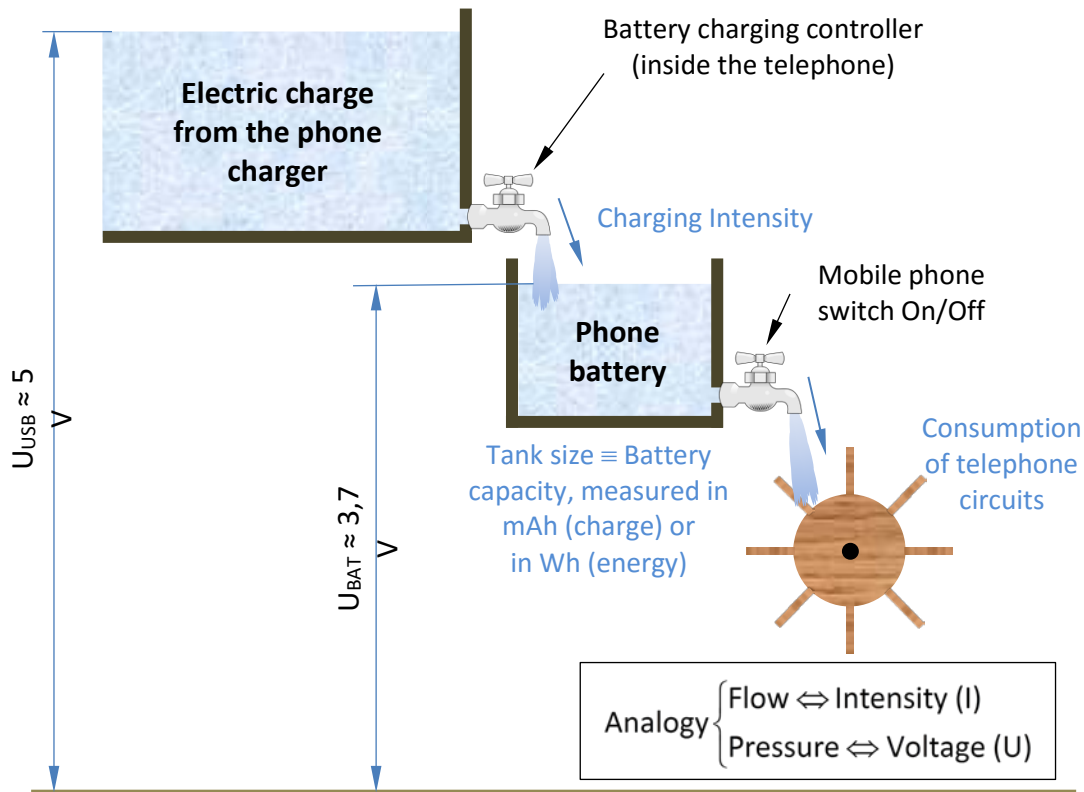


## Experimenting when recharging your mobile phone

This activity seeks to clarify some basic concepts of electrical engineering through an everyday activity such as the recharge of the battery of a mobile phone. The hydraulic analogies of “electric fluid” and “electric current” are shown in the figure below.



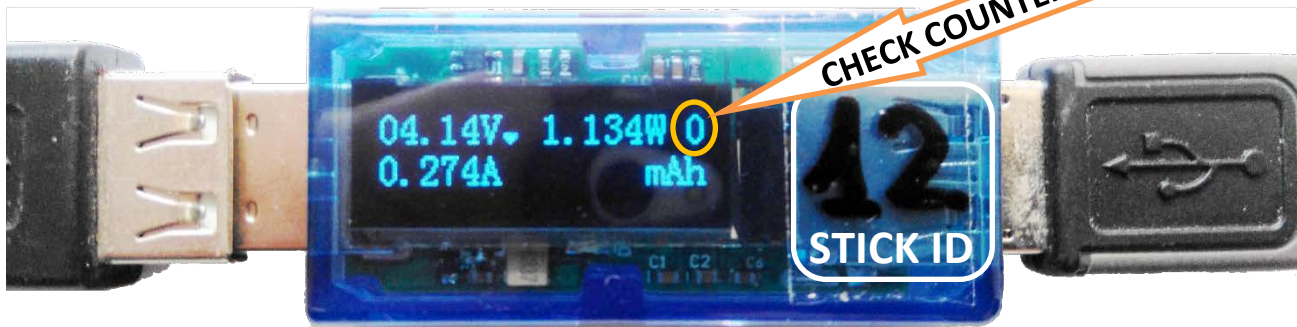
A primary battery can only be discharged, converting chemical energy into electrical one. But a rechargeable battery (or secondary battery) can also transform electrical energy into chemical. Its operation is based on a reversible electrochemical cell, consisting of two electrodes immersed in an electrolyte. The battery technologies are named after their electrode chemicals: lead-acid (Pb), nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and ion-lithium (Li-ion).

