# THE CHARACTERISTICS OF A SOURCE OF EMF

Object: To illustrate the behavior of a typical seat of electromotive force, emf, with respect to: (a) the dependence of terminal voltage on internal resistance and current (b) the condition for maximum power output.

Apparatus: Seat of emf with internal resistance (a 3v battery with an "internal" resistor of 30 to 40 ohms), external load consisting of a dial-box resistor (1-10,000 ohms), 100 milliampere meter, 5v voltmeter momentary contact switch, and 6 leads.

Theory: The internal resistance of a good storage cell is too low to illustrate the point of this experiment. Hence it is necessary to connect a resistance in series with the battery to make a "battery" with a higher internal resistance. The circuit diagram shows the effective battery B joined through a switch, S to the variable, resistive load, R. A and V are a low-resistance ammeter and a high-resistance voltmeter. E and r represent the emf and internal resistance, respectively, of the battery. (The analysis will apply equally well to a D.C. generator.)
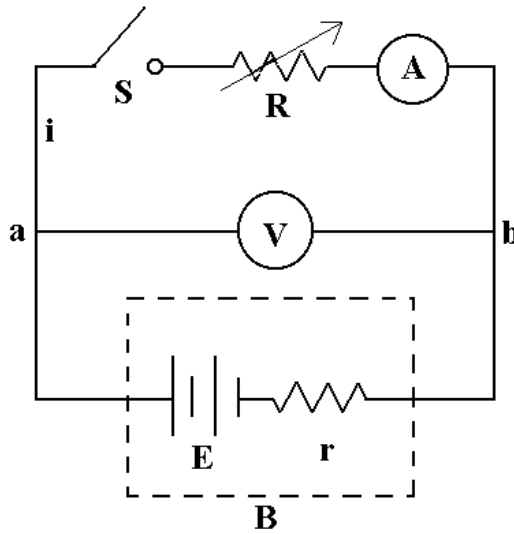
Let i be the current read on A, and let V be the voltage or terminal potential difference of the battery read on V. Note that V is also the potential difference across the external load, the resistance of R and A combined. Let P be the power in units of watts delivered by the battery to the external load. The fundamental relations for the circuit are then:

$$i = E / (R + r) \tag{1}$$

Where, the current through the voltmeter has been treated as negligible,

$$V = E - ir = i\,R \tag{2}$$

Where, the resistance of the ammeter has been treated as negligible, and

$$P = i\,V = i^2 R. \tag{3}$$

Be sure you <u>understand</u> these relations. Ask questions. As a rule, the emf E and the internal resistance r of a generator are considered to be constant.

By using Eq. (1) in Eq. (3), you may show that

$$P = E^2 R / (R + r)^2. \tag{4}$$

Note that P approaches zero both for very small and for very large values of load resistance R. Hence the power delivered will be a maximum for some intermediate load resistance. To find the value of R which results in maximum power, one differentiates Eq. (4) with respect to R and equates the derivative to zero. The solution of this relation yields

$$R = r, \text{ for P at maximum.} \tag{5}$$

Under these conditions, the load is said to be "matched" to the seat of emf.

Although P is now a maximum, the power (i^2r) dissipated in the battery or generator is as great as the power (i^2R) delivered to the load. Hence this arrangement is not ordinarily used with batteries or generators. This principle is however of fundamental importance in many circuit applications, as in "matching" speakers to audio amplifiers.

<u>**Procedure:**</u> Connect the circuit components, except for one battery lead; see that all contacts are firm. <u>After the circuit has been checked by the instructor</u>, set R to about 300 ohms and close S. Tabulate the readings of A and V and P for a series of decreasing values of R including a column for P. By computing P as you proceed, the changes in R may be made in suitable steps. These should be large at first (100 or 200 ohms) but much smaller (5or 10 ohms) as R approaches r in value. You should change R only 1 or 2 ohms at a step in the vicinity of P_{max}.

<u>**Report:**</u> Plot the following graphs, each on a full sheet.

1) V as a function of i.
2) P as a function of R for values of R up to 100 ohms.

Data: **(Example for r =39 ohms)**

Resistance (ohms)	I	V	Power P= IV
300			
200			
100			
90			
80			
70			
60			
50			
48			
46			
44			
42			
41			
40			
39			
38			
37			
36			
35			
34			
33			

Problems:

1) Show that Eq. (4) follows from Eq. (1) and (3), and that Eq. (4) with Eq. (5) gives $P_{max} = E^2/4r$.

2) Determine the experimental values for E and r using the data from the first graph and equation (2). From the second graph, read P_{max} and compare with $E^2/4r$. Read R for P_{max} and compare with r.

3) Show that at maximum power output, the terminal voltage of the battery is half its emf.

Questions:

1) Why is a dead battery characterized by a high internal resistance?

2) Explain why batteries of low current capacity have higher internal resistances than those batteries of high current capacity, e.g., a 12 v flashlight battery vs. a 12 v car battery.