26 Excess and deficit of electrons

Subject:

The terminals of power supplies and batteries are marked with a plus and a minus sign. When discussing simple electric circuits it is often said, that at the minus terminal there is an excess of electrons and at the plus terminal there is an electron deficit.

Deficiencies:

Here we have to do with two incongruities, which are related to one another. We shall show that

– it is awkward to tag the terminals with a plus and a minus sign;

– it is often awkward, and sometimes incorrect to say that at the terminal at lower potential there is an excess of electrons and at the high potential terminal there is a deficit.

The plus and the minus sign suggest, that some physical quantity has a positive or negative value at the corresponding terminal. Does such a quantity exist?

One might think at the electric charge. Let us first ask for the amount of charge sitting on the terminals of a battery including the respective electrode. Its value depends on the capacitance C_B of the battery. We thus treat the battery as a capacitor. The electric charge on the terminals, together with the electrodes and the internal conductors is

$$Q = C_B \cdot U_B \,, \qquad (1)$$

where U_B is the voltage of the battery. Q would be the charge of the terminal (and electrode) if the midpoint between the electrodes would be at Earth potential. The electric potential of the plus electrode would then be by $U_B/2$ above and the minus electrode by $U_B/2$ below Earth potential. However, this is a special case that is almost never realized. In general the average potential of the battery will be different from the Earth potential and thus the battery will carry a net charge, whose counter charge sits at the Earth. The net charge is then:

$$Q = C_{plus} \cdot U_{plus} + C_{minus} \cdot U_{minus} \,,$$

where C_{plus} and C_{minus} are the capacitances of the plus and minus terminals against the Earth, and U_{plus} and U_{minus} are the voltages between the terminals and the Earth. The capacitances C_{plus} and C_{minus} are typically of the same order as C_B, whereas U_{plus} and U_{minus} depend on the circuit as a whole; it may be grounded somewhere but it may also be carried at a high positive or negative electric potential. Thus, in general one cannot say that the plus terminal carries positive and the minus terminal negative electric charge.

These considerations show that the plus and minus sign at the batterie's terminals neither correspond to the electric potential. The plus terminal must not be at a positive potential and the minus terminal must not be at negative potential. And there is no other quantity that would be correctly characterized by the plus and the minus sign.

There is no doubt that this designation is the cause of incorrect conclusions.

It also follows that the claim that there is an excess of electrons at one terminal and a deficit at the other cannot be generally correct. A student will believe that such a statement means that the plus terminal is not electrically neutral but that it carries positive charge. We just have seen that this must not be true.

But even if we arrange the electric potentials in such a way that the plus terminal's potential is positive and the minus terminal's negative (when Earth potential is defined as zero), so that the plus terminal is positively charged and the minus terminal negatively, even now it would be out of place to characterize the terminals by speaking of an electron excess or deficit.

The capacity C_B in equation (1) is of the order of 10^{-10} F. Since a typical voltage is 1 V the excess charge is of the order of 10^{-10} C. When mentioning an excess or deficit of electrons one suggests that this has something to do with the flow of charge or electrons that flow in the circuit under typical conditions. However, the charge that is crossing a section of the wire of the circuit with a light bulb in one second is greater by 10 orders of magnitude.
The inappropriateness of the argument can best be seen when comparing the battery in the electric circuit with a water pump in a water circuit. A battery without a load would correspond to a water pump that is filled with water but with its inlet and outlet blocked. Nobody would characterize the inlet and outlet by saying there is an excess and a deficit of water. The slight excess and deficit that actually exists is due to the non-zero compressibility of the water. But we see immediately that this excess is not a necessary condition for the operating of the pump. The pump would do just as well with a liquid of zero compressibility.

Origin:

Most of the subjects of our column concern concepts or descriptions that in a former time have been justified. Here we have an example of an incongruity that was an incongruity from the beginning.

Disposal:

Characterize the terminals of a battery or a power supply with "high" (H) and "low" (L) instead of plus and minus. This is common use among electronic engineers. This labeling refers to the electric potential. Another possibility would be to label them "out" an "in", which refers to the electric charge, and not to the electrons.

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