Voltage Sources*

Object

To measure the emfs and the internal resistances of given chemical cells.

Theory

The emf of a cell is difficult to measure because a voltmeter connected across it will always draw some current. This current produces a potential drop across the internal resistance of the cell. As a result, the voltmeter reading becomes less than the emf. A spent cell has an increased internal resistance which lowers its voltage as measured by a voltmeter. However, the emf should never change as it is a property peculiar to the chemical reaction producing it.

Let us consider a cell of emf $\mathcal{E}$ and internal resistance r connected to a voltmeter of internal resistance R as shown below. Let the the voltmeter reading be V.

If i is the current in the loop, then Kirchhoff's loop rule gives

$$\mathcal{E} - ir - iR = 0.$$

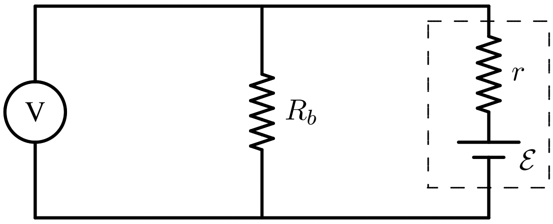
The voltage across the cell, as measured by the voltmeter can be written as

$$V = \mathcal{E} - ir.$$

Eliminating i from these two equations, we get

$$r = \frac{(\mathcal{E} - V)R}{V}. \tag{1}$$

The measured voltage V and the internal resistance of the voltmeter are known quantities. That still leaves r and $\mathcal{E}$ as unknowns in this equation. To find them, we need another equation. This we can do by connecting a known resistance R_b in parallel to the voltmeter as shown below.



This lowers the effective voltmeter resistance to the parallel combination of R and R_b:

$$R_1 = \frac{RR_b}{R + R_b}. \tag{2}$$

As a result the voltmeter reading will change. Let the new voltmeter reading be V_1. So, in equation 1, we can replace R by R_1 and V by V_1 to get

$$r = \frac{(\mathcal{E} - V_1)R_1}{V_1}. \tag{3}$$

Now, we can eliminate r between equations 1 and 3 to get

$$\mathcal{E} = \frac{R - R_1}{R/V - R_1/V_1}. \tag{4}$$

This allows us to compute the emf $\mathcal{E}$ of the cell from measured quantities. We can use this computed emf in equation 1 or 3 to find r.

The measurement method

Connect the voltmeter directly across a cell to measure its voltage V. Read the internal resistance R of the voltmeter stamped on its face. Then, connect a resistance box in parallel to the voltmeter. Start with a high resistance R_b for the resistance box. Then lower R_b until the voltmeter reading is significantly less than V (maybe about half of V). Measure this voltage V_1. Compute R_1 using equation 2. Then compute $\mathcal{E}$ from equation 4 and r from equation 1 or 3. We shall call these the *measured* values of $\mathcal{E}$ and r.

Some trials

Make the above measurements for two separate cells (say $\mathcal{E}$ and r for the first cell and $\mathcal{E}'$ and r' for the second cell).

Combine the two tested cells in parallel and measure the emf $\mathcal{E}_p$ and internal resistance r_p of the combination. Compute $\mathcal{E}_p$ and r_p theoretically from the known values of $\mathcal{E}$, $\mathcal{E}'$, r and r'. Compare these theoretical values to the measured values.

Combine the two tested cells in series and measure the emf $\mathcal{E}_s$ and internal resistance r_s of the combination. Compute $\mathcal{E}_s$ and r_s theoretically from the known values of $\mathcal{E}$, $\mathcal{E}'$, r and r'. Compare these theoretical values to the measured values. For this case, you may have to change the voltmeter if $\mathcal{E}_s$ is too large for the original voltmeter scale.