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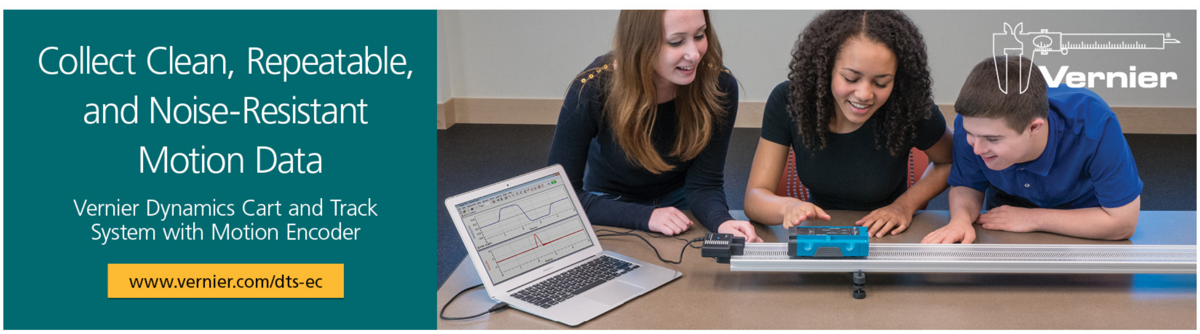

A Fan-tastic Alternative to Bulbs: Learning Circuits with Fans

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The incandescent bulb has been a useful tool for teaching basic electrical circuits, as brightness is related to the current or power flowing through a bulb. This has led to the development of qualitative pedagogical treatments for examining resistive combinations in simple circuits using bulbs and batteries, which were first introduced by James Evans[1] and thoroughly expanded upon by McDermott and others.[2-4] This paper argues that replacing bulbs with small computer fans leads to similar, if not greater, insight of experimental results that can be qualitatively observed using a variety of senses. The magnitude of current through a fan is related to the frequency of the rotating fan blades, which can be seen, heard, and felt by the students. Experiments using incandescent bulbs only utilize vision, which is not ideal as the human eyes' perception of brightness is skewed because the response to light intensity is logarithmic rather than linear.[5]

Bulbs, fans, and circuits

Students will become less and less familiar with incandescent bulbs as they are increasingly being replaced by more efficient compact fluorescent light bulbs (CFLs) and light-emitting diodes (LEDs).[6] This will increase the potential for confusion when they encounter incandescent bulbs solely in the classroom setting. Without a foundational familiarity and easy access to incandescent bulbs, the pedagogical value of using them to teach simple circuits decreases. Simply replacing the incandescent bulbs with either CFL or LED bulbs is not viable because their brightness does not correlate to the current flowing through each bulb. Although other methods such as Genecons[7] and fluid-based[8] analogies have been proposed as alternatives, the use of fans retains the fundamental nature of the bulb circuits. Students are also likely to be familiar with the operation of fans, as they are a relevant and abundant technology.

Fan selection and experimental preparation

Finding the "right" fan that demonstrates experimentally the desired principles in the most consistent and lucid way is similar to selecting the "right" bulb, as not all bulbs will operate as desired under lab conditions. Seven different models of small computer fans were purchased and assigned a letter A to G. Each type of fan was either 5 V or 12 V as this voltage range is similar to those used with bulbs. They are also compatible for using combinations of 1.5-V batteries or power supplies. The model number, specification, and distributor for each fan model can be found in Table I. All of the selected fans must be wired so that the red lead connects to positive and the black lead connects to negative; this must be maintained in combination circuits as well.

Each model was initially tested by wiring two fans both in series and parallel. Fans that exhibited the desired behavior in both configurations were then wired into various three- and four-fan arrangements. Only fans B, E, and G were successful in all configurations while the other models locked up when additional fans were added in series or in parallel. This may be a result of large current fluctuations from the non-ideal performance of the fans, which would then lead to self-inductance or back EMF effects. Fans B and G were also eliminated as they required much more power to spin than fan E. For instance, the B fans required ~11 V when four fans were wired in series, while the E fans only required ~6 V. As a result, the E fans were used for all subsequent experiments (AD0405MB-C50).[9]

Table I. Computer fans tested and outcomes with select manufacturer specifications. Unit price is the cost when purchased in fall 2015 from Newark Electronics[9] and Amazon.[10] Fan "E," highlighted in gray, is the fan selected for these experiments.

