Heating of Conductor by Electric Current

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Annotation: This contribution focuses on demonstrational experiments that utilize or demonstrate heating of a conductor by current.

Baked Apple

If you want to introduce the Electric current chapter with an unforgettable experiment, take an apple, a plastic dish, two longer conductors with banana plugs (plugs with full plastic case without screws or contacts sticking out of it), two bigger nails and two crocodile clips.

ATTENTION – the experiment needs mains electricity – work with maximal caution!!!

Put the apple in the dish and thrust the nails in it. The nails MUST NOT touch each other inside the apple! Attach the conductors with the clips to the nails. Lastly plug the conductors into the wall socket. Firstly nothing happens. Then the apple begins to hum a little and some steam will begin to blow out of the apple along the nails. The apple is boiling inside and the steam flows out until all the water is away. Then the apple conducts current through an electric arc – in a darkened room we can see that the apple shines. To turn the apple off, pull the both conductors from the socket first.

For safety reasons it is appropriate to use a false adaptor in experiments that use mains electricity. It can be made from a plastic electricity box or from a real spent adaptor. You simply put two socket holes in one side of the box and terminate a regular power cord with a plug on the other end. The socket holes are connected directly to mains but the students do not know about it and they will not try to plug banana plugs into the mains. The circuit is turned on and off by inserting the cable in the wall socket and pulling it out. It is much safer than to operate with banana pins directly in the mains socket.

Burning Springs and Pencils

To demonstrate heating of the conductor by electric current it is convenient to use a conductor that can be heated to such a high temperature that it shines. We need a 12 V source that is capable to give current of about 8 A and conductors with crocodile clips. All experiments must be made above a nonflammable surface (at least an aluminium foil).

The springs from ball pens or similar springs or steel string proved to be good shining metal conductors. We put the two ends of the spring into the clamps and turn on the source. In the ideal case the spring begins to shine. If it only heats, move the clamps closer together (after the spring has cooled down). Too short spring blows immediately and hot sparks sputter from its ends like from a sparkler.

A graphite lead from a pencil can be used as well. ATTENTION – graphite behaves as a semiconductor – its resistivity decreases with growing temperature. So the lead initially seems not to conduct but as it gets heated, its resistivity decreases and it begins to glow. If the lead does not glow but only becomes hot, move the clamps closer together. If you have a source robust enough, the lead is brought to yellow glowing after a while.

With a 24 V source we can also connect a whole pencil that has both ends sharpened. The wooden case of the pencil is heated by the lead, the varnish burns and the wood carbonizes gradually.

If you have a demonstrational ammeter with range at least 10 A, you can demonstrate the temperature-resistivity dependence of both metal and graphite. After they get hot, blow some air on them – they will get cooler. The spring conducts higher current if cooled, the graphite conducts worse.

A Pair of Bulbs [1]

We need two identical bulbs for the following experiment. A good choice is 24 V/25 W bulbs. If we connect them in series to a 12 V source, they shine visibly but do not dazzle.

We make a serial circuit with these 2 bulbs and with one extra socket between the bulbs so that we can either connect both bulbs to the circuit or only one of them. First we connect both bulbs – they glow moderately. Then we move one of the source conductors to the middle socket – the bulb that is connected shines much more intensely, the other one goes out because it is not connected in the circuit.

The next operation must be made as fast as possible – we move the conductor from the middle socket back into the first socket so that both bulbs are connected in a serial circuit. A surprising effect takes place – only the bulb that was recently shining begins to shine again but the other bulb remains dark. The dark bulb begins to glow after a few seconds and the shining bulb gradually loses its brightness until they both glow moderately again.

I recommend repeating the experiment; the students can count down the switching aloud. We can also switch the bulbs to show that they are the same.

The cause of the phenomenon is the difference of the temperatures of the bulbs. The fiber of the bulb that was shining recently is still hot. Thence it has a higher resistance than the fiber of the cold bulb and also a higher voltage. The temperatures and resistances become equal after a while. We can measure the resistance of the fiber after this demonstration. The ohmmeter gives only a small current so it does not substantially change the temperature of the fiber. The resistance of a cold fiber is 2 Ω, the resistance of the fiber just after shining is 5 Ω. We can estimate the temperature of the fiber on the basis of a well-known formula $R = R0\times(1 + \alpha\Delta t)$, where $\alpha = 0{,}0044\ K{-}1$ for tungsten (which is the presumptive material of the fiber). It yields 340 °C.

The current through the bulb at operational voltage of 24 V is 1 A which corresponds to a temperature of 2 520 °C and agrees with the information given by the producer (see for example [2]).

Heating Coil

For the following experiment we need the heating element from an electric kettle such as 230 V/2100 W. We connect the heating coil to a source of 24 V. Then we try to find a volunteer that would be compliant to hold the coil in a bare hand (it will not be easy to find someone after we have spoken about the power output of the coil). The coil surprisingly heats very mildly.

The voltage is about 10 times lower than in full operation so the output is similarly lowered. Input is $P = VI$ so the output is about 21 W. (We neglect the change of resistance due to a change of temperature which gives a higher output because $P = V^2/R$.)

Fuse

We make a serial circuit with a 12 V bulb, 12 V power supply and a switch. Between the conductors there is a short steel string (placed above a nonflammable surface such as a piece of aluminium foil). We connect the circuit – the bulb shines. We short contact (after a warning) the bulb with scissors or another metal object – the current suddenly rises and the string blows.

References

[1] Piskac V.: *Light bulbs take a while to get going.* Physics Education, January 2006

[2] http://www.bulbs.com/lightingguide/tech_i_history.asp (cited on 21. 8. 2006)