Al-Mustaqbal University College
Biomedical Engineering Department

Subject: Biomedical Instrumentation Design.

Class (code): 4th (BME426)

Lecture: 2

BME426

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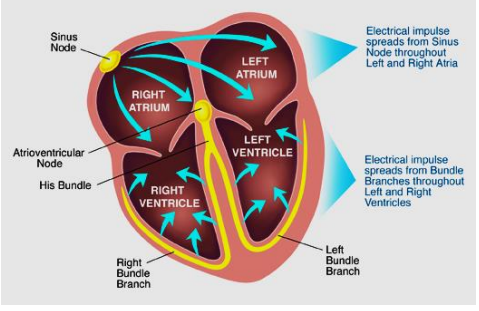
Biomedical Instrumentation Design

The Electrocardiogram (ECG)

- The heart has its pacemaker system for generating and conducting action potentials.
- Sino-atrial node (SA node): a group of cells located in the top right atrium.
- SA node initiates the heart activity and acts as the primary pacemaker of the heart.
- The SA node generates impulses at the normal rate of the heart, about 72 beats per minute at rest.



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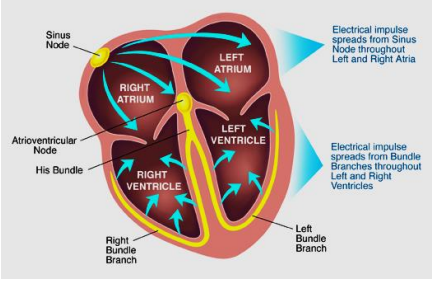
The Electrocardiogram (ECG)

- Since the body acts as a purely resistive medium, the potential field generated by the SA node extends to the other parts of the heart.
- The wave propagates through the right and left atria at a velocity of about 1m/s.
- About 0.1s are required for the excitation of the atria to be completed.
- The action potential contracts the atrial muscle and the impulse spreads through the atrial wall about 0.04s to the AV (atrio-ventricular) node.



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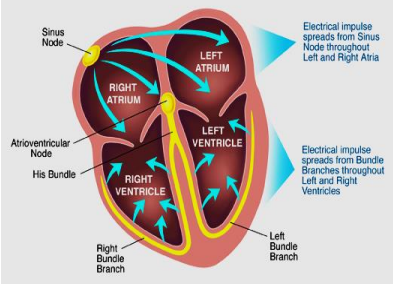
The Electrocardiogram (ECG)

- AV node is located in the lower part of the wall between the two atria.
- The AV node delays the spread of excitation for about 0.12s, then, a special conduction system, known as the bundle of His carries the action potential to the ventricles.
- The atria and ventricles are thus functionally linked only by the AV node and the conduction system.
- The AV node delay ensures that the atria complete their contraction before there is any ventricular contraction.
- The impulse leaves the AV node via the bundle of His.



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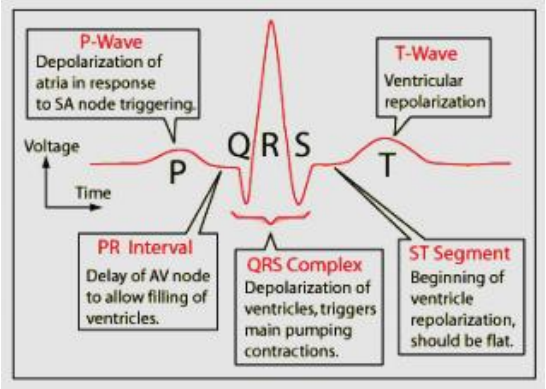
The Electrocardiogram (ECG)

› The normal wave pattern of the electrocardiogram is shown below.

› The PR and PQ interval, measured from the beginning of the P wave to the onset of the R or Q wave, respectively, marks the time, which an impulse leaving the SA node takes to reach the ventricles..



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ECG Electrodes

› The ECG electrode is usually composed of a small metal plate surrounded by an adhesive pad coated with conducting gel to help transmit the electrical signal.

› The wire that connects the ECG electrode to the ECG machine is clipped to the back of the electrode.

› Electrodes (small, plastic patches) are placed at certain locations on the chest, arms, and legs.

