Using L-type calcium channel, we’ll see how Goldman–Hodgkin–Katz flux equation can be implemented in MOOSE. This will also serve as a guide to using HHChannel2D.

L-type calcium channel has two gates in which one is entirely membrane potential dependent and other is an instantaneous gate which depends on internal calcium concentration. The channel also uses ghk flux equation instead of the quasi-ohmic equation to model its driving force.

MOOSE currently does not have an in-built class to implement ghk. We’ll use HHChannel2D class for this since the ghk equation has both v and ca as parameters.

HHChannel2D is similar to HHChannel class which is generally used to model channel kinetics in MOOSE. The parameters that are to be filled are:

* Ek. This is the reversal potential of calcium. As we’ll be using ghk, any value can be filled here. We’ll use 0.140
* Xpower = 2
* Ypower = 0
* Zpower = 1

As ghk as well as the calcium dependent gate does not involve any differential equations to be solved, we’ll use an instant flag and combine ghk and ca dependent gate into one.

* Xindex = 'VOLT\_INDEX'
* Yindex is not filled
* Zindex = 'VOLT\_C1\_INDEX'. This tells the solver that the tableA and tableB that we’ll set up will have voltage dependence along columns and concentration dependence along the rows.

For other channels, Xindex, Yindex, and Zindex can take the following values:

VOLT\_INDEX, C1\_INDEX, C2\_INDEX, VOLT\_C1\_INDEX, VOLT\_C2\_INDEX, and C1\_C2\_INDEX

The first term tells the solver what the vertical axis of tables depends on and the second term tells the solver what the horizontal axis depends on. VOLT refers to membrane potential. C1 and C2 to any conc that is input in concen and concen2 fields respectively.

* instant = 4. This will tell the solver to set the value of the Z gate to A/B directly.

HHChannel2D automatically sets HHGate2D gates inside its path. HHGate2D gates take the following values for L-type calcium channel:

* xminA
  + For Xgate, it’s the minimum membrane potential we expect in the model (As we’ve used ‘VOLT\_INDEX’). We use -0.100V. (for tableA)
  + For Z gate, it’s the minimum membrane potential we expect in the model (As we’ve used ‘VOLT\_C1\_INDEX’). We use -0.100V. (for tableA)
* xmaxA
  + For Xgate, it’s the maximum membrane potential we expect in the model (As we’ve used ‘VOLT\_INDEX’). We use 0.100V. (for tableA)
  + For Z gate, it’s the maximum membrane potential we expect in the model (As we’ve used ‘VOLT\_C1\_INDEX’). We use 0.100V. (for tableA)
* xdivsA. Number of divisions to control the granularity as interpolation is used by MOOSE. We use 3000. (for tableA)
* We use the same values similarly for xminB, xmaxB, and xdivsB for tableB
* yminA
  + For Xgate, anything can be filled or this can be skipped since Xindex is ‘VOLT\_INDEX’ and there is no dependence for horizontal axis.
  + For Zgate, it’s the minimum internal calcium concentration we expect in the model (As we’ve used ‘VOLT\_C1\_INDEX’). We use 1e-12mM. (for tableA)
* ymaxA
  + For Xgate, anything can be filled or this can be skipped since Xindex is ‘VOLT\_INDEX’ and there is no dependence for horizontal axis.
  + For Zgate, it’s the maximum internal calcium concentration we expect in the model (As we’ve used ‘VOLT\_C1\_INDEX’). We use 0.5mM. (for tableA)
* ydivsA
  + For Xgate, anything can be filled or this can be skipped since Xindex is ‘VOLT\_INDEX’ and there is no dependence for horizontal axis.
  + For Zgate, it’s the divisions for granularity. We use 5000.
* We use the same values similarly for yminB, ymaxB, and ydivsB for tableB

We first set tableA and tableB for Xgate. Since, there is no dependence along horizontal axis, the dimensions of tableA and tableB should be (xdivs,1).

For Zgate, we combine the ca dependent gate and ghk equation into a single equation.

Where ki is some constant for the ca dependent gate, ca is internal calcium concentration, v is membrane potential, cao is external calcium concentration which remain constant, ev is exp(z\*v\*F/R/T), and ECa is reversal of calcium that we set before. z is +2 for calcium, F is faraday constant, R is gas constant, and T is temperature in Kelvin. We’ve assumed that permeability\*z\*z\*F\*F\*cao/R/T is the total conductance of the channel.

The dimensions of tableA and tableB should be (xdivs, ydivs). tableB should all 1s.

At the end, we connect a calcium dynamics mechanism to this channel and vice versa using Mstring.

* Addmsg1 = moose.Mstring( Ca\_L.path + '/addmsg4' )

Addmsg1.value = '../Ca\_conc concOut . concen'

This tells the solver that take whatever is there in the concOut field of ../Ca\_conc and fill the L-type Ca channel’s concen field with it. In this case, it’s the internal calcium concentration.

* addmsg2 = moose.Mstring( Ca\_L.path + '/addmsg2' )

addmsg2.value = '. IkOut ../Ca\_conc current'

This tells the solver that take whatever is there in the IkOut field of the present element (in this case L-type Ca channel) and fill the ‘current’ field of ../Ca\_conc