The Future of Electrochemistry

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The birth of modern electrochemistry is usually linked to the discovery of “animal electricity”—the movement of muscles in a frog’s leg induced by charge—by Luigi Galvani in the late 1700’s. Very shortly thereafter, corresponding studies by Alessandro Volta demonstrated that the “animal electric fluid” described by Galvani is, in fact, just one example of a conducting electrolyte and that the elemental nature of the metallic electrodes in contact with the electrolyte is of first order importance in determining the electrochemical response. These twin concepts, of a metallic electrode and an electrolyte, laid the foundations for all subsequent electrochemical science. However, the road from “animal electricity” to “green energy” has been long and full of uncertainty, even for such seemingly simple systems such as the production of hydrogen and oxygen in electrolyzers or the reaction between hydrogen and oxygen to produce water and electrons in Grove’s “gas voltaic battery” that today is known as the fuel cell. A new era began by establishing relationships between interfacial properties and rates of electrochemical reactions, as described first by Frumkin’s school and later developed by Gerisher, Parsons, Bockris, Yeager, and many others. As this work matured it found a myriad of application in analytical, synthetic and materials chemistry and, in particular, in the field of energy conversion and energy storage.

The development of atomic and molecular-level understanding of solid-liquid interfaces in aqueous electrolytes has resulted a revolution in the field of electrochemistry, enabling the design of interfaces tailored to the efficient making and breaking of specific chemical bonds, as well as providing insight into the redistribution of electrons that are associated with these transformations. This knowledge is already employed to power commercial devices, such as Toyota’s MIRAI FCEV or Tesla’s EV, as well as to drive the industrial-scale production of chemicals (e.g. ammonia, chlorine) and electrochemical fuels (e.g. hydrogen).

In some respects, electrochemistry is in a more robust state of health at the present time than ever before. In the near future it would be highly desirable to develop new experimental and computational methods that can rationalize, resolve, and ultimately understand the complex nature of electrochemical interfaces. Of particular importance is developing deep insights into the stability of the electrochemical interface in order to establish functional links between activity, stability, and selectivity at atomic and molecular levels. Such knowledge will allow for the development of guiding principles for the design of new, cost-effective cathode and anode materials for both fuel cells and batteries. Developing these insights will require us to overcome the large gap in understanding of surface electrochemistry in aqueous vs. organic environments. Links between these two artificially divided systems will define a new landscape of parameters that govern interfacial vs. bulk properties that guide materials synthesis, ion intercalation, interphase formation, electrode corrosion, electrolyte decomposition, etc. The development of in situ methods for exploring interfaces in organic environments will quickly be followed by exploring new chemistries that will ultimately determine the future of energy storage systems. Overall then, there are persuasive reasons to anticipate that electrochemistry will continue to expand rapidly into a discipline that is even more integrated across fields such as chemistry, physics and biology.

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