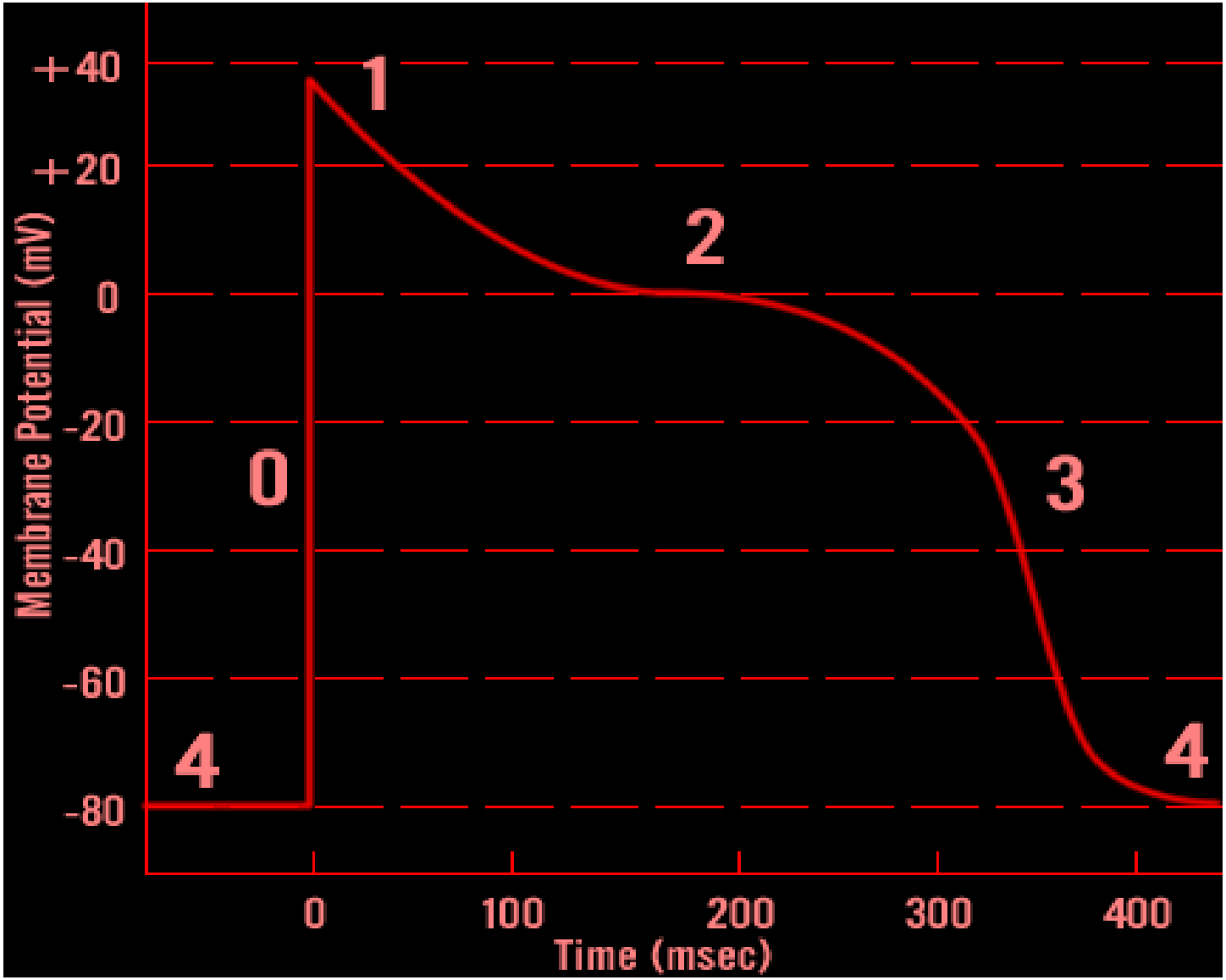
ACTION POTENTIAL OF A CONTRACTILE MYOCARDIAL CELL:A TYPICAL VENTRICULAR CELL

- Unlike the membranes of the autorrythmic cells, the membrane of the contractile cells remain essentially **at rest at about -90mv** until excited by electrical activity propagated by the pacemaker cells.


2 Plateau (maintained depolarization) due to Ca^{2+} inflow when voltage-gated slow Ca^{2+} channels open and K^+ outflow when some K^+ channels open
3 Repolarization due to closure of Ca^{2+} channels and K^+ outflow when additional voltage-gated K^+ channels open
1 Rapid depolarization due to Na^+ inflow when voltage-gated fast Na^+ channels open
Membrane potential (mV)
+ 20
0
– 20
– 40
– 60
– 80
– 100
0.3 sec
Depolarization
Repolarization
Refractory period
Contraction

ACTION POTENTIAL OF A CONTRACTILE MYOCARDIAL CELL:A TYPICAL VENTRICULAR CELL

- **Depolarization**
  - Opening of fast voltage-gated Na+ channels.
  - Rapid Influx of Sodium ions leading to rapid depolarization.
- **Small Repolarization**
  - Opening of a subclass of Potassium channels which are fast channels.
  - Rapid Potassium Efflux.
- **Plateau phase**
  - 250 msec duration (while it is only 1msec in neuron)
  - Opening of the L-type voltage-gated slow Calcium channels & Closure of the Fast K+ channels.
  - Large Calcium influx
  - K^+ Efflux is very small as K^+ permeability decreases & only few K channels are open.
- **Repolarization**
  - Opening of the typical, slow, voltage-gated Potassium channels.
  - Closure of the L-type, voltage-gated Calcium channels.
  - Calcium Influx STOPS
  - Potassium Efflux takes place.


+40
+20
0
-20
-40
-60
-80
Membrane Potential (mV)
0
100
200
300
400
Time (msec)
0
1
2
3
4
4

Summary of Action Potential of a Myocardial Contractile Cell

- **Depolarization**= Sodium Influx
- **Rapid Repolarization**= Potassium Efflux
- **Plateau**= Calcium Influx
- **Repolarization**= Potassium Efflux

Action Potentials of different cardiac cells: