



Energy for generations

science & technology in action

10th edition

www.sta.ie

The Electric Car

Introduction

We are so used to the **internal combustion engine (ICE)** that we are inclined to think that the electric car is a new idea. In fact, the electric car made its first appearance in the 1880s and by the 1890s there were fleets of electric taxis in London and New York. It is interesting to learn that an electric vehicle held the world road speed record between 1899 and 1902 (106 km/h). However, petrol and diesel engines dominated the scene after that. This was due to technical improvements in the internal combustion engine and the availability of cheap fuel.

In this lesson we discuss the evolution of the electric car, the science and technology behind it and the reasons why it is becoming more important to modern life.

What is an electric car?

An **electric vehicle (EV)** is a vehicle that uses an **electric motor** to propel it. Vehicles equipped with only an electric motor are called 'fully electric' or **pure electric vehicles**. Those equipped with both an ICE (internal combustion engine) and an electric motor are called hybrid electric vehicles. Those vehicles with an ICE and which can also be charged from an electrical source are called plug in hybrid electric vehicles (PHEV). In hybrids, the ICE and the electric motor can be arranged in **series** or in **parallel**. In the series configuration the battery powers the electric motor but, when the charge in the battery gets low, the ICE drives a **generator** that recharges the battery. In the parallel setup either the ICE or the electric motor (or both) can turn the car wheels directly. There are many types of electric vehicle, including trams, trains, trucks and cars. Cars that use electric motors are often referred to as **ecars**.

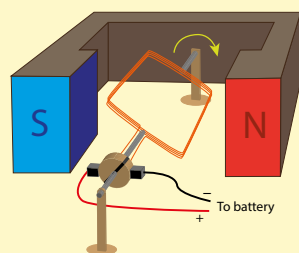
There are also vehicles that use **fuel cells** to charge the batteries. These cells convert the **chemical energy** from a fuel into electricity. Hydrogen is commonly used as a fuel for this purpose. (The most environmentally friendly way of producing the hydrogen is by **electrolysis** of water using renewable energy sources.)

Solar cars also exist. They use **photoelectric cells** that use sunlight to generate the electrical energy to charge the batteries.

The electric motor

An electric motor is a device that converts **electrical energy** into **motive force (mechanical energy)**, either linear or rotational. Rotational force is called **torque** and the torque produced by an electric motor is instantaneous and constant. This is why electric cars have better **acceleration** than standard vehicles.

Fundamental to the motor's operation is the fact that when a conductor located in a **magnetic field** is carrying a current, a force is exerted on the conductor. (**Lorentz Force Law**)



Why is the ecar coming back?

There is no doubt that the ecar is on its way back and there are several compelling reasons for this. Currently, there is serious concern about the reliability and cost of fuel imports. There is also environmental concern about the **pollution** and **greenhouse gases (GHG)** caused by exhaust **emissions**. Aside from these issues, ESB research has shown that drivers find that the ecar provides a very satisfying driving experience. They particularly value the smoothness and comfort of the journey, the silence of the motor and the superior acceleration from standstill. However, the fact that batteries need to be recharged presents a challenge. Drivers of standard cars know that they will be able to refuel easily because of the widespread existence of filling stations. Electric car drivers do not have this confidence on long journeys, a problem known as **range anxiety**. This is why ESB engineers are installing a national network of **charge points**. www.esb.ie/chargepointmap

The battery is the key

The first battery used in an electric vehicle was the **lead-acid battery** which was invented in 1859. Everyone is familiar with the fact that batteries become ineffective when they lose their **charge** and that only some can be **recharged**. Clearly an ecar battery should be rechargeable. It also needs to deliver enough **power** to the motor and be light enough for the car to carry effectively. The battery in wide use at present is the **lithium ion (Li-ion)** battery. These lightweight batteries have the advantage of high **energy density** i.e. they store more energy per unit of volume than other batteries.

