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Motors and bulbs in series

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One of Paul Hewitt's "Figuring Physics" that appeared in this journal dealt with the heating of a motor.[1] This phenomenon can be demonstrated with a miniature motor and a bulb as part of a series of activities with "batteries and bulbs."[2] Students examine the effect on the brightness of a single bulb[3] when a second, identical bulb is placed in series with it (Fig. 1). The second bulb is then replaced with the motor[4] (Fig. 2). When the motor is running,[5] the first bulb is dimmer than it was in series with the other bulb. However, if the shaft of the motor is held so it cannot move (like Hewitt's saw motor), the bulb is noticeably brighter. If one uses the brightness of the bulb as a qualitative measure of current, then there is clearly more current when the motor is not moving. This provides an opportunity to introduce some very interesting physics.

The motor consists of a multi-turn coil that rotates in a fairly uniform magnetic field. It has an internal resistance r, and when it is turning, a back-emf ε_b is induced as the turns of the coil move through the magnetic field.[6] The magnitude of the back-emf is proportional to the motor's angular speed; its direction is opposed to that of the external dc source (battery or power supply) V. The circuit with a bulb (resistance R) in series with the motor may be drawn[7] schematically as shown in Fig. 3. If the shaft of the motor is held motionless, the back-emf vanishes and so the current I flowing in the circuit increases. This results in the bulb glowing more brightly and in more power being dissipated in the internal resistance of the motor.

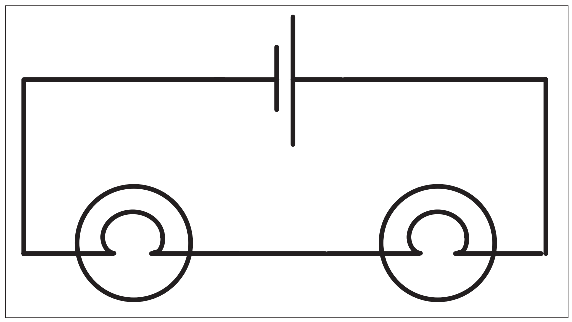

Fig. 1. Two identical bulbs in series.

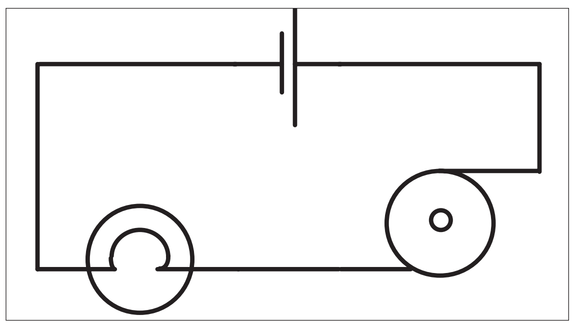

Fig. 2. One bulb in series with a miniature motor.

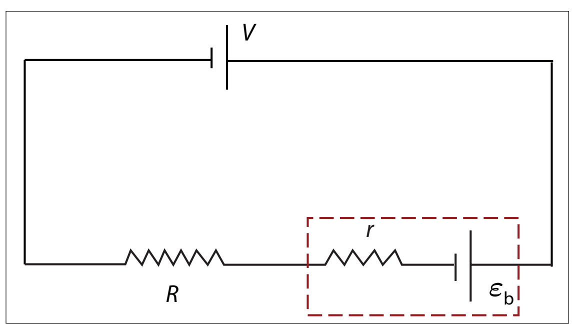

Fig. 3. Schematic of one bulb in series with motor.

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It is possible to do this simple demonstration in a more quantitative way using an ammeter and voltmeter. For example, we typically find that with the motor turning, the potential difference across the motor is around 0.8 V, and the current in the circuit is approximately 0.06 A. When the shaft is kept from turning, the voltage across the motor drops to about 0.2 V and the current increases to around 0.07 A. Of course, this experiment is complicated by the fact that the resistance of the bulb increases with current.[8-10] This could be avoided by replacing the bulb (after the qualitative demonstration has been done) with a fixed resistor having about the same resistance (≈ 40 Ω).

This experiment may be performed using very simple apparatus. Its analysis may be extended with greater sophistication for more advanced students. It also allows the comparison of the effect of a small motor in a "simple" circuit with that of Hewitt's large saw motor.

References

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2. See, for example, James Evans, "Teaching electricity with batteries and bulbs," *Phys. Teach.* **16,** 15–22 (Jan. 1978); Arnold Arons, *The Various Language: An Inquiry Approach to the Physical Sciences* (Oxford, New York, 1977), pp. 129–143; Lillian C. McDermott and the Physics Education Group, University of Washington, *Physics By Inquiry: An Introduction to Physics and the Physical Sciences, Vol. II* (Wiley, New York, 1996), pp. 383–517; Robert J. Whitaker, *An Inquiry Into Physics* (Kendall-Hunt, Dubuque, IA, 1995; 1998), pp. III.3–III.56.
3. We use #48 bulbs (Delta Education, Cat. No. 560-020-5864) in the demonstration.
4. Motors from PSSC ticker-tape timers were used.
5. Two (fairly) fresh "D" cell batteries in series are used to power each circuit.
6. Hugh D. Young and Roger A. Freeman, *University Physics*, 9th ed. (Addison-Wesley, 1996), pp. 888–890.
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