Chapter 3 Biological measurement

3.1 ECG signals

Learning objectives

- → Explain what makes the heart beat.
- → Explain what an ECG trace is.
- → Measure an ECG trace and describe what it tells you about the heart.

Basic action of the heart

Each time your heart beats, its electrical potential changes by more than 100 mV as the muscles of the heart contract and relax in a sequence that forces blood from the two atrial chambers of the heart into the corresponding ventricles and then out to your arteries.

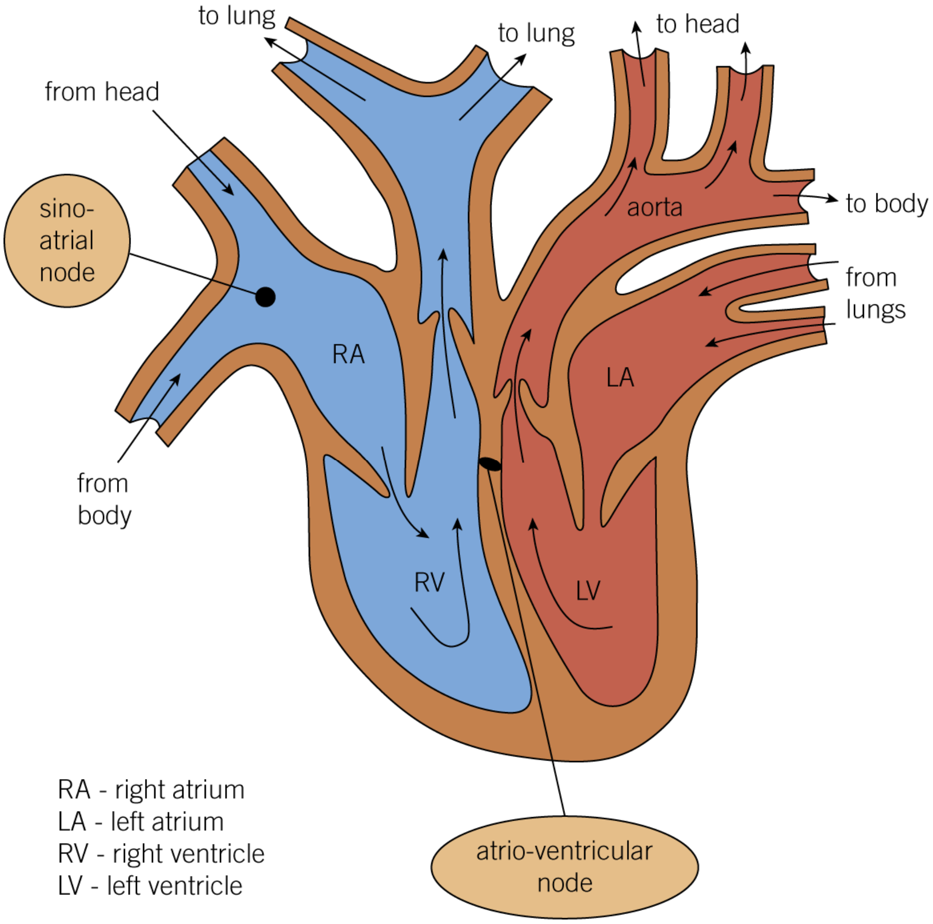

Figure 1 *Inside the heart*

Figure 2 shows how the potential of the heart changes from its 'resting' potential at –80 mV each time the heart beats. An electrical impulse generated at the sino-atrial (SA) node causes positive ions to move into, then out of, the nerves and muscle cells in the heart. This makes the muscles contract and then relax in sequence. As shown in Figure 2, the cells 'depolarise' to zero potential at first then become positive then 'repolarise' back to the resting potential of –80 mV before the next impulse.

