Boston Scientific
Defibrillators and how they work

Although the annual number of premature deaths in Ireland due to cardiovascular disease (CDV) has been declining since 1974, at about 52 per 100,000, it is still significantly above the EU average (42 per 100,000, prior to the accession of some Eastern European states). If treated quickly a heart attack patient’s chance of survival can be dramatically improved.

The Normal Heart-Beat Cycle
The cardiac cycle has two distinct phases — the diastole phase and the systole phase. In the diastole phase, the heart ventricles are relaxed and fill with blood. In the systole phase, the ventricles contract and pump blood around the body through a system of arteries.

These events are triggered by the sinoatrial node — a collection of modified myocytes that acts as the heart’s pacemaker.

Ventricular Fibrillation
Normally the pulse rate (heart rate) is appropriate for the body’s oxygen demand. Problems can arise if the heart rate is too low or too high. If the speed is very high it can lead to ventricular fibrillation (VF) in which the heart muscle quivers and does not pump efficiently, if at all. This condition is generally fatal if not treated quickly.

Normal heart-beat can be restored by delivery of a controlled electric shock. This process is called defibrillation.

What is a Defibrillator?
Defibrillators have been in use for about sixty years. The earlier machines were comparatively large and not really portable. Emergency portable defibrillators (also called AEDs or automatic external defibrillators) are today available in many public buildings, schools, clubs etc. and small defibrillators can now be implanted surgically in patients with certain chronic heart problems.

Intelligent Defibrillators
Over recent decades there have been major advances in the design of defibrillators. Much of this work stemmed from efforts to produce implantable devices. Modern defibrillators include sensors that can detect the cardiac rhythm and are programmed to ‘decide’ whether a shock is required and to deliver it correctly.

How Does a Defibrillator Work?
In essence the ‘shock’ circuit in a defibrillator has three key components: a high voltage source, a capacitor and switches.

The Voltage Source
Modern defibrillators use direct current (dc) rather than the alternating current (ac) which earlier models used. This poses a problem for designers of battery-operated devices. Transformers cannot step up direct current. The problem is solved as follows.

A battery drives an oscillator circuit; in effect this produces a current that is switched on and off at a high frequency (e.g. 1000 times per second), although it is still going in one direction only. If this pulsed direct current is fed into a suitable transformer the required output voltage can be generated. The factor by which the voltage is stepped up is the ratio of the number of turns on the input and output coils of the transformer. For example, if the input coil (‘primary’) has 200 turns and the output coil (‘secondary’) has 20,000 turns then the voltage is stepped up by a factor of 100. A 5 V input would then result in a 500 V output.

The alternating output voltage is rectified by means of a diode and fed into a capacitor which stores the high voltage charge.

The Capacitor
A capacitor consists of two flat conductors or ‘plates’ (usually of aluminium foil) with an insulator between them. A conducting lead is attached to each plate. In practice the whole capacitor assembly is often rolled and inserted in a ‘can’ with two connections.

![Diagram of capacitor and defibrillator circuit](image-url)
Circuit

The diagram shows a simplified version of a defibrillator circuit. With all switches open the ‘paddles’ are attached across the patient’s chest. S1 is then closed in order to charge the capacitor. S1 is then opened and S2 is closed; this causes the capacitor to discharge through the patient, hopefully restoring normal cardiac rhythm.

Energy Considerations

The capacitance of a capacitor is the amount of electric charge it can store for every volt applied to it. The unit of electric charge is the coulomb (symbol: C). The unit of capacitance is called a farad (symbol: F). One farad = 1 coulomb per volt.

With regard to defibrillators the amount of energy stored in a capacitor is very important. It can be calculated as follows: \[ E = \frac{1}{2} CV^2 \], where \( E \) is the energy in joules, \( C \) the capacitance in farads and \( V \) the electric potential (voltage) measured in volts. This energy, which may be more than 100 J, is dissipated in the patient’s body over a small time interval (about 10 milliseconds or one hundredth of a second). For example, if the capacitance is 1000 µF (microfarad) and the voltage is 500 V then the stored energy is 125 J. Early defibrillators delivering about 400 joules sometimes caused further cardiac injury.

Electric Current

The electrical resistance of the skin is the main contributor to the human body’s resistance. If the skin is dry the resistance from one hand to the other might be over 100,000 ohms. This is dramatically reduced if the area of contact is large and the skin is moistened with a suitable conductive paste or gel. The electrodes provided with AEDs are generally self-adhesive and are pre-coated with conductive gel. They can reduce the body’s resistance (across the chest) to about 20 ohms.