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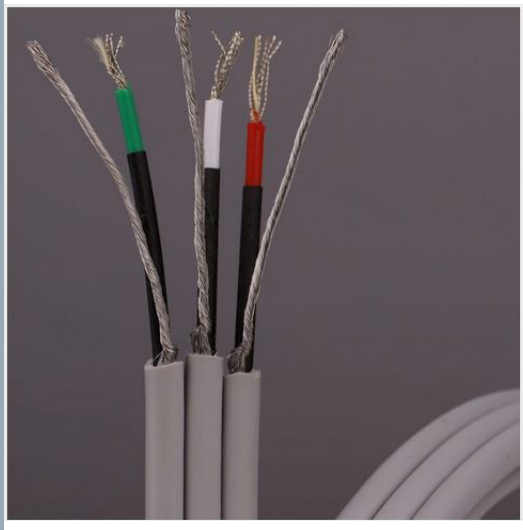
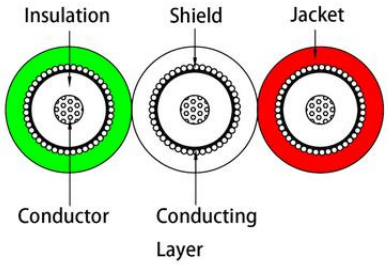
ECG Electrodes





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Color coding of ECG Electrodes

	AHA (*American Heart Association*)		IEC (*International Electrotechnical Commission*)	
Location	**Inscription**	**Colour**	**Inscription**	**Colour**
Right Arm	**RA**	White	**R**	Red
Left Arm	**LA**	Black	**L**	Yellow
Right Leg	**RL**	Green	**N**	Black
Left Leg	**LL**	Red	**F**	Green
Chest	**V1**	Brown/Red	**C1**	White/Red
Chest	**V2**	Brown/Yellow	**C2**	White/Yellow
Chest	**V3**	Brown/Green	**C3**	White/Green
Chest	**V4**	Brown/Blue	**C4**	White/Brown
Chest	**V5**	Brown/Orange	**C5**	White/Black
Chest	**V6**	Brown/Purple	**C6**	White/Violet

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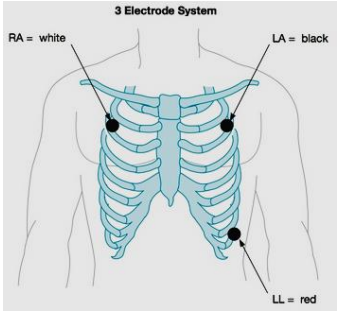
ECG Electrodes Placement

› The placement of the ECG electrodes on the patient has been established by medical protocols. The most common protocols require the placement of the electrodes in a 3-lead, a 5-lead or a 12-lead configuration.

› A 3-lead configuration requires the placement of three electrodes; one electrode adjacent each clavicle bone on the upper chest and a third electrode adjacent the patient's lower left abdomen.



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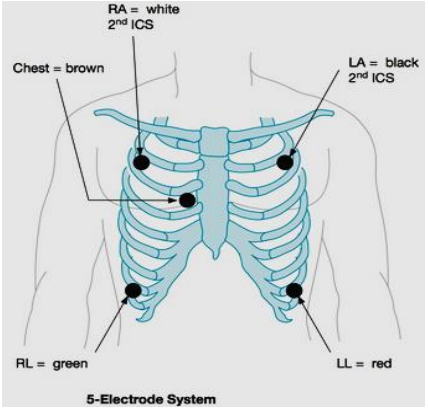
ECG Electrodes Placement

› The 5-lead configuration requires the placement of the three electrodes in the 3-lead configuration with the addition of a fourth electrode adjacent the sternum and a fifth electrode on the patient's lower right abdomen.



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ECG Electrodes Placement

- The A 12-lead configuration requires the placement of 10 electrodes on the patient's body.
- Four electrodes, which represent the patient's limbs, include the left arm electrode (LA lead), the right arm electrode (RA lead), the left leg electrode (LL lead), and the right leg electrode (RL lead).
- Six chest electrodes (V1-V6 leads) are placed on the patient's chest at various locations near the heart.
- Three standard limb leads are constructed from measurements between the right arm and left arm (Lead I), the right arm and the left leg (Lead II) and the left arm to left leg (Lead III).

