A Child's Flashlight and *RC* Circuit Concepts

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A Playskool® child's flashlight[1] can serve as an effective "real-world" device for students to develop their understanding of dc circuit concepts, specifically multiloop configurations, switches, and *RC* time constants. Last year, as the final exercise in the dc circuits portion of our introductory physics lab, our students analyzed and modelled a child's flashlight whose relevant feature is that the bulb dims quickly (≈ 20 s) when left on, thus saving the batteries. The dimming of the bulb is suggestive of an exponential decay that may be modelled by an *RC* circuit. The exercise described here could be incorporated into any lab covering *RC* circuits.[2]

The child's flashlight has behavior that is complex enough to be interesting, but can be modelled quite simply using resistors, capacitors, and switches. The flashlight, shown in Fig. 1, has *two* switches. The "main" is a two-position switch; the "handle" switch is of the spring-loaded momentary type. A few minutes of careful observation show that the flashlight exhibits the behavior summarized in Table I. For the last combination (main switch forward/handle switch down) the bulb behavior depends on the order in which the switches are thrown. If the main is moved forward first and then the handle is moved up and released, the bulb lights and then dims gradually over roughly 20 s. Any other sequence leading to the forward/down combination will not light the bulb.

Our classes perform a five-week sequence of labs investigating dc circuits.

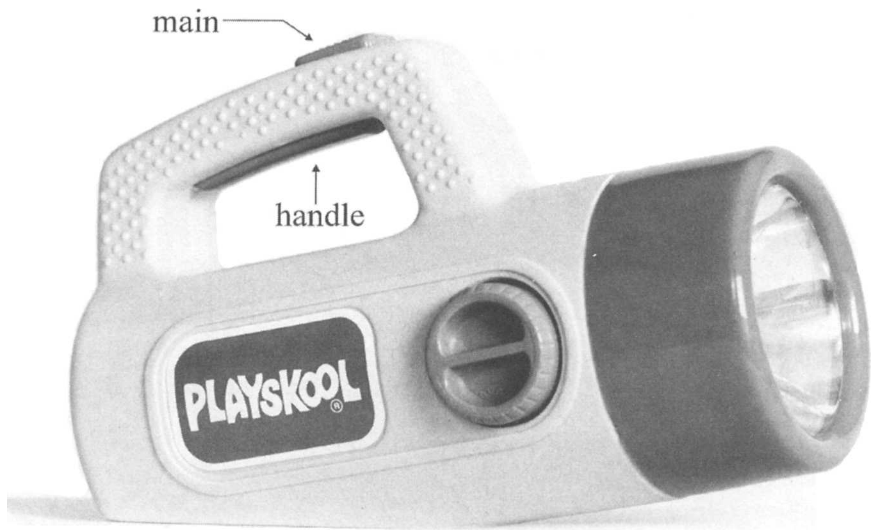

Fig. 1. Child's flashlight with the two switches labeled.

In the first week students do a qualitative analysis of successively more complex combinations of batteries and flashlight bulbs (PR-2)[3] to get a feel for series, parallel, and combination circuits. This is followed by a quantitative analysis of the same circuit combinations using digital multimeters to measure current and voltage, ultimately leading to the loop and junction rules. The meters are then used to obtain *I-V* curves of both bulbs and resistors to better understand ohmic and nonohmic behavior. Next, the students examine exponential decay by measuring voltage as a function of time in *RC* circuits consisting of resistors, capacitors, switches, and batteries.

Last year, during the fifth week, we asked our students to model the behavior of a Playskool child's flashlight. (The measuring equipment and circuit elements from each of the previous labs were still available.) We gave each group one of the flashlights and instructed them to produce a detailed circuit diagram using batteries, bulbs, resistors, capacitors, and switches to account for their observations. Students were told that the flashlight operates on 3 V and has a bulb similar to those studied previously, but they were not allowed to open the flashlight. As part of their final report for the dc circuit labs they were asked to include a discussion of their schematic and the reasoning behind the approximate component values.

The two key tasks in this exercise are to determine a combination of two

Table I. Bulb condition for switch combinations.