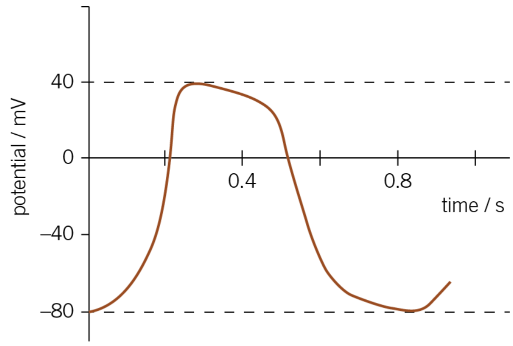

Figure 2 *The variation of heart potential during a heart beat*

Electrocardiograms

The change of electrical potential of the heart is conducted through body fluids and tissue to the skin, causing changes of potential of the order of 1 mV which can be detected by electrodes connected to an amplifier. An electrocardiograph (ECG) is designed to measure and record the potential difference between two points on the surface of the body. An ECG trace provides important information about the condition of the heart.

The pd between any two points on the body surface is due to:

- the conductivity of the body fluids
- the position of the points on the body
- the potential of the heart.

The electrodes are normally connected to two limbs with a third limb earthed.

A recording of the variation of such a pd with time is called an **electrocardiogram** or ECG trace. Figure 3 shows a typical ECG trace for a healthy person.

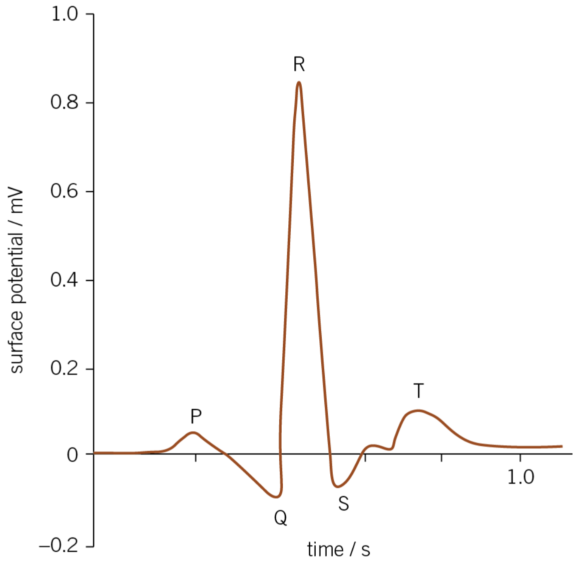

Figure 3 *An ECG trace of a healthy person*

The main features of the ECG trace shown in Figure 3 can be summarised as follows.

- The peak pd is about 1 millivolt and lasts about 0.1 s.
- The main features of the trace are labelled as **P**, **Q**, **R**, **S**, and **T** according to convention.
- The wave at **P** is due to depolarisation and contraction of the atrial heart muscles when blood that has entered the heart is forced into the ventricles.
- Between P and Q, the impulse is delayed at the atrio-ventricular (AV) node to allow the ventricles to fill.
- **QRS** is due to depolarisation after Q and contraction after R of the ventricles' heart muscles when blood is pushed out of the heart.
- The wave at **T** is caused by repolarisation and relaxation of the heart muscles after blood is pushed out of the heart from the ventricles.

To measure and display an ECG waveform, the pd between two chosen points on the body surface must be amplified from about 1 mV to about 1 V to enable it to be displayed on an oscilloscope, a chart recorder, or a computer VDU screen. Figure 4 represents the amplifier with leads from the patient to the amplifier's input terminals and a suitable instrument connected to the amplifier's output terminals.