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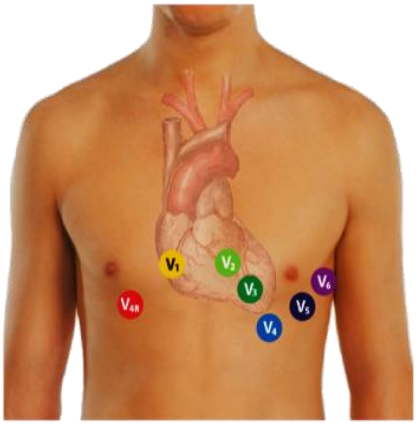
ECG Electrodes Placement

- The ten electrodes provide 12 measurement points consisting of Leads I, II, III, AVL, AVR, AVF, and V1-V6, with the right leg electrode typically used as a ground.



- V_1: 4th intercostal space to the right of the stemum
- V_2: 4th intercostal space to the left of the stemum
- V_3: directly between the leads V_2 & V_4
- V_4: 5th intercostal space at midclavicular line
- V_5: Level with V_4 at left anterior axillary line
- V_6: Level with V_5 at left midaxillary line *(directly under the midpoint of the armpit)*
- V_{4R}: 5th intercostal right midclavicular line

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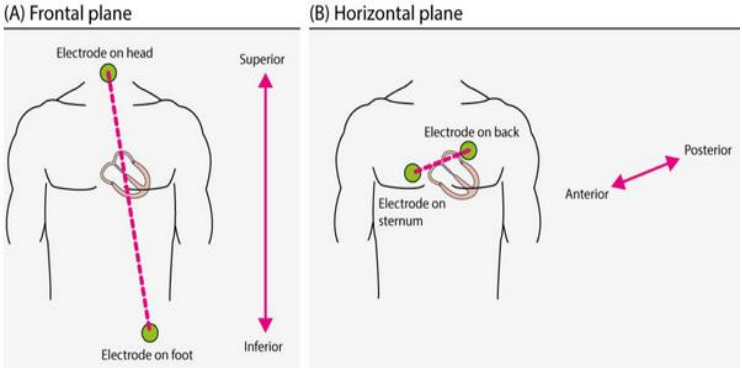
Biomedical Instrumentation Design

Anatomical plane of the heart

› The heart's electrical activity can be observed from the horizontal and frontal planes.

› The ability of a lead to detect vectors in a certain plane depend on how the lead is angled in relation to the plane, which in turn depend on the placement of the exploring lead and the reference point.



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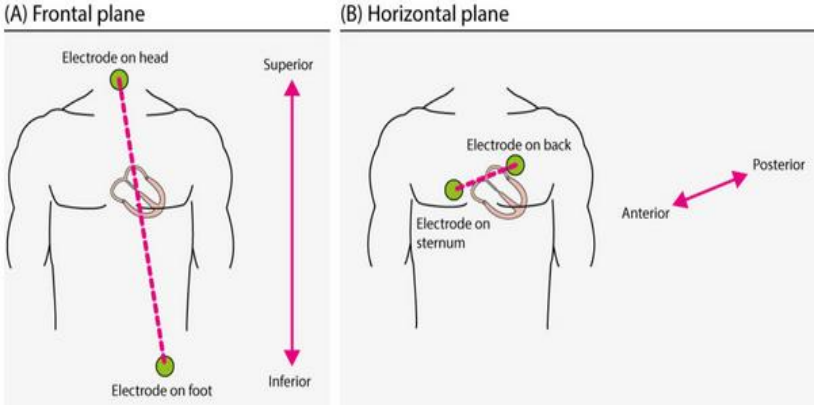
Anatomical plane of the heart

› Now consider a lead with an electrode placed on the sternum and the other electrode placed on the back (on the same level). This lead will be angled from the back to the anterior chest wall, which is the horizontal plane. This lead will primarily record vectors traveling in that plane.



