TAP 125- 4: Charging capacitors

Practising with current, charge and electron flow

You should already be familiar with the relationship between current, charge, potential difference and time. Try these few simple calculations as a reminder. You will have to recall or look up the value for the charge of the electron.

1. How much charge passes a point in a circuit when a current of 8 A flows for 5 s?

2. A charge of 120 C passes through a battery in 4 minutes.
    Calculate the average current?

3. To start a car engine takes 80 A for 6 s.
    Calculate how much charge flows through the motor?

4. The beam current in an oscilloscope is 2 mA.
    Calculate how many electrons strike the screen in 16 s.

5. A charge of 20 C flows through a 1.5 V cell.
    Calculate how much energy has been transferred from the cell to a lamp connected across it?

The current in a hand calculator is very small, for example, 0.0006 mA.

6. How many electrons per second does this represent?

7. How long would it take for one coulomb of charge to flow?

The capacitor – an unusual circuit element

The diagram shows the symbol for a capacitor.
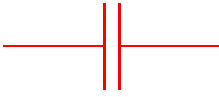
The symbol shows the idea behind the construction. There are two conducting surfaces with a non-conducting gap between them. This gap may literally be an air gap or it may be filled with an insulator, sometimes called a dielectric. It is important that this gap does not conduct when the capacitor is working. The construction means that charge can never flow **through** the capacitor, but can flow in the circuit **to** it (and **from** it).

In the circuit shown, an uncharged capacitor is connected to a battery.
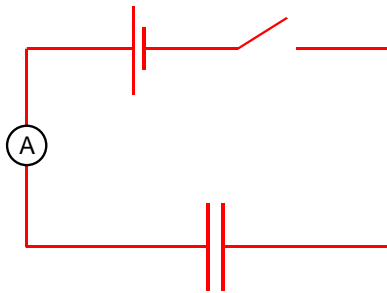
When the switch is closed, an ammeter will show a current. You may well have done or seen an experiment to demonstrate this.

8.   Which way will electrons flow? Redraw the circuit and put arrows on to show the direction of electron flow.

9.   If a current of 100 μA passes for 2 s, how much charge flows through the battery? How many electrons flow through the battery?

When a capacitor has been connected across a battery for some time, the flow of charge stops. The capacitor is said to be **charged**. We talk about the 'charge on the capacitor' and this is equal to the charge that has flowed through the battery during the charging process. The capacitor is left with one surface positively charged and the other negatively charged.

10.   Which surface (or plate) has gained electrons and which has lost electrons, and how many has each plate lost or gained?

11. When the capacitor shown in the circuit above is charged, a charge of 150 μC flows through the battery. Redraw the diagram and mark on it the charge (with sign) on each plate. What is the net charge on the capacitor (i.e. taking account of the signs)?

You will perhaps have realised by now that what really happens when a capacitor is charged is that the pulse of current results in a redistribution of charge. The overall charge of the circuit is zero, as it was at the start of the process. One plate (or surface) of the capacitor has acquired a surplus of electrons at the expense of the other.

Two further questions, for discussion.

12. How much charge is needed to charge a capacitor?

13. Can we go on adding charge indefinitely to a capacitor?

Practical advice

It is intended that the first seven questions be used as a warm-up exercise to remind students about any previous work they will have done on electric current. They will have met the equation $Q = It$ in their work on basic electricity and the questions are designed to test that they can handle charge confidently before moving on to capacitors.

The second section focuses on the flow of charge in a circuit containing a capacitor but stops short of using or developing $Q = CV$, which follows later. The idea of the questions, which are not all calculations, is to promote thinking about how the charging of a capacitor represents a redistribution of charge in a circuit in which nothing is either lost or gained. You may like in your teaching to sow the seed of how the redistribution of charge results in storage of energy which can be tapped into at any future time. Students also have opportunities in these questions to practise dealing with very small and very large numbers and with the use of standard form.

Solutions

1. 40 C
2. 0.5 A
3. 480 C
4. 2.0×10^{17}
5. 30 J
6. 3.75×10^{12}
7. Approximately 19 days
8. Arrows away from negative and towards the positive terminal

9. 2×10^{-4} C, 1.25×10^{15}

10.   The plate near the negative terminal has gained electrons, the other has lost electrons. The number in each case is 1.25×10^{15}

11.   Zero charge overall

Worked solutions

1.

$$Q = It = 8 \text{ A} \times 5 \text{ s} = 40 \text{ C.}$$

2.

$$I = \frac{Q}{t} = \frac{120 \text{ C}}{4 \times 60 \text{ s}} = 0.50 \text{ A.}$$

3.

$$Q = It = 80 \text{ A} \times 6 \text{ s} = 480 \text{ C.}$$

4.   Charge striking the screen in 16 s = 2×10^{-3} A $\times$ 16 s = 32×10^{-3} C, so the number of electrons striking the screen in 16 s is equal to:

$$\frac{32 \times 10^{-3} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 2.0 \times 10^{17}.$$

5. $W = QV = 20 \text{ C} \times 1.5 \text{ V} = 30 \text{ J.}$

6.   In 1s the charge flow is equal to 0.0006×10^{-3} C = 6.0×10^{-7} C, so the number of electrons is equal to

$$\frac{6.0 \times 10^{-7} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 3.75 \times 10^{12}.$$

7.   The time for 1 C is equal to

$$\frac{1 \text{ C}}{0.0006 \times 10^{-3} \text{ A}} = 19 \text{ days (approx.).}$$

8.   The circuit diagram should show arrows away from negative and towards the positive terminal of the cell.

9.

$$Q = It = 100 \times 10^{-6} \text{ A} \times 2 \text{ s} = 2 \times 10^{-4} \text{ C}$$

$$\text{number of electrons } = \frac{2 \times 10^{-4} \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 1.25 \times 10^{15}.$$

10.   The plate near the negative terminal has gained electrons, the other has lost electrons. The number in each case is 1.25×10^{15}.

11.   The plate nearest the negative side of the cell will have -150 µC and the plate nearest the positive side of the cell will have $+ 150$ µC. Zero charge overall.

12.   Points raised might refer to the battery voltage available.

13.   Discussion expected to lead to discussion of electrical breakdown of dielectric.

External references

This activity is taken from Advancing Physics Chapter 10, 50S