		Main switch	
		Backward	Forward
Handle switch	Up	OFF	ON
	Down	OFF	see text

switches that reproduces the behavior summarized in Table I and to find values of circuit components that would cause the bulb to dim in approximately 20 s. The problem can be solved with the schematic shown in Fig. 2. Note that the main switch is a double-pole single-throw. The right half of this switch is necessary so that the bulb will be immediately extinguished when the main is in the backward position. The left half is necessary to prevent the possible charging of the capacitor while the main switch is in the backward (open) position. With a working combination of switches we now need to determine appropriate component values. Based on the previous dc circuit labs, we know that the light from the bulbs used is no longer visible when the voltage is about one-tenth of the rated voltage. Assuming approximately exponential behavior we use two time constants as the interval necessary for the bulb to go out, thus the RC time constant is about 10 s. Although the bulb is nonohmic, over the range that it is lit the I-V curve yields an effective resistance on the order of 10 Ω. With this resistance value a capacitor on the order of one farad is needed to produce an acceptable decay time.[4]

We make the following observations based on discussions with students in the lab and on reading their reports. First, the better students were able to make the arguments just given and successfully model the flashlight. Second, for the remaining students the most difficult part of the analysis was determining an appropriate switch configuration; the most common error was a failure to recognize the need for the double-pole single-throw main switch. Finally, the need for a capacitance in the neighborhood of one farad was troubling for many students who indicated that this large value of capacitance was "unreasonable," "impractical," or even "dangerous." These are legitimate concerns, given that in their previous labs they used 4700-μF capacitors and their textbook[5] suggests that practical capacitors are typically measured in microfarads or picofarads. To get the time constant of 10 s with the familiar 4700-μF capacitors, some added a several-kΩ resistor in series with the bulb. Although this would give the correct decay time, these students failed to recognize that the current would be so low that the bulb would not light.

Regardless of their success in modelling the flashlight, many students were

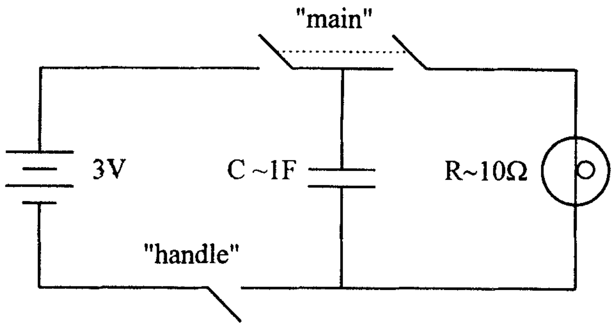

Fig. 2. Possible schematic for flashlight.

uncomfortable with the process of (in their words) "guessing" at component values. The fact that they needed to estimate the time constant and the resistance of the bulb to obtain an approximate value for the capacitance was unsettling. This may be due to the fact that too many of our homework and exam problems have answers to three significant figures and that nonohmic devices are usually neglected in the problem sets.

In addition, we were surprised at how few students actually attempted to build a prototype in the lab. Given the preceding lab work, we had hoped that this would be a natural part of the modelling process. Those groups that did build a prototype verified the correctness of their schematic and noted the need for larger capacitors than were available. Although attempts to combine the available capacitors in parallel fell short, the results were sufficient to convince the students that their model was correct. (An option would be to have 1-F capacitors[6] available for students requesting larger values.) Apparently, many groups did not see the experimental approach as appropriate for this type of exercise, which some of them termed a "theory" problem.

Our experience with this exercise suggests that contact with a real-world device and its associated complexities and uncertainties is valuable for students. We need to do more to give students practice with problems in which estimating and measuring are integral steps in producing a solution.

Acknowledgments

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References

1. Playskool® flashlight, item #144.03, available at toy stores or call Playskool at 1-800-752-9755.
2. See the lab manuals that accompany standard introductory texts. Some other approaches are described in Herbert T. Wood, *Phys. Teach.* **31**, 372 (1993) and John G. King and A.P. French, *Phys. Teach.* **33**, 188 (1995).
3. The PR-2 bulb is the one used in the flashlight and is readily available, e.g., Radio Shack.
4. While we were able to mimic the flashlight behavior with an *RC* circuit, curiosity got the better of us. We opened a flashlight and found that along with resistors and capacitors it utilizes solid state devices. A spokesperson for Playskool informed us that the design is proprietary, so the schematic is not shown here.
5. Paul Fishbane, Stephen Gasiorowicz, and Stephen T. Thornton, *Physics for Scientists and Engineers* (Prentice Hall, Englewood Cliffs, NJ, 1993), p. 762.
6. Panasonic, NEC, and others make capacitors with values up to 1 F. They are available through electronics supply houses or scientific equipment suppliers, e.g., Mouser Electronics 800-346-6873, PASCO scientific 800-772-8700.