Subject:
The electric potential gradient in a zero-current pn junction is the cause of a "field current". The field current is compensated by the "diffusion current". The diffusion current flows in the opposite direction and is a consequence of the concentration gradient of the charge carriers.

Deficiencies:
When in a conducting material an electric potential gradient exists and the chemical potential has the same value everywhere, there is a current of charge carriers. The charge carriers are "driven" by the electric potential gradient. An electric current will also flow when there is a chemical potential gradient (caused for instance by a concentration gradient) and the electric potential has the same value everywhere. In this case the "driving force" of the charge carriers is the chemical potential gradient. Thus, there are two possibilities to "pull at the particles": the electric potential gradient pulls at the quantity \( Q \), i.e. the electric charge, whereas the chemical potential gradient pulls at the quantity \( n \), i.e. the amount of substance.

In general, both gradients are different from zero and the resulting driving force is due to both gradients. It can be described by means of the electrochemical potential \( \eta \). The electrochemical potential is essentially the sum of the electric potential \( \phi \) and the chemical potential \( \mu \):

\[
\eta = \mu + z \cdot F \cdot \phi.
\]

Then for the electric current density we get:

\[
\vec{j} = -\frac{\sigma}{zF} \text{grad}\eta.
\]

\( \sigma \) is the electric conductivity, \( z \) the number of elementary charges of each charge carrier and \( F \) the Faraday constant.

It is possible that the gradient of the electrochemical potential is zero. That means that both driving forces are equal and opposite and thus compensate each another. In this case there is no electric current. We have "electrochemical equilibrium".

Now, instead of saying, that a particle current can be driven in two ways, or that there are two "driving forces", it is often said that the electric potential gradient causes a "field current" and the chemical potential gradient causes a "diffusion current", and that both of these currents superpose to the total current. Then, in the case of the electrochemical equilibrium we would have two currents of the same magnitude flowing in opposite directions.

The problem with this interpretation is that each of these currents separately should produce entropy (and thereby heat). But we know that the total current is dissipationfree. There is no entropy production. And how are we supposed to imagine this situation on the microscopic scale: Should we believe that some of the charge carriers comply with the electric potential gradient and others with the concentration gradient? If we consider an arbitrarily chosen charge carrier: to which current does it belong?
That this description is inconvenient can also be seen by comparing the situation with a similar one, in which nobody would make a decomposition in opposite currents. Consider the air of the atmosphere. It is also subject to two driving forces: The gradient of the gravitational potential pulls the air molecules downward, the pressure gradient pulls them upward. When the air is motionless and the temperature uniform both driving forces are equal and opposite, they compensate each another. Why do we not say in this case that there is a field current downward and a diffusion current upward?

**Origin:**

Probably several causes add up: 1. The simple and powerful tool "chemical potential", although introduced in physics more than a hundred years ago, is today nearly unknown and scarcely used. 2. The electrochemical potential is not taken seriously as a physical quantity.

**Disposal:**

There are two driving forces for charge carriers: an electric driving force that pulls at the electric charge and a chemical driving force that pulls at the amount of substance. Since the electric charge and the amount of substance are tightly coupled both potentials can be combined to one single potential, the electrochemical potential. The gradient of the electrochemical potential is responsible for the particle current.

_Friedrich Herrmann and Peter Würfel, Karlsruhe Institute of Technology_