ELECTROMOTIVE FORCE

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References: Griffiths, David J. (2007), Introduction to Electrodynamics, 3rd Edition; Pearson Education - Problem 7.5.

The *electromotive force* $\mathscr{E}$ (abbreviated emf) is the voltage produced by a source of electric field, such as a battery or, as we'll see in a few posts, a time-varying magnetic field. Although it is called a 'force' it actually has the dimensions of energy as it is defined as

$$\mathscr{E}=\oint\mathbf{f}\cdot d\ell \tag{0.1}$$

where $\mathbf{f}$ is the total force per unit charge and the integral is taken around a closed loop (typically an electric circuit). The force can be produced by a variety of things, such as chemical reactions (as in most household batteries), solar power, etc. Any real battery has an internal resistance which detracts from the effective voltage the battery can deliver. If this resistance is r, then the net emf is $\mathscr{E}-Ir$ where as usual I is the current flowing through the circuit.

Suppose a battery with a constant emf and internal resistance is placed in a circuit with a variable resistor R. The maximum power that can be delivered by varying R can be found as follows. The voltage across R is $\mathscr{E}-Ir=IR$ (from Ohm's law), and the power delivered to R is $P=I^{2}R$, so

$$\begin{aligned}
I &= \frac{\mathscr{E}}{r+R} && (0.2)\\
P &= \frac{\mathscr{E}^{2}R}{(r+R)^{2}} && (0.3)\\
\frac{dP}{dR} &= \mathscr{E}^{2}\left[\frac{1}{(r+R)^{2}}-\frac{2R}{(r+R)^{3}}\right]=0 && (0.4)\\
1 &= \frac{2R}{r+R} && (0.5)\\
R &= r && (0.6)
\end{aligned}$$

Thus the maximum power is delivered when the resistance in the circuit is equal to the battery's internal resistance.

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