Letter	A	B	C	D	E	F	G
P/N	MC32893	MC36256	MC36292	MC36281	AD0405MB-C50	MB50100V2-0000-A99	2510S
Manufacturer	Multicomp	Multicomp	Multicomp	Multicomp	ADDA	Sunon	ACE
Unit price	$3.21	$3.97	$2.41	$3.19	$7.09	$6.28	$1.91
Voltage rating	12 VDC	5 VDC	5 VDC	5 VDC	5 VDC	5 VDC	5 VDC
Current rating	145 mA	205 mA	235 mA	180 mA	160 mA	235 mA	120 mA
2 in series?	No	Yes	No	No	Yes	No	Yes
2 in parallel?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3 in series?	X	Yes	X	X	Yes	X	Yes
3 in parallel?	X	Yes	X	X	Yes	X	Yes
Distributor	Newark	Newark	Newark	Newark	Newark	Newark	Amazon

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The selected fans were modified by painting one blade white to improve the visibility of fan speed, and alligator clips were soldered to the wires of each fan in order to simplify circuit construction. A variety of disciplines use different symbols for a fan. For example, some use a motor or inductor symbol, while others use a more realistic image of a fan. A three-blade symbol was chosen to represent a simple pictorial representation of a fan, which can be drawn relatively easily or represented graphically in circuit diagrams as shown in Figs. 1 and 2.

As with bulbs, choosing an appropriate voltage value for the power supply is equally important for fans. If the voltage is not chosen correctly, bulbs may either burn out entirely or not emit any visible light as a result of insufficient current. For fans, however, an appropriate voltage must be high enough for all of the fans to "self-start" without an external push, but not high enough to burn the fans out. The selected E fans required an applied voltage drop of ~1.5 V per fan in order to allow a self-start, while they were observed to burn out if ~8.0 V per fan was applied. The power supply was set to 7.5 V when demonstrating series and parallel circuits with a maximum of four fans. This voltage is advantageous as it can be supplied by five D cell batteries and does not run against the current output limitation of most power supplies. The same 7.5 V or lower voltage can also be used in combination circuits, as the voltage required may vary depending on the desired learning objectives and which senses the students are using to make their observations.

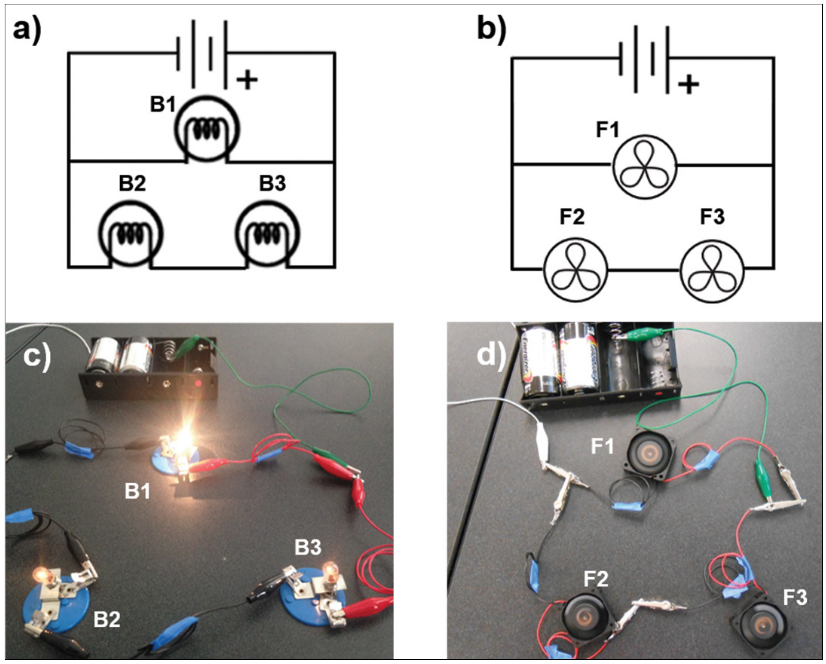

Fig. 1. Circuit diagrams for a combination bulb (a) and fan (b) circuits of two in series with one in parallel, as well as pictures of wired bulb (c) and fan (d) circuits. See a video of the fan experiment at *TPT Online* at http://dx.doi.org/10.1119/1.4972490_1.