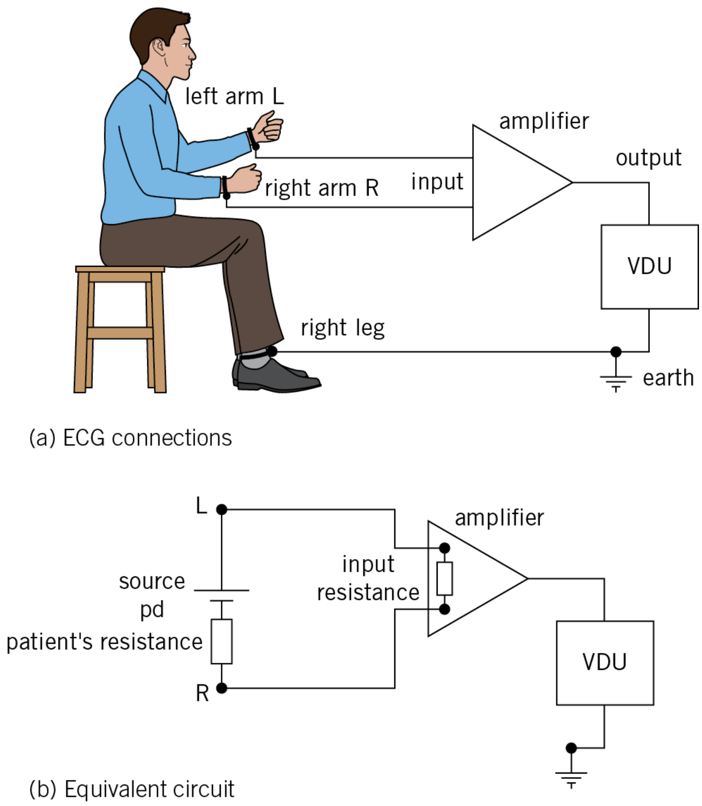

Figure 4 *Making an ECG trace*

The amplifier must have the following characteristics.

- **Its voltage gain** (i.e., $\frac{\text{the amplifier output pd}}{\text{the input pd to the amplifier}}$) must be of the order of 1000 over a frequency range up to about 20 Hz. Beyond this frequency, unwanted signals due to muscle activity or from the mains supply must be filtered out.

- **Its frequency response** should be even across the frequency range otherwise the output voltage from the amplifier will be distorted.
- **A high input impedance** (i.e., opposition due to effects such as resistance, capacitance and back emf) is essential otherwise a significant fraction of the input pd will be lost due to body resistance and contact resistance where the electrodes are on the skin. Contact resistance is lowered as much as possible by removing body hair, cleaning the skin and then using a conducting paste between the electrode surface and the skin. However, the remaining resistance due to body fluids can be as much as 1000 Ω. The input resistance of the amplifier and the patient's electrical resistance form a potential divider so the source pd is split between the two resistances. If the input resistance is not much higher than the patient's resistance, the input pd to the amplifier will be significantly less than the source pd.
- **The amplifier must have a high signal-to-noise ratio** otherwise the output signal is masked by random electrical signals (i.e., noise) generated in the amplifier itself. The output pd of the amplifier is either displayed on an oscilloscope, a chart recorder, or a computer screen.

Link

The potential divider was looked at in Topic 13.5, The potential divider, in Year 1 of the *AQA Physics* student book.

Summary questions

1 A human heart is supplied with energy at an average rate of 2.0 W. Estimate the energy supplied to it in one day.

2 **a** Draw a labelled diagram of an ECG trace obtained from a person with a healthy heart, showing how the pd varies with time during one heart beat.

b Label the main features P Q R S and T on your trace and describe how they relate to the changes in the heart that take place during one heart beat.

3 **a** Explain why it is essential for an ECG amplifier to have a high input impedance.

b An ECG amplifier is connected to a patient as shown in Figure 4(b).

The amplifier has an effective input resistance of 70 kW. The total resistance of the patient in the ECG circuit is 20 kW and the pd across the input terminals of the amplifier has a maximum value of 0.70 mV.

Calculate:

i the maximum pd generated by the patient's heart at the electrodes connected to the patient

ii the maximum input pd if the patient's resistance was reduced to 1 kΩ.

4 State three essential characteristics of an ECG amplifier other than high input impedance, giving a reason why each characteristic is essential.