# Solar cell theory: some general implications for physics

P.T. Landsberg[1] and T. Markvart[2]
[1]Faculty of Mathematical Studies
[2]School of Engineering Sciences
University of Southampton, Southampton, UK

Solar cell theory can teach us some things about thermodynamics and statistical mechanics with the added advantage that one knows that the systems studies are of importance. Here we develop this theme by using two examples from the literature.

Example 1

Starting with thermodynamics, the Carnot efficiency refers of course to reversible processes which conserve the entropy. Its use in solar cell theory has been discussed extensively. The more detailed insight provided by statistical mechanics has also been noted. Thus it was shown [for example by the present authors and also Badescu] how the Carnot factor can be extracted from more realistic results. This is a useful exercise, and teaches us about statistical thermodynamics, since the Carnot factor is readily lost, for example, if several sources of radiation act simultaneously or if the solar cell sees the sun only for a fraction of the available solid angle.

There are many other instances which illuminate the use of thermodynamics and statistical mechanics in solar cell work, notably in connection with the discussion of heterojunctions and impact ionisation (see the works of, for example, Brendel and Werner)

Example 2

Another contribution to statistical thermodynamics arising from solar cell studies comes from aspects of mass action law and its possible generalisations. Mass action is well known to fail for degenerate semiconductors as the appropriate concentration products can then depend on the electron and hole concentrations (or both) instead of being constants.

Turning to the transport equations for heat conduction and diffusion, they are part of both semiconductor theory and irreversible thermodynamics. In solar cells they enter the theory via the matrix of Onsager coefficients [see recent work by the present authors]

$$\begin{pmatrix} -I \\ I_{qin} \end{pmatrix} = \begin{pmatrix} L_{pp} & L_{pq} \\ L_{qp} & L_{qq} \end{pmatrix} \begin{pmatrix} \Delta\mu / T \\ \Delta\left(\frac{1}{T}\right) \end{pmatrix}$$

where

$$\Delta\left(\frac{1}{T}\right) = \frac{1}{T} - \frac{1}{T_S}$$

Here T is the ambient temperature and Ts is typically the temperature of the solar radiation. Thus, $\Delta\mu/T$ and $\Delta(1/T)$ are the generalised 'forces' corresponding to the flows.

There are important differences in magnitude between the quantities required here and those which occur normally. Ts is ~6000K compared with a room temperature of only 300K. Solar energies are of the order of 0.5eV compared with ambient thermal energies of only 25 meV. How can these comparatively large quantities be accommodated in extended (non-linear) irreversible thermodynamics ?

It is this question which is of interest and has been raised in our recent paper. While it may not have a unique answer, it is worth considering further.