Learning with fans in the introductory laboratory

The design of our tutorial-style fan experiments follows the same structure and questioning as our previous bulb experiments with updated circuit diagrams and language, allowing for multiple sensory observations. Students engage the content over multiple lab sessions while recording their observations in experiment-specific handouts. This provided opportunities for students to observe the fan behavior in various circuits using multiple senses. In addition to experiments, students complete a variety of conceptual questions in laboratory, lecture, and other course-related work. Some conceptual questions involving bulbs were retained, allowing students to engage in both fan and light bulb questions to help generalize their models.

Figure 1 shows the combination circuit diagram of two in series with one in parallel for bulbs (a) and for fans (b). Pictures involving the behavior of each circuit are also shown in (c) and (d) of Fig. 1 for bulbs and fans, respectively. All pictures were taken with a Nikon Coolpix s4300 at a shutter speed of ~1 ms. The expected behavior for this configuration would be that the speed of the two fans in series, F2 and F3, would be equal but less than that of F1, suggesting that the fan speed is indeed related to the current. Each of these fans has only one blade painted white, which allows for the fan speeds to be shown in Fig. 1(d). A white "arc" is clearly depicted on the blades of fans F2 and F3. These arcs are roughly the same length, which suggests that their speeds are comparable. Fan F1, however, is moving so fast that there is no visable arc; instead there is a complete white circle. These observations suggest that the current through F1 is larger than that of F2 and F3, and that F2 and F3 have similar currents. This result is identical for the same circuit that is wired with bulbs, where B2 and B3 should appear to be the same brightness but lower than B1 [Fig. 1(c)].

Figure 2 shows the combination circuit diagram of two in parallel with one in series that includes the same designations as Fig. 1 for both light bulb and fan circuits.[11] Here ~4.5 V is supplied by three D cell batteries. The fan circuit demonstrates the expected result rather well. It portrays F1 moving quickly as it has all the current moving through it, whereas F2 and F3 are each spinning slower as the current is split between them. With the bulbs, on the other hand, B1 shines brightly while the brightness of B2 and B3 is impossible to discern. This discrepancy of current flowing through the bulbs without shining, in a way, defeats the purpose of using a bulb pedagogical model.

In practice, the students were able to discern the differences among fans quite easily. They described that any initial doubt they may have had from a visual comparison of the fan blades alone was quickly put to rest after they also felt and heard the differences. This was especially true for the case of

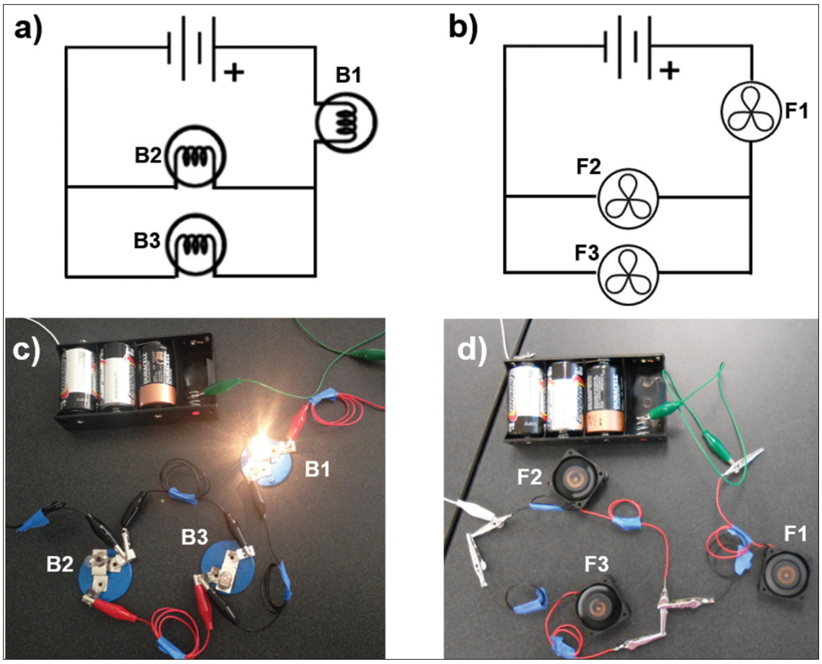

Fig. 2. Circuit diagrams for a combination bulb (a) and fan (b) circuits of two in parallel with one in series, as well as pictures of wired bulb (c) and fan (d) circuits. See a video of the fan experiment at *TPT Online* at http://dx.doi.org/10.1119/1.4972490_2.