Know your batteries

An electric battery converts chemical energy into electrical energy. A battery is a collection of **cells** and each cell contains two **electrodes (cathode and anode)**. These are located in an **electrolyte** that allows **ions** to move between them. The electrodes are connected to terminals. The chemical reactions at the electrodes produce an **electromotive force (emf)** between the terminals. This is the terminal voltage. Batteries that cannot be recharged after they have been discharged are called **primary (or disposable) batteries**. Examples are the **alkaline** batteries used for many portable devices. **Secondary batteries** can be charged after discharged and, hence, are known as **rechargeable** batteries. The **lead-acid** battery used in standard cars is a common example. Another is the **lithium ion** battery used in electric cars. The small lithium ion batteries used in portable devices such as mobile phones are very familiar. Batteries are also classified as wet or dry. A **wet cell** battery has a liquid electrolyte while a **dry cell** uses a paste as an electrolyte.

Charging the batteries

ESB has a nationwide charge point network. The charge points are accessed using an **RFID (Radio Frequency Identification)** access card which can be used both in the ROI and Northern Ireland. Some of the public points are **Fast Chargers** and these provide an 80% charge in approximately 25 minutes, while a full charge on a standard point can take between 1 and 6 hours depending on the model of ecar. Fast Chargers are available approximately every 60 km along motorways and main inter-urban routes to service drivers taking longer journeys. In general, ecars are supplied with a 7-pin plug that is used to charge the battery from public charge points and home charge points; it allows for the controlled and safe charging of the EV.



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Ecar owners can also take advantage of a technical development called **regenerative braking**. When the brakes of an ICE car are applied to slow a car down energy is wasted, mainly as heat. In other words some of the ICE car's **kinetic energy** is transformed into useless **heat energy**. Regenerative braking uses this kinetic energy to drive the electric motor as a generator to produce the electricity to charge the batteries.



What does the future hold?

The total **cost of ownership** is a measure that is often used to compare ecars with ICE vehicles. This measure includes purchase, maintenance and running costs. An ecar has relatively low maintenance and running costs. ESB estimates that the cost of electricity for charging the battery is around 2 cents per km. This is cheaper than petrol or diesel.

In addition, the grant which is currently available for the purchase of electric vehicles makes the cost competitive with standard cars. As demand rises, manufacturers will achieve **economies of scale**, and production costs will decrease.

At present on average 20% of all electricity produced in Ireland is from **renewable sources**. This will increase significantly over the coming years leading to further **decarbonisation** of electricity. This low carbon energy can be used to electrify the transport sector to eliminate emissions and also to improve air quality in our cities and towns.

Electric cars can also be used to store excess wind power produced at night or during low demand periods. Unless there is additional demand or a storage system in place at these low demand periods, this electricity is lost forever. Ecars present an opportunity to utilise the excess capacity by storing the energy in car batteries with smart charging.

The benefits go beyond transportation, as the electricity grid is also poised to gain from better utilisation of renewable energy and more effective energy management. Possible future benefits of electric cars may include using this stored energy of the battery to power your home (Vehicle to Home) or to even sell electricity back to the grid (Vehicle to Grid).

Research on other energy sources, such as solar and fuel cells, is ongoing. It is also important to realise that people are now familiar with the standard ICE car for over 100 years. Even if there were no cost issues it would take time for this mindset to change. Another important consideration is that the average car journey in Ireland (and many other countries) is actually less than 20 km, hardly a distance to generate much range anxiety. When all factors are considered, there is little doubt that we will see many more ecars on our roads over the next few years.



ESB's 32 ecar ambassadors who are taking part in The Great Electric Drive. Follow them on Facebook and the ESB ecars blog.



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About ESB

ESB is an energy utility, active in electricity generation, transmission and distribution as well as the supply of electricity, gas and energy services. The company has a regulated asset base of €8.5 billion and 42 per cent of Ireland's electricity generating capacity, including 800MW of renewable generation (wind, hydro and pumped storage).

Established in 1927, ESB operates through a portfolio of brands: ESB Networks, Electric Ireland, Northern Ireland Electricity and ESB International.

About ESB ecars

ESB ecars is responsible for the roll-out of a nationwide charging infrastructure as well as the supporting IT and Communications platforms. There are 1,200 public electric vehicle charge points across the island of Ireland, providing reliable low carbon transport options for drivers.

