METHANE FUEL CELL

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Reference: Daniel V. Schroeder, *An Introduction to Thermal Physics*, (Addison-Wesley, 2000) - Problem 5.5.

As another example of a fuel cell, suppose we burn methane in oxygen according to the reaction

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2 \tag{0.1}$$

The Gibbs free energyΔG and enthalpyΔH changes for this reaction can be obtained from the ΔG and ΔH values in Schroeder's book (all values for 1 mole at 298 K and 1 bar). As the reaction occurs at room temperature and pressure, we'll assume that the water product appears as a liquid rather than as a gas.

	ΔG (kJ)	ΔH (kJ)
CH_4	-50.72	-74.81
O_2	0	0
H_2O	-237.13	-285.83
CO_2	-394.36	-393.51

The ΔG for the reaction is the sum of the values for the products minus the sum for the reactants:

$$\Delta G = (-394.36 - 2\times 237.13) - (2\times 0 - 50.72) = -817.9 \text{ kJ mol}^{-1} \tag{0.2}$$

The value is per mole of methane molecules.

A negative ΔG means that the energy of the products is lower than that of the reactants, so the tendency is for the reaction to 'run downhill', that is, it will occur spontaneously in the direction shown.

The corresponding ΔH is found the same way:

$$\Delta H = (-393.51 - 2\times 285.83) - (2\times 0 - 74.81) = -890.36 \text{ kJ mol}^{-1} \tag{0.3}$$

The Gibbs energy represents the maximum energy that may be extracted as 'other' (that is, not due to volume changes) work, in this case electrical work. Thus we may extract up to 817.9 kJ of electric work per mole of methane burned.

As the reaction occurs at constant pressure, ΔH represents the *total* energy difference between the reactants and products. Since the enthalpy drop is greater than the amount of electrical work extracted, the excess is discarded as heat. The amount of heat is

$$Q = 890.36 - 817.9 = 72.46 \text{ kJ mol}^{-1} \tag{0.4}$$

The overall reaction occurs in two phases, one at each electrode. At the negative electrode we have

$$\mathrm{CH_4} + 2\mathrm{H_2O} \rightarrow \mathrm{CO_2} + 8\mathrm{H}^+ + 8e^- \tag{0.5}$$

At the positive electrode, we have

$$2\mathrm{O_2} + 8\mathrm{H}^+ + 8e^- \rightarrow 4\mathrm{H_2O} \tag{0.6}$$

As 8 electrons are pushed around the circuit for each methane molecule, the energy ΔG is distributed over 8 moles of electrons, so the energy per electron is

$$E = \frac{|\Delta G|}{8 \times 6.02 \times 10^{23}} = \frac{817.9 \times 10^3}{8 \times 6.02 \times 10^{23}} = 1.70 \times 10^{-19} \text{ J} = 1.06 \text{ eV} \tag{0.7}$$

Thus the voltage of the fuel cell is 1.06 volts.