Contractile cells have a long refractory period during which they cannot reach threshold.
Action potentials in the SA and AV Nodes are small, slowly rising, and so conduct slowly.

Action potentials in the atria, AV bundle, bundle branches, His-Purkinje system, and ventricles are large, rapidly rising, and conduct rapidly.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Conduction Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA Node</td>
<td>Very slow</td>
</tr>
<tr>
<td>Atrial Myocardium</td>
<td>Fast</td>
</tr>
<tr>
<td>AV Node</td>
<td>Very slow</td>
</tr>
<tr>
<td>AV Bundle</td>
<td>Very fast</td>
</tr>
<tr>
<td>Bundle branches</td>
<td>Very, very fast</td>
</tr>
<tr>
<td>His-Purkinje system</td>
<td>Very, very fast</td>
</tr>
<tr>
<td>Ventricular Myocardium</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Normal activation sequence.
The action potentials are not the same in all regions of the heart. Action potentials in the SA and AV Nodes are small, slowly rising, and so conduct slowly. The SA and AV Nodes depolarize spontaneously during diastole ("pacemaker activity"). Action potentials in the atria, AV bundle, bundle branches, His-Purkinje system, and ventricles are large, rapidly rising, and conduct rapidly.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Conduction Velocity</th>
<th>Rate of Pacemaker Firing (/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA Node</td>
<td>Very slow</td>
<td>60-100</td>
</tr>
<tr>
<td>Atrial Myocardium</td>
<td>Fast</td>
<td>None</td>
</tr>
<tr>
<td>AV Node</td>
<td>Very slow</td>
<td>40-55</td>
</tr>
<tr>
<td>AV Bundle</td>
<td>Very fast</td>
<td>25-40</td>
</tr>
<tr>
<td>Bundle branches</td>
<td>Very, very fast</td>
<td>25-40</td>
</tr>
<tr>
<td>His-Purkinje system</td>
<td>Very, very fast</td>
<td>25-40</td>
</tr>
<tr>
<td>Ventricular Myocardium</td>
<td>Moderate</td>
<td>None</td>
</tr>
</tbody>
</table>

Pacemaker activity is fastest in the SA Node; slow in the AV Node; and very slow and unreliable in the AV bundle, bundle branches, and His-Purkinje system.
The Electrocardiogram (ECG): A record of potential differences generated during depolarization and repolarization of the heart recorded from the body surface.

Photograph of a complete electrocardiograph, showing the manner in which the electrodes are attached to the patient. In the case the hands and one foot being immersed in jars of salty solution.
The Electrocardiogram (ECG): A record of potential *differences* generated during depolarization and repolarization of the heart recorded from the body surface.

⇒ **ACROSS** = TIME 1 mm across = $\frac{1}{25}$th second = 0.04 seconds

⇒ **UP and DOWN** equal **VOLTAGE** (AMPLITUDE, POTENTIAL DIFFERENCE)

1 mm up = 0.1 mv 10mm = 1mv, baseline = 0 mv = isoelectric
The Electrocardiogram (ECG): A record of potential *differences* generated during depolarization and repolarization of the heart recorded from the body surface.

The “Grid”

Potential difference between right arm and left arm (Lead I)

Potential difference between left arm and left leg (Lead III)

1 mV

0.04 sec

0.20 sec

P wave - Atrial depolarization

QRS complex - Ventricular depolarization

T wave - Ventricular depolarization

Why do the waves recorded in the ECG go up in some leads and down in others?
Lead

• an organized method of placing a positive and negative electrode on the surface of the body to detect the electrical activity of the heart (which is constant)
• as positive and negative positions change, the recording of the same event changes
• each leads appearance is different
• the AXIS of a LEAD by definition goes from - to +
An ECG lead provides a graphic illustration of the electrical potential difference between two points on the skin surface. The leads shown below are the bipolar limb leads, which use two electrodes (a positive + and a negative -) to record the electrical potential difference in the frontal plane.

In limb lead I, the POSITIVE electrode is placed at the left arm and the negative electrode at the right arm. Its axis is directed from right to left, at zero degree from horizontal.

In limb lead II, the POSITIVE terminal is placed at the left leg and the negative terminal at the right arm. Its axis is directed inferiorly from right to left, 60 degrees clockwise from horizontal.
In limb lead III, the POSITIVE lead is placed at the left leg and the negative lead at the left arm. Its axis is directed inferiorly from left to right, 120 degrees clockwise from horizontal.

**Augmented Limb Leads and Their Axes**

The leads shown below are called the augmented limb leads, which also record the electrical potential in the frontal plane. They are called unipolar leads, however, because the center of the heart is used as a reference point and the electrode (positive \( + \)) is placed on the limbs and used as the other point.

Lead \( aVR \) is a unipolar limb lead with a positive terminal on the right arm. Its axis is directed upward and right, perpendicular to the lead III axis.
If current flows in same direction as axis of lead, ECG stylus is deflected strongly upward from baseline in that lead.

If current flows obliquely to axis of lead, stylus is deflected less strongly upward, its height varying with angle that vector of current makes with axis.

If current flow is perpendicular to the axis of the lead, there is no deflection, as if there were no current flow.
If current flow is in a direction opposite to the axis of the lead, the stylus is deflected strongly downward.

If current flows obliquely in a direction opposite to the axis of the lead, the stylus is deflected less strongly downward.

And, if current flow is perpendicular to the axis of the lead, there is no deflection, as if there were no current flow.
List in order the steps by which the heart’s conduction system initiates normal ventricular systole

1. Cardiac impulse originates at SA node
2. Action potential spreads throughout right and left atria
3. Impulse passes from atria into ventricles through AV node (only point of electrical contact between chambers)
4. Action potential briefly delayed at AV node (ensures atrial contraction precedes ventricular contraction to allow complete ventricular filling)
5. Impulse travels rapidly down interventricular septum by means of bundle of His
6. Impulse rapidly disperses throughout myocardium by means of Purkinje fibers
7. Rest of ventricular cells activated by cell-to-cell spread of impulse through gap junctions. This is ventricular systole
Electrocardiogram (ECG)

- Record of overall spread of electrical activity through heart
- Represents
  - Recording part of electrical activity induced in body fluids by cardiac electrical impulse that reaches body surface
    - Not direct recording of actual electrical activity of heart
  - Recording of overall spread of activity throughout heart during depolarization and repolarization
    - Not a recording of a single action potential in a single cell at a single point in time
  - Comparisons in voltage detected by electrodes at two different points on body surface, not the actual potential
    - The heart as a DIPOLE

Fig. 9-13, p. 242