Find out more about ESB at www.esb.ie



Find this and other lessons on www.sta.ie



The Electric Car

Syllabus references

The main syllabus references for the lesson are:

Leaving Certificate Physics

- Mechanics: Force; Work, Energy, Power
- Electricity: Charge, Potential
- Current in a magnetic field; motors

Leaving Certificate Technology

- Energy, Electricity
- Option: Electronics and Control

Leaving Certificate Chemistry

- Option 2: The Electrochemical Series: Different combinations of metals produce different voltages in a simple cell.

Junior Certificate Science

- Force and Energy; Chemical and magnetic effects of an electric current.

Science and Technology in Action is also widely used by Transition Year classes.

Learning Outcomes

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

- Define the term 'electric vehicle'.
- Distinguish pure and hybrid electric vehicles.
- Describe the function of the electric motor.
- State why improvements in electrochemical storage technologies are critically important.
- Identify some advantages of the ecar over ICE vehicles.
- Describe the role of ESB in the popularisation of electric vehicles in Ireland.

General Learning Points

These are additional relevant points which are used to extend knowledge and facilitate discussion.

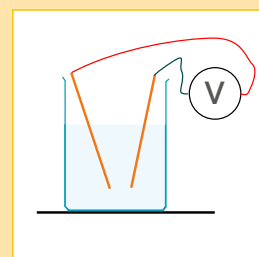
- Electric cars were popular in the late 19th century and early 20th century. They were more comfortable and easier to use than the internal combustion engine vehicles of the time. However, further development of the ICE, (including the electric starter), and fast refuelling ensured that the electric car fell into disuse.
- The first viable electric car was built in London by an engineer named Thomas Parker in 1884. He was also responsible for electrifying tram systems and the London Underground,
- The charge point system being developed by ESB ecars has many smart features including: measuring and communicating usage data and giving the electricity system operators the ability to control EV power demand and reduce or increase load depending on requirements.

Student Activities

1. Investigating simple cells

The principle of the electrochemical cell is easy to demonstrate. All you need is a glass of water and a few rods or wires of different metals (copper, steel, magnesium, zinc...).

Use a voltmeter to measure the voltage produced; this is typically less than one volt.



Use different pairs of metals and record the voltage and the polarity in each case produced.

2. Investigate the effect of adding some salt or dilute acid to the water. The voltage will not be changed dramatically but since the conductivity is increased the cell should be able to deliver greater current and so have more power. To measure the power just add a resistor (try 1 kΩ or 10 kΩ) across the terminals of the voltmeter; the power, P , is then equal to V^2/R (in watts).

$$V = I.R \Rightarrow I = V/R.$$
$$P = V.I = V (V/R) = V^2/R$$

3. Instead of using a glass of water, simply place a selection of metals on someone's hand and check the voltages as before. If the person is wearing a ring it can be included in the comparison; you should be able to distinguish between pure gold and alloys.

True/False Questions

- | | | |
|---|---|---|
| a) Light travels faster than radio waves. | T | F |
| b) In a series e-vehicle the engine drives the generator to charge the motor. | T | F |
| c) Lithium ion batteries are used only in mobile phones. | T | F |
| d) Lead-acid batteries have a higher energy density than lithium ion batteries. | T | F |
| e) An electric motor is lighter than an internal combustion engine delivering the same power. | T | F |
| f) The electric car was invented in the 1980s. | T | F |
| g) A magnetic field is a crucial component in an electric motor. | T | F |
| h) An electric motor delivers constant torque. | T | F |
| i) The ESB Charge Point Network provides around 200 charge points. | T | F |
| j) A fuel cell generates energy by burning hydrogen. | T | F |
| k) Primary batteries can be recharged at any time. | T | F |

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

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Examination Questions

Leaving Certificate Physics (HL) 2005, Q. 11

Read the following passage and answer the accompanying questions.

