

# CHAPTER 21

## Electrostatics

### 21.1

### INTRODUCTION

Electrostatic effects are very common in our everyday experience. Have you ever wondered about peculiar electricity effects? For example, what do the following situations have in common?

- You've greeted your best friend in the library after wandering around looking for books and you both get an electric shock as you touch.
- Removing a synthetic shirt or blouse at night in a darkened room leads to a display of tiny little sparks.
- After travelling in the car you receive a rather nasty little electric shock from the door handle when you get out.

Did you realise that these effects all occur after one type of material has been rubbed against another? Other examples of similar effects:

- Dust always seems to stick to the screen of the television set or computer monitor and gets worse as you try to take it off with a cloth.
- Some cars travel around with funny belts hanging down onto the road.
- Lightning always strikes the oldest and tallest trees in the forest.
- Some groups of balloons never seem to want to stay together properly.
- People sitting on plastic chairs in the office pose a possible danger to sensitive computer or electronic equipment.

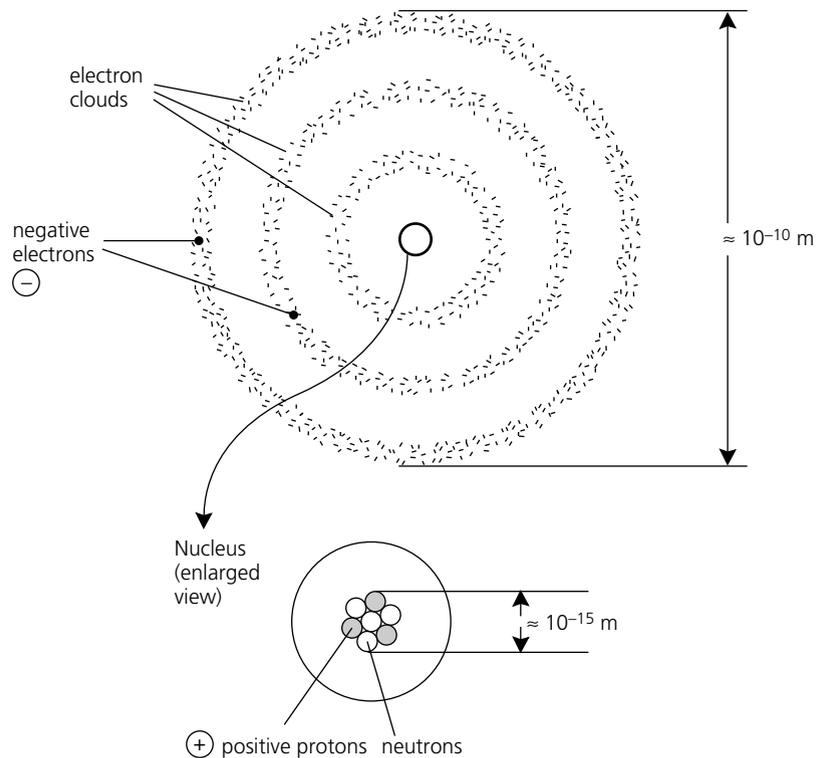
These are all due to the presence of electric charge built up on objects around us as a result of frictional processes. This electric charge is very important in nature. Electric forces and charges control many natural effects and are seen in dramatic circumstances such as lightning strikes. Much of our modern technology relies on controlling electric charges, either trying to eliminate their effects or making use of their attracting or repelling properties. In this chapter the aim is to understand the nature of electric charge and the ways in which charge behaves. This will help us to understand the operation of application devices such as spark dischargers, electrostatic generators, photocopiers and fax machines, lightning arrestors and even the various forms of biological electrostatic defences such as those possessed by animals like the electric eels and rays. Physicists regard the force of electricity as a fundamental force of nature that is ultimately responsible for other forces such as **friction**, contact pushes, **adhesion** and **cohesion**.

### 21.2

### ELECTRIC CHARGE

The first step in understanding electrostatic effects is a knowledge of the structure of atoms and matter. Recall that all matter is composed of atoms, which are the building blocks consisting of a very small and dense central nucleus, containing **protons** and **neutrons**, and layer-like regions called clouds surrounding this nucleus, which contain **electrons**. Figure 21.1 shows the relative diameters of a typical atomic nucleus as well as the outer electron cloud

**Figure 21.1**  
Simple model of the atom.



for a general atom. From this type of model it is possible to conclude, as did Lord Rutherford in about 1913 using alpha particle scattering experiments, that the atom is mostly empty space. It is also possible to conclude that the particles within the nucleus are very tightly bound together, with the protons being positively charged and the neutrons being **neutral**, that is, with no net charge. The electrons, especially the outermost ones, are very loosely bound to the nucleus in most atoms and are negatively charged.