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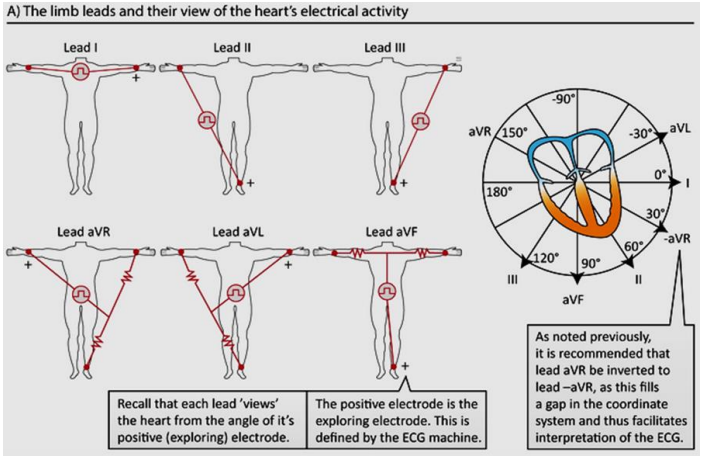
Anatomical plane of the heart

› The limb leads, of which there are six (I, II, III, aVF, aVR and aVL), have the exploring electrode and the reference point placed in the frontal plane, and detect vectors traveling in the frontal plane.



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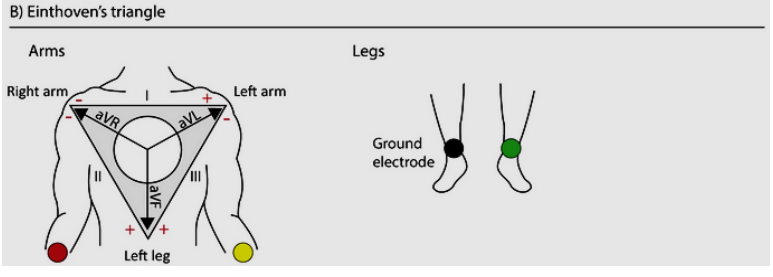
Biomedical Instrumentation Design

Anatomical plane of the heart

› The chest leads are excellent for detecting vectors traveling in the horizontal plane.

› Only three leads, namely leads I, II and III (which are actually Willem Einthoven's original leads), are derived by using only two electrodes.

› The remaining nine leads use a reference that is composed of the average of either two or three electrodes.



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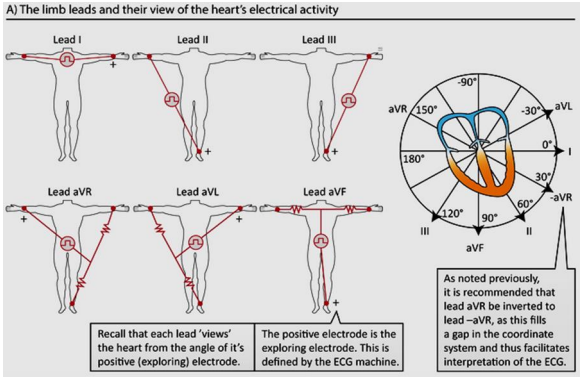
Einthoven's Leads

› Leads I, II and III compare electrical potential differences between two electrodes.

› Lead I compares the electrode on the left arm with the electrode on the right arm, thus observes the heart "from the left" because its exploring electrode is placed on the left (at an angle of 0°).



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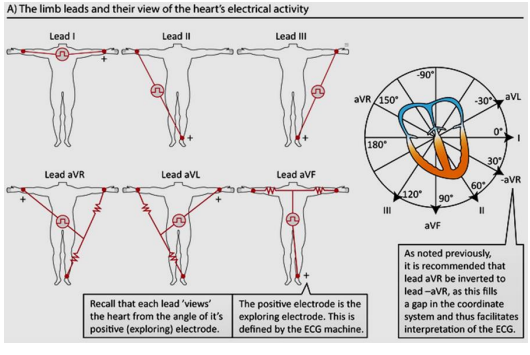
Einthoven's Leads

› Lead II compares the left leg with the right arm, with the leg electrode being the exploring electrode, and observes the heart from an angle of 60°.

› Lead III compares the left leg with the left arm, with the leg electrode being the exploring one, and observes the heart from an angle of 120°.



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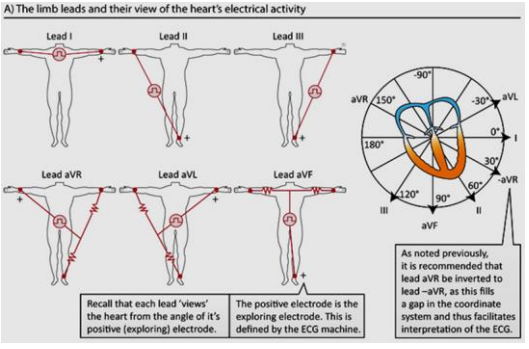
Goldberger's Leads

› In these leads, exploring electrode is compared with a reference which is based on an average of the other two limb electrodes. The letter a stands for augmented, V for voltage and R is right arm, L is left arm and F is foot.