“The scientist whose research would unite electricity and magnetism was Michael Faraday. He developed the first electric motor in 1821, showing that a current carrying conductor could be made to revolve around a magnet. He went on to expand on Oersted’s observation that an electric current produces a magnetic effect. Perhaps, Faraday thought, the opposite was also true: a moving magnetic field could generate an electric current. This was to be called electromagnetic induction. Soon he had created the first electric generator, and everyday life would never be the same again. His experiments with induced currents produced the transformer.”
Adapted from *Milestones of Science; Curt Supple; 2000*

- (i) List three factors that affect the force on a current-carrying conductor placed near a magnet.
- (ii) What energy transformation takes place in an electric motor?
- (iii) What is the function of a commutator in a dc motor?
- (iv) Draw a sketch of the output voltage from an ac generator.
- (v) How are the slip rings connected to an external circuit in an ac generator?
- (vi) A transformer and an induction coil can both be used to change a small voltage into a larger voltage. What is the basic difference in the operation of these two devices?
- (vii) Name the Irish physicist who invented the induction coil.
- (viii) Give two factors that affect the efficiency of a transformer.

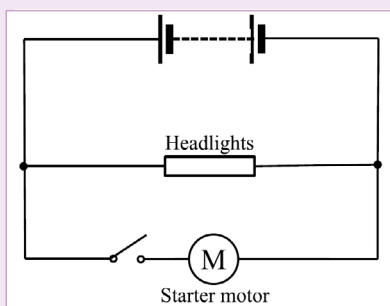
Leaving Certificate Physics (HL) 2001, Q. 10

Define (i) potential difference, (ii) e.m.f. (electromotive force).

Describe an experiment to measure the internal resistance of a cell.

In the diagram, a car battery has an e.m.f. of 13.75 V and an internal resistance of 0.08 Ω . The effective resistance of the car headlights is 1.50 Ω and the effective resistance of the starter motor is 0.20 Ω . Calculate:

- (i) the potential difference across the headlights when they are the only load on the battery;
- (ii) the total current flowing in the circuit while the starter motor is switched on;
- (iii) the potential difference across the headlights while the starter motor is switched on.



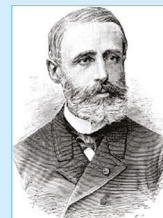
Did You Know?

- Ireland has many advantages as a location for the successful adoption of electric vehicles. These include short inter-urban routes, high levels of wind power and mild climate, a single service provider and a unified distribution network. Government support is also available; purchasers of new electric vehicles can avail of grants of €5,000 for an ecar and €2,500 for a hybrid. About 70 percent of the world’s lithium comes from brine (salt lakes) and the rest from hard rock.
- ESB and not-for-profit organisation FoodCloud have teamed up for the new Food Rescue Project, which uses an ESB electric car to collect surplus good food and deliver it to local charities in the Dublin city area. 72,000 meals are expected to be delivered in a year.
- *Who Killed the Electric Car* (2006) and *The Revenge of the Electric Car* (2011) are documentary films relating some interesting facts about ecar development (www.youtube.com).
- You can find out all about the ecar at www.esb.ie/ecars.

Biographical Notes

Gaston Planté (1834–1889)

Gaston Planté was a French Professor of Physics. In 1859, he invented the lead-acid cell which formed the first battery that could be recharged. His first one was made of a roll of two sheets of lead separated by a linen cloth (some reports say rubber strips). This was immersed in a solution of sulfuric acid. Although most famous for this invention, in 1885 he had discovered the first fossils of a huge prehistoric flightless bird, now named after him (*Gastornis parisiensis*).



His design was further improved by French chemical engineer **Camille Alphonse Faure** (1840–1898) who increased the capacity of the lead-acid battery leading to their large scale manufacture.

Revise The Terms

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

Acceleration, alkaline batteries, anode, cathode, chemical energy, electric car, ecar, electric vehicle (EV), economies of scale, electric motors, electrolysis, electrolyte, electromotive, force, emf, emissions, fuel cell, generator, heat energy, hybrid electric vehicle (PHEV), internal combustion engine (ICE), kinetic energy, lead-acid, Li-ion, lithium ion, Lorentz Force Law, magnetic field, mass produce, mechanical energy, motive force, parallel, photo electric cells, pollution, pure electric vehicle, regenerative braking, renewable sources, RFID (Radio Frequency Identification), series, solar car, torque, total cost of ownership.

Check the Glossary of terms for this lesson on www.sta.ie