Using \( V = IR \) we can calculate the peak defibrillation current. If \( V = 500 \) volts then the current is 25 amperes. The pulse lasts only about a hundredth of a second (10 ms) and so the risk of surface burns to the skin is reduced.

Waveforms

As a capacitor discharges its voltage falls and so does the current through the patient. Plotting the voltage or the current against time gives a characteristic graph or waveform. The waveform resulting from a single capacitor discharge is monophasic, i.e. the current is on one direction only. Modern defibrillators are generally biphasic; successive current pulses are in opposite directions. Biphasic defibrillators are considered to be more effective and today virtually all new defibrillators are of this type.

Boston Scientific

Boston Scientific is the world’s largest medical device company dedicated to less-invasive medicine. It has more than 28,000 employees and 26 manufacturing, distribution and technology centres delivering more than 15,000 products in over 45 countries. For more than twenty five years, Boston Scientific has improved the quality of patient care and the productivity of health care delivery through the development and advocacy of less-invasive medical devices to help clinicians improve patient care by reducing risk, trauma, cost, procedure time and the need for aftercare.

With corporate headquarters in Natick, Massachusetts and major operations in North and South America, Boston Scientific has established three key strategic sites in Ireland — Clonmel, Cork and Galway — employing in excess of 3,000 employees across the broad range of activities in which the company is involved.

Boston Scientific in Clonmel

The Clonmel operation is responsible for the production of implantable pacemakers and defibrillators that offer life saving therapy for patients suffering from cardiac arrhythmias and heart failure. It currently employs more than 600 people, many of whom specialise in a range of engineering disciplines e.g. Electrical, Mechanical, Biomedical, Quality, R&D and Industrial along with other functional areas such as Supply Chain, Human Resources, Finance, Process Development, IT and Manufacturing.

Boston Scientific Clonmel actively promotes and participates in the local community through initiatives such as their Schools Programme where BSC facilitates local students on work experience and sponsors a Student of the Year Award in local schools, culminating in an opportunity for summer work. BSC is actively involved in Junior Achievement activities, with over 16 employees delivering programmes in the region.

You can find this and other lessons at www.sta.ie.
Find out more about the work of Boston Scientific at www.bostonscientific.com.
Teaching Notes

Syllabus References

**Leaving Certificate Biology**

H.3.2.4 Heartbeat Control: An awareness of specialised heart muscle.

Tissue and the existence and location of pacemaker nodes (SA and AV).

**Leaving Certificate Physics**

Electricity (p. 32 - 38).

Electric potential, potential difference, current, circuits, resistance, capacitance, inductance.

Learning Outcomes

On completion of this lesson, students should be able to:

- Understand what is meant by the cardiac cycle and the meaning of ventricular fibrillation.
- Describe the basic operation of a defibrillator.
- Outline how a defibrillator circuit works.
- Outline the dangers associated with the use of defibrillators.
- Calculate the amount of energy stored in a charged capacitor.
- Describe the difference between monophasic and biphasic defibrillators.

General Learning Points

The following information can be used to revise the lesson’s main learning points and inform discussion.

- The average annual rate of premature death in Ireland due to cardiovascular disease (CDV) is about 52 per 100,000. Many lives could be saved by proper use of a defibrillator.
- If the heart rate becomes abnormally high the heart muscle may produce very rapid but ineffective contractions; this condition is called ventricular fibrillation - a condition that is generally fatal if not treated quickly.
- The main electrical components of a defibrillator are: an oscillator, a transformer, a rectifier, a capacitor and a switch.

- A capacitor stores electric charge. The unit of capacitance is a coulomb per volt (known as a ‘farad’, symbol: F).
- In monophasic defibrillators the electrical output is in one direction. In biphasic defibrillators successive pulses are of opposite phase (i.e. opposite electrical direction).
Student Exercises

Student Activities
Construct models of molecules (real or imaginary) using atoms with ‘hooks’ according to the following two simple rules:
1. hooks link to hooks
2. no hooks should be left unattached.

The numbers of hooks for different atoms are shown in the diagram.

For example O has two hooks while H has just one. Given any number of O’s an H’s the following could be constructed (on paper or using ball-and-stick models): H-H H-O-H O=O H-O-O-H etc.

Design your own set of ‘molecules’ and then check in a text book or on the internet to see if the compounds actually exist.

Robert Kane’s *Elements of Chemistry* (American edition) was published in 1851. In common with many chemists of his day he believed that the formula for water was HO (not H$_2$O). The fact that electrolysis of water produced twice as much hydrogen as oxygen did not convince him.

What arguments would you present in favour of H$_2$O (rather than HO)?