› In aVR the right arm is the exploring electrode and the reference is composed by averaging the left arm and left leg.



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Goldberger's Leads

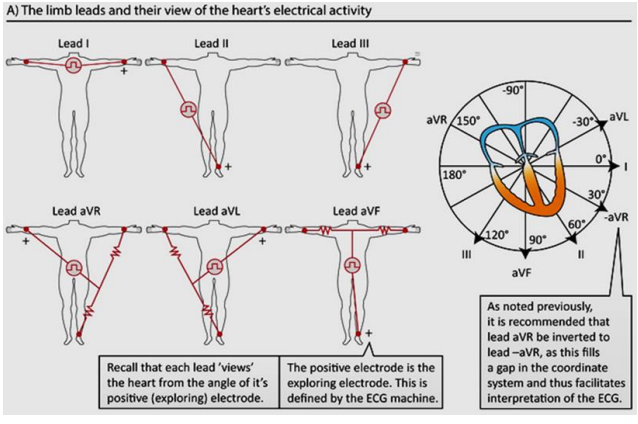
› In lead aVL the left arm electrode is exploring and the lead views the heart from -30°.

› In lead aVF the exploring electrode is placed on the left leg, so this lead observes the heart directly from south.

$$aVL: \quad \frac{Lead\ I - Lead\ III}{2}$$

$$-aVR: \quad \frac{Lead\ I + Lead\ II}{2}$$

$$aVF: \quad \frac{Lead\ II + Lead\ III}{2}$$



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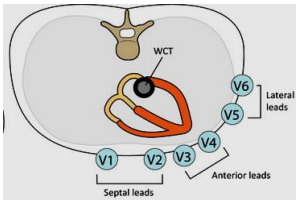
Chest Leads (Precordial Leads)

› Frank Wilson and colleagues constructed the Wilson's central terminal (WCT), a theoretical reference point located approximately in the center of thorax, or more precisely in the centre or Einthoven's triangle.

› WCT is computed by connecting all three limb electrodes (via electrical resistance) to one terminal. This terminal will represent the average of the electrical potentials recorded in the limb electrodes.

› WCT serves as the reference point for each of the six electrodes which are placed anteriorly on the chest wall.



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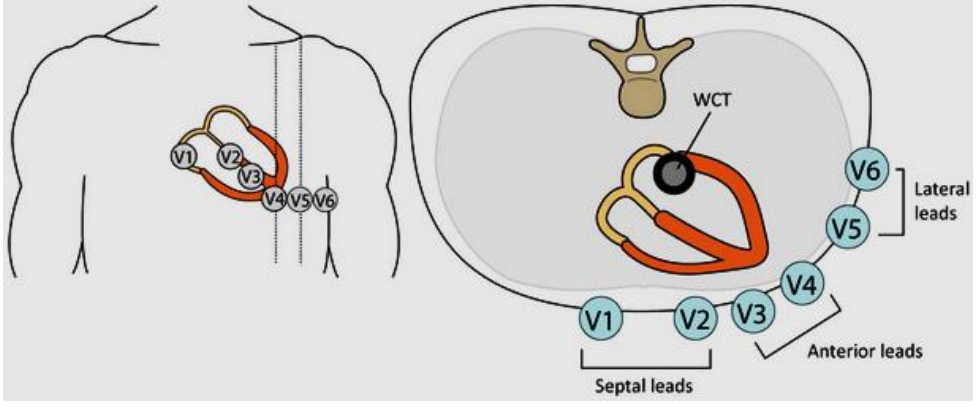
Chest Leads (Precordial Leads)

› The chest leads are derived by comparing the electrical potentials in WCT to the potentials recorded by each of the six electrodes (leads) placed on the horizontal plane of chest wall.



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Anatomical Aspects of the Precordial Leads

- V1-V2 ("septa) leads"): primarily observes the ventricular septum, but may occasionally display ECG changes originating from the right ventricle.
- V3-V4 ("anterior leads"): observes the anterior wall of the left ventricle.
- V5-V6 ("anterolateral leads"): observes the lateral wall of the left ventricle.