**Table 21.1** ATOMIC PARTICLE PROPERTIES

|                 | ELECTRON                  | PROTON                     | NEUTRON                 |
|-----------------|---------------------------|----------------------------|-------------------------|
| Relative charge | -1                        | +1                         | 0                       |
| Coulomb charge  | $-1.6 \times 10^{-19}$    | $+1.6 \times 10^{-19}$     | 0                       |
| Mass            | $9.11 \times 10^{-31}$ kg | $1.673 \times 10^{-27}$ kg | $1.675 \times 10^{-27}$ |
| Atomic location | orbital cloud             | central nucleus            | central nucleus         |
| Discovered      | 1897                      | 1913                       | 1932                    |
|                 | J. J. Thompson            | E. Rutherford              | J. Chadwick             |

Table 21.1 compares the properties of the three fundamental atomic particles. Any atom that has equal numbers of protons and electrons is said to be neutral as it will have no net electric charge. Remember that the neutrons act simply as a nuclear glue and do not alter the positive–negative balance of the atom. The simplest atom in nature, the hydrogen atom, only has one electron and one proton, whereas lawrencium, a very complex atom, has 103 electrons, 103 protons and 157 neutrons. If an individual atom of any element is made to gain or lose some of its electron particles then it is said to have become an **ion**. Positive ions have lost electrons and negative ions have gained electrons over and above the normal atomic number. Ions are quite important in various types of chemical reactions.

In electrostatics it is normal to consider blocks of materials that have become **electrically charged**; this means that the material itself, such as a glass rod, has either had

extra electrons placed onto it, or had some of its atomic electrons removed from it. It has thus become net electrically charged or electrified. The ancient Greeks had found that the material they called 'Elektros' attracted bits of hair and small pieces of straw dust when it was rubbed with cloth or animal fur. Today we call this material amber. It is actually fossilised tree resins. Similarly, in laboratory experiments it is easy to show that Perspex rods rubbed with rabbit fur can attract small torn pieces of paper, or that polythene strips if rubbed with the same rabbit fur will subsequently repel each other when freely suspended on a set of free pivots. This type of experiment is often best carried out under a set of heat lamps so as to provide a very dry atmosphere in order to prevent moist ionised air quickly dissipating the electric charges.

This technique of using a cloth or piece of fur to rub a solid such as glass, Perspex, wax or polythene will electrify the object due to a process called 'friction charging'. In this process the energy supplied to the outermost atomic electrons allows them to move from the material with the least affinity or attraction for electrons to that material with the most affinity for electrons. The process is also referred to as **triboelectric** separation of charge. The word is derived from the Greek *tribein*, meaning 'to rub'. Electrons are therefore transferred from one object to another, one object becoming positive as it loses electrons, say the rabbit fur, and the other object becoming negative as it gains electrons, say the polythene strip. Note that in this example of the separation of charge process, the fur will most likely lose its charge quite quickly either by direct contact with the experimenter's hand or by loss to the atmosphere. It will thus regain neutrality. This quite often makes it difficult to show that the fur has in fact become electrically charged.

**Table 21.2 TRIBOELECTRIC SERIES**

|   |  |  |
|---|--|--|
| + | Atoms have a low affinity for electrons  |  |
|   | Rabbit or cat fur                        |  |
|   | Acetate                                  |  |
|   | Perspex                                  |  |
|   | Glass                                    |  |
|   | Wool                                     |  |
|   | Lead                                     |  |
|   | Silk                                     |  |
|   | Paraffin wax                             |  |
|   | Polythene                                |  |
|   | Ebonite                                  |  |
|   | Copper                                   |  |
|   | Rubber                                   |  |
|   | Amber                                    |  |
|   | Sulfur                                   |  |
|   | Gold                                     |  |
| - | Atoms have a high affinity for electrons |  |

Every material's atoms have their own specific tendency to gain or lose electrons easily. Table 21.2 lists the triboelectric series showing several materials in order, from those that have a low affinity for electrons and will tend to become positively charged to those that have a high affinity and become negatively charged in frictional experiments. This series is easy to read because any material will become positive by losing electrons if rubbed with any other material lower in the series list. For example, glass can become positively charged when rubbed with a silk handkerchief but negatively charged if rubbed with rabbit fur. Acetate or Perspex rods can become positively charged if rubbed with a woollen cloth while polythene or ebonite rods will become negatively charged when rubbed with the same woollen cloth.

In the triboelectric separation process the frictional charging simply involves a transfer of negative charge or electrons from one object to another. It is important to realise that

**Photo 21.1**

Free pivot apparatus with charged rods.



#### NOVEL CHALLENGE

In the mid-1700s, French experimentalist François du Fay observed that a charged gold leaf was attracted by some electrified substances and repelled by others. He called the two types 'vitreous' and 'resinous'. Use Table 21.2 and your knowledge of what substances are classified as vitreous and resinous to decide if the resinous rod would have a positive or negative charge.

#### PHYSICS FACT

In the eighteenth century, British sailing ships had their gunpowder store (the 'magazine') lined with copper to make it waterproof. Sailors had to put on thick felt slippers to avoid generating a spark by electrification. They learnt this the hard way.