What is the key to the argument based on the volumes of hydrogen and oxygen released in electrolysis of water?

True/False Questions
(1) Elements can be decomposed into substances.
(2) Compounds are composed of two or more elements chemically combined.
(3) The atoms in a molecule of hydrogen peroxide (H$_2$O$_2$) are bonded by single bonds only.
(4) The atoms in a molecule of carbon dioxide (CO$_2$) are bonded by single bonds only.
(5) A diamond is composed of carbon atoms only.
(6) Silicon atoms typically form six single bonds.
(7) Atoms that are covalently bonded share electrons.
(8) The bonding in sodium chloride is covalent.
(9) In a single covalent bond two electrons are shared, one from each atom.
(10) Both silicon and carbon have a valency of two.

Check your answers to these questions on www.sta.ie.

Examination Questions
Leaving Certificate Chemistry (OL) 2010, Q. 5
The English scientist, pictured on the right, introduced his atomic theory in the early 1800s. He stated that all matter is made up of tiny, indivisible particles called atoms. He also stated that the atoms of a particular element are all the same, especially in regard to mass.

- Name the English scientist.
- Explain by reference to a named element why he was incorrect in stating that all the atoms of a particular element have the same mass. What term is used for atoms of the same element that have different atomic masses?
- Diagrams of nitrogen and hydrogen atoms are shown on the right. Nitrogen and hydrogen combine to form ammonia.
  - State the valency (i) of nitrogen, (ii) of hydrogen, in ammonia.
  - Explain how these valencies arise by reference to the noble gases.
  - Use dot and cross diagrams to describe the bonding in the ammonia molecule. What is the shape of the ammonia molecule?
- Define electronegativity. Use electronegativity values to predict the type of bond formed between nitrogen and hydrogen.

Leaving Certificate Chemistry (OL) 2011, Q. 5
- Define (i) atomic number, (ii) mass number.
- Name the English scientist, pictured on the right, who identified electrons as negatively charged subatomic particles in the 1890s.
- Neils Bohr described a theory of atomic structure that involved the electrons occupying shells, orbits or fixed energy levels. What is the maximum number of electrons that can occupy the second shell (main energy level)?
• Draw a diagram showing the arrangement of electrons in an oxygen atom. Use dots (•) or crosses (×) to represent the electrons.
• Define electronegativity.
• Use electronegativity values to predict the type of bonding that occurs in a water molecule.
• Draw a dot and cross diagram to show the bonding in a water molecule. State the shape of a water molecule.

**Did You Know?**
The crystal structure of silicon is the same as that of a diamond.
Silicon and oxygen make up 74.3% of the Earth’s crust (oxygen, 46.6% and silicon 27.7%).
Crystals of pure SiO₂ are called quartz; tiny traces of iron can change its colour forming gems such as citrine and amethyst.

**Biographical Notes**

**Stanislao Cannizzaro (1826–1910)**
Cannizzaro was born in Palermo, Sicily in 1826. His father was a police magistrate and the family was prosperous. In 1841 he began to study medicine but later switched to chemistry. In 1848 he participated in the failed revolt and fled to France. In 1851, at the age of just twenty five, he was appointed professor of chemistry in Piedmont – the nearest Italian province to France. A few years later he took up a professorship in Genoa.

In his research he came across Avogadro’s hypothesis (published in 1815) which had been overlooked for about forty years. Cannizzaro realised that Avogadro’s brilliant insight, that equal volumes of gas at the same pressure and temperature held equal numbers of particles, would solve a lot of major controversies relating to atomic weights. (Ampère had come up with the same idea in 1818, but it too was overlooked or dismissed.) Mendeleev’s Periodic Table of Elements (1869) owed a lot to Cannizzaro’s work on atomic weights.

In 1860 the first international chemistry conference was called by Kekulé. At the conference, which was held in Karlsruhe, Germany, Cannizzaro’s input was overwhelmingly accepted. One could argue that modern chemistry took off at Karlsruhe.

**Revise the Terms**

*Can you recall the meaning of the following terms?*  
Reviewing terminology is a powerful aid to recall and retention.

aggregate, atom, caffeine, carbon, cement, chemical composition, chlorine, compound, concrete, covalent bond, diamond, electron, electron energy levels, elements, essence, exothermic, fluorine, hydrogen, ion, ionic, kiln, limestone, mineral, molecule, nitrogen, nucleus, octet rule, outer energy level, oxide, oxygen, periodicity, phosphorus, shale, silicon, sulfur, water.

*Check the Glossary of Terms for the lesson on www.sta.ie.*