The batteries supply electric energy to many portable devices because their weight, volume and cost are reasonable (for small equipment) and they provide a fair constant voltage until their chemicals are exhausted. Other technologies such as supercapacitors, wireless energy transfer, fuel cells, solar panels and generator sets are preferred to the batteries in some applications.

In contrast to the battery, a capacitor stores charge and energy creating an electric field in the insulator between its electrodes. Although this phenomenon is faster than electrochemical reactions, it cannot compete in weight and in volume with the batteries. Moreover, the linearity between electric field and charge origins that the voltage across a capacitor decreases as it decreases the energy which stores, requiring complex circuits for its full charge and discharge.


During this experiment, the USB stick provided by the teacher will be utilized to meter the voltage, current, power, charge and energy drawn by the telephone. In the activity sheet, you will have to write down those values and the charge state of the battery at the beginning, one hour later and at the end of the charging process. These annotated values will be used to check the main relationships that exist between the measured magnitudes. Before connecting the device to be

recharged, please check that the current and power measured by the stick is practically zero. Please, check also that digit 0 appears in the top right corner (indicating that the first charge counter is selected). If other digit were shown in the top right corner, change it to 0 by short pressing the stick back button<sup>1</sup>.



After plugging the phone to the USB cable, the voltage will decrease in most chargers. In those cases, the internal USB resistance can be calculated as the voltage drop divided by the current.

The USB stick measures the transferred charge in mAh and the energy in mWh. The transferred charge during an hour, expressed in mAh, is the average current, expressed in mA. Conversely, the transferred energy in mWh during an hour is the hourly average power, expressed<sup>2</sup> in mW. You may use the timer or the alarm of the phone to remind you to write down the measured values one hour later the beginning. You can check the charge-current and energy-power relationship in your activity sheet.

The remaining battery percentage (i.e., battery state of charge  $B_{\#}$ ) is typically shown in the upper left corner of the device display, close to the battery icon . The nominal capacity of a battery (in other words, the mAh amount printed in the battery) indicate the maximum charge that it can store. But a total discharge of a battery usually causes its irreversible deterioration. The mobile devices indicate on the screen the percentage of available or net battery. When they indicate that the available charge is 0%, the battery has reached the level of discharge that is not advisable to exceed. To extend battery life, the battery management system does not allow the battery discharge below a certain level. In other words, when the phone displays 0% energy, there might be around 20% charge, left in the battery to safeguard it. Therefore, the useful battery charge might be about 80% of the nominal capacity.

At the end of this activity, the transferred charge is compared with the battery percentage displayed in the phone. With these values, the available capacity ( $Q_{\text{available}}$ ) and the available energy ( $E_{\text{available}}$ ) can be estimated. Note that it has not been taken into account the efficiency of the charging and discharging process and the actual consumption of the phone while it is charging. In addition, the battery percentage displayed in the phone has some uncertainty since it is estimated with sophisticated algorithms that compensate for the influence of temperature, battery ageing, screen illumination, apps and processes running in the phone, etc.

<sup>1</sup> The charge counter flashes with a non-zero value when you plug-in it, because the meter will flash the last stored value for a while. Regardless of what is blinking after plugging in, the charge and power is always reset each time it is disconnected from the USB port provided you use counter 0.

<sup>2</sup> To switch between the regular screen (voltage, current, power, and charge) and the screen with only charge and energy, you can double-click very fast (less than 0.5 between two consecutive presses) on the back yellow pushbutton. In addition, a long press (duration between 2 s and 4 s, equivalent to releasing the button when a red LED starts to blink) switches the display of charge to supplied energy (or vice versa). **After using the yellow pushbutton, always check that the counter 0 is selected.** If needed, set the counter back 0 with short presses (less than 2 s).