TAP102- 2: Shuttling ball and ions in flame

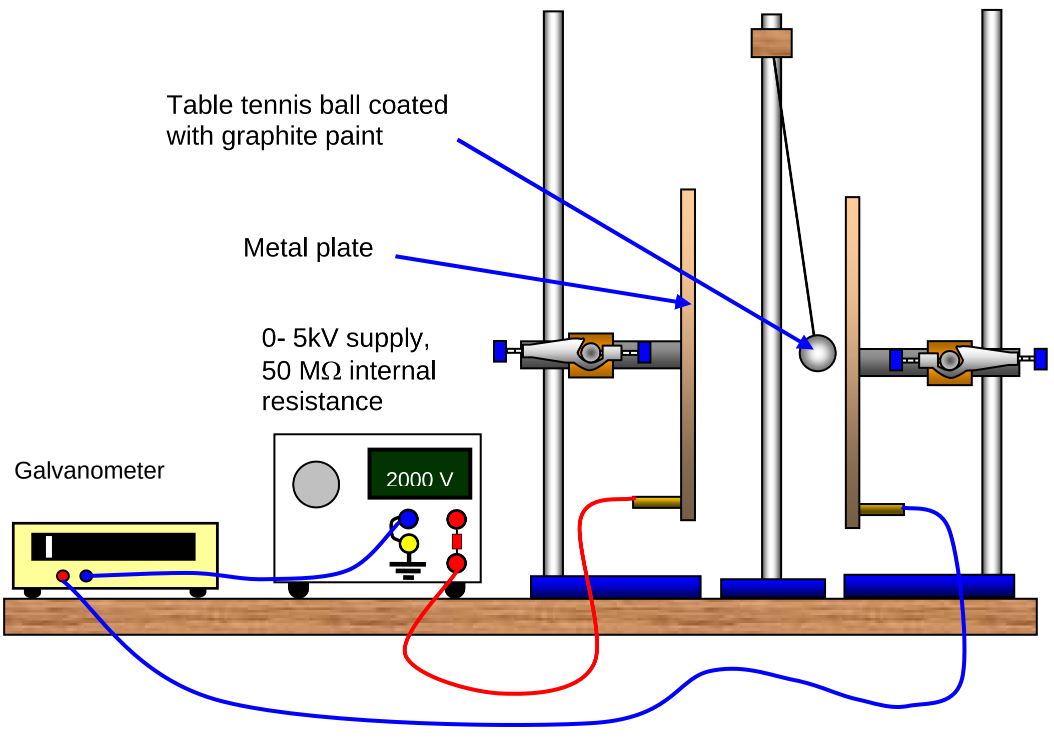
Charges carried by a moving object

An electric current is just a charge moving from one place to another. This charge can be carried by anything, in this case a table tennis ball.

Requirements

- ✓ EHT power supply, 0 – 5 kV dc
- ✓ pair of conducting discs, insulated and clamped vertically
- ✓ leads, 4 mm (N.B. no side screws in 4mm plugs)
- ✓ colloidal graphite coated table tennis ball suspended on 1.5 m of nylon monofilament
- ✓ very tall retort stand, boss and clamp to support nylon monofilament
- ✓ light-spot galvanometer
- ✓ stroboscopecandle and matches

Safety Note	The EHT power supplies approved for use in schools are safe but can give a shock large enough to make a person jump.



A shuttling charge is an electric current

Connect a pair of metal plates across a large potential difference. No current passes across the gap between them, unless there is a spark. But hang a conducting ball in the gap and let it touch one plate. It picks up charge from that plate. Charged, the ball is repelled by that plate and attracted by the other one. So it swings across until it touches the second plate. There, it delivers its charge, and is pulled back to the first plate. The sequence repeats, and the ball shuttles to and fro between the plates.

A sensitive current meter connected between the plates shows that a current is flowing. It is likely to be only a few microamperes.

You can calculate the charge carried by the ball if you know the current and the time of travel of the ball between the plates, because the current is the rate at which the ball carries charge across the gap.

Remove the ball. Now put a candle flame in the gap. The flame is hot enough for atoms in it to be ionised. These ions will also travel across the gap. Now you cannot see them move, but you can see the current indicated on a meter. The current will be considerably larger than that carried by the shuttling ball. Soot from positive carbon ions (candle wax contains carbon) will be deposited on the negatively charged plate.

Things to remember

1. You will have seen a moving charge-carrying ball deliver an electric current which can be detected on a meter.
2. You should have calculated charges and currents using $I = Q/t$ and numbers n of electrons transported per second.
3. You should be getting used to calculating with very large and very small numbers.
4. You should know that a hot flame can ionise atoms within it, so that flames can be electrical conductors.

Practical advice

A Van de Graaff generator may be used instead of the 5 kV power supply. Ensure that the galvanometer is earthed and that no sparks jump to it. Start with the plates close enough together (about 6 cm apart) for the ball to shuttle automatically. If the stroboscope is to be used to measure the frequency of movement of the ball, the laboratory needs to be darkened.

It may be helpful to have the whole of the plates and the retort stand on a large sheet of insulator, to permit rotation of the whole apparatus in order to allow the entire class a clear view of the volume between the plates.

Here the emphasis is on current as a flow of charge with a visible carrier in the form of a shuttling ball, and then as ions in a flame.

A graphite painted table tennis ball (use colloidal graphite paint) is suspended on a 1.5 m of insulating nylon thread, suspended between two metal plates held on insulating rods about

6-8 cm apart. The dome of the Van de Graaff generator is connected to the nearest plate, and the far plate is earthed to the base of the generator. The ball shuttles between the plates and charge is clearly set in motion. The frequency of shuttling can be increased by increasing the potential difference (faster motion of belt, or increased output from EHT supply), or by moving the plates closer. The current can be measured by placing a sensitive light beam galvanometer in the earth return circuit. The meter indication shows that a moving charge constitutes an electric current. The direction of the charge flow and the sign of charge on the generator dome can be found. Such a galvanometer has a typical sensitivity of 25 mm / μA, and a current of a few μA can usually be achieved.

A stroboscope can be used to find the frequency of shuttling. It is important to freeze the motion at one end rather than the middle to avoid visual aliasing (increase strobe rate until two images of the ball, one at each plate, are seen and then drop to half this rate).

A number of calculations are worth doing:

- Number of coulombs flowing per second
- Number of electrons flowing per second
- Charge on the ball (typically about 10 nC)

The demonstration can be completed by replacing the shuttling ball with a candle flame, and measuring the ionisation current carried by the ions in the hot gases of the flame. The current from the ions in the hot flame will conduct a current several orders of magnitude larger, so the sensitivity of the galvanometer will need to be decreased to measure current of the order of milliamperes. The ions are produced in oppositely charged pairs from the originally neutral candle wax. The C^+ ions responsible for the brightness of the flame will be attracted to the negatively charged plate and will deposit as carbon black when they hit the plate and become neutralised.

Alternative approaches

The slow but visible movement of coloured ions as current carriers is a good alternative. The ionisation current in a miniature neon indicator lamp taken above its striking voltage (about 60 V), could also be demonstrated, using an EHT supply and suitable 50 mA meter.

Be safe

If a 5 kV supply is used, ensure that the large series resistor (typically 50 MΩ) is included in the output circuit to limit shocks to very mild ones. A teacher should do this demonstration, but the activity could be repeated by a post 16 student under close supervision.

External references

This activity is taken from Advancing Physics Chapter 2, 40D, which was an adaptation of Revised Nuffield Advanced Physics experiment E1.