one to four fans in series. A variety of other configurations involving three and four fan circuits with switches were also tested and no configuration was found that failed to yield the expected results. Wiring a switch into the circuit allowed another visualization of the speed of the fan. The faster the fan spins, the longer it takes the fan to stop, which adds one more observation that suggests a larger current in the fan during operation. These observations indicate fans might be a superior approach to teaching simple circuits in comparison to bulbs.

Limitations of fans and bulbs

As with bulbs, there are limitations when using computer fans to demonstrate simple circuits. If fans are used at low voltages, the back EMF produced by any changing current may prevent the fans from "self-starting," which requires an external push to get them moving. However, once the fans are in motion, they maintain a consistent and reproducible rate. If excessive (not damaging) voltage is used, the speeds become difficult to discern by the eye alone, although sound and touch remain valid indicators. Furthermore, due to the internal resistance of the batteries and current limited operation of lower end power supplies, the fans may spin slower than predicted as more elements are added to the circuit in parallel. Finally, all fans in the circuit must be the same model, and adequate voltages must be supplied for uniform fan speeds to be achieved. Notably, most of the fan limitations are shared by bulbs as well. As fans are adopted as a pedagogical model of simple circuits, it is expected that the limitations of fans will be overcome as they were for bulbs. These limitations for fans are still not quite as limiting as those found with bulbs, specifically the temperature-dependent resistance of the bulbs.

Extensions and conclusion

Fans have successfully been used to demonstrate concepts of simple resistive combination circuits that are typically investigated using incandescent light bulbs. The ability to make comparisons between fans through the use of multiple senses is a significant improvement from the sensory limitations when comparing the brightness of bulbs. Furthermore, preliminary measurements of current and voltage in circuits have indicated that quantitative comparisons are possible, and that fans have a relatively constant resistance even though they are not simple resistors. This result encourages us to find a fan with a significantly different "resistance," which would allow for comparisons of circuits with different resistances. It may also be possible to use fans with other circuit elements such as RC circuits. Ultimately, small 5-V computer fans are widely accessible, affordable, and easy to use. These qualities make them an ideal replacement for traditional incandescent light bulbs while at the same time keeping alive the pedagogical spirit that makes bulbs so successful.

References

1. James Evans, "Teaching electricity with batteries and bulbs," *Phys. Teach.* **16**, 15–22 (Jan. 1978).
2. Lillian C. McDermott and Peter S. Shaffer, "Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding," *Am. J. Phys*. **60**, 994–1003 (Nov. 1992).
3. Peter S. Shaffer and Lillian C. McDermott, "Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies," *Am. J. Phys.* **60**, 1003–1013 (Nov. 1992).
4. Dan MacIsaac, Gary Kanner, and Graydon Anderson, "Basic physics of the incandescent lamp (lightbulb)," *Phys. Teach.* **37**, 520–525 (Dec. 1999).
5. Jianhong Shen, "On the foundations of vision modeling I. Weber's law and Weberized TV (total variation) restoration," *Physica D: Nonlinear Phenomena* **175** (3/4), 241–251 (2003).
6. "The Energy Independence and Security Act of 2007," Public Law 110-140 (Dec. 2007), https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm.
7. Dean Livelybrooks, "Feel the difference between series and parallel circuits," *Phys. Teach.* **41**, 102–103 (Feb. 2003).
8. Hans Pfister, "Illustrating electric circuit concepts with the glitter circuit," *Phys. Teach.* **42**, 359–363 (Sept. 2004).
9. Newark Element14 Product Information (2015), http://www.newark.com/, accessed Oct. 13, 2015.
10. Amazon.com, Inc., http://www.amazon.com.

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