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COMMENTARY

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This commentary is on the concept used by Ding and Luo (2013) to measure the rate of entropy production in normal cell and cancerous cell lines under an alternating electric field. The authors placed the 96-well plate containing the cells (incubated for 60 min in an incubator at 37°C) in the electric field for 300 s and recorded the change of temperature of cells and culture medium \( T_J(t) (t = 0-300\text{ s}) \) with a transducer. The control group was placed in the same apparatus without electric field, and the change of temperature \( T_C(t) \) was also recorded. The heat transfer rates of \( Q_C \) and \( Q_F \) without and with alternating electric fields (AEFs), respectively, from the cell to outward are calculated from Fourier’s law of heat conduction. The contribution of heat transfer from the medium was obtained and subtracted to determine the net heat transfer with or without (AEFs) from the cell only. The entropy change of a cell with or without AEFs is expressed by the entropy balance:

\[
\Delta S = d_e S + d_i S = \dot{Q}_i / T + \sigma
\]

which shows that the rate of change of entropy per unit volume of substance is due to the entropy flow and the entropy production \( \sigma \), which is positive for irreversible internal phenomena. The \( (d_e S/dt) \) denotes the boundary phenomenon. Entropy production inside an elementary volume by irreversible phenomena is the local values of the sum of entropy productions represented by:

\[
\sigma = \sum_i f_i X_i
\]

where \( f_i \) is the flow and \( X_i \) is the thermodynamic force. The total rate of entropy production is due to heat flow, mass flow, viscous stress, electrical effect, chemical reactions, and any other external field effect (Luo, 2009; Demirel, 2014). The difference of the entropy changes of the cells is:

\[
\Delta S_F - \Delta S_C = (d_e S_F - d_e S_C) + (d_i S_F - d_i S_C)
\]

in which the net entropy production is expressed by:

\[
\Delta \sigma = (d_i S_F - d_i S_C)
\]

The difference of entropy flows are obtained by the heat flow measurements. The authors arbitrarily assumed that the net rate of entropy production is related the entropy flow difference by:

\[
\Delta \sigma = k(d_e S_C - d_e S_F)
\]

where \( k \) is assumed as a constant \((k > 1) \) and independent of AEF strength; the value of \( 1/k \) represents the fraction of field-induced entropy production in a cell which is transferred as entropy flow from the cell. This is confusing because the entropy flow arbitrarily became the heat dissipation because of the entropy produced in the cells and the entropy flows are related total entropy changes for the two types of cell by:

\[
\begin{align*}
\frac{[\Delta S_F - \Delta S_C\text{\{cancer\}}]}{[\Delta S_F - \Delta S_C\text{\{normal\}}]}
&= \frac{[(1 + k)(d_e S_F - d_e S_C)\text{\{cancer\}}]}{[(1 + k)(d_e S_F - d_e S_C)\text{\{normal\}}]}\frac{\text{\{cancer\}}}{\text{\{normal\}}}
\end{align*}
\]

The authors stated that, if the values of \( k \) are the same in cancer and normal cells, the ratio above is the “electro-induced” entropy production ratio (EEPR) and it is assumed that the measured entropy difference \( \Delta S_F - \Delta S_C \) is equal to \((d_e S_F - d_e S_C)\). This ratio does not affect the fact that entropy difference \( \Delta S = \Delta S(V, T) \) (state variable) still depends on two process variables, entropy flow and entropy production. Moreover, the “fraction” of field-induced entropy production \((1/k)\) in the form of entropy flows would not be the same in the two types of cells. This is because the transported entropy flow is the “waste heat” representing the part of free energy of the cell that is not converted to useful work and

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would not be equal in normal and cancerous cells because of different types of metabolisms used based on different types of information processing by these cells (Demirel, 2010). The authors are measuring the ratio of the two entropy flows represented by:

\[
\frac{(d_e S_F - d_e S_C)(\text{cancer})}{(d_e S_F - d_e S_C)(\text{normal})}
\] (3)

and this can be referred to as the electroinduced entropy flows ratio. It would be the entropy production ratio at the stationary state for individual cells, for which:

\[
d_e S/dt = -d_i S/dt = -\sigma < 0
\]

so that the entropy produced by the external field within the cells must be discharged (transported) fully across the boundary by the entropy flows, and hence there is no need to introduce "k".

References


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