1 Gating Functions and Parameters for Implemented Models

1.1 Wang 1994

The model and corresponding parameters were obtained from Wang 1994. The model contains six types of currents (i.e. currents passing through particular ion channel):

- T-type calcium current: $I_T(V) = g_T \cdot s_\infty^3(V) \cdot h \cdot (V - V_{Ca})$
  - $s_\infty(V) = 1/(1 + \exp(-(V + 65)/7.8))$
  - $\frac{dh}{dt}(V) = 2 \cdot (h_\infty - h)/\tau_h$
  - $h_\infty(V) = \frac{1}{1+\exp((V+79)/5)}$
  - $\tau_h(V) = h_\infty \cdot \exp((V + 162.3)/17.8) + 20$
- Sag (or, h-) current: $I_H = g_\mathrm{H} \cdot H^2 \cdot (V - V_\mathrm{H})$
  - $\frac{dH}{dt}(V) = (H_\infty(V) - H)/\tau_H(V)$
  - $H_\infty(V) = \dfrac{1}{1 + \exp((V + 69)/7.1)}$
  - $\tau_\mathrm{H}(V) = \frac{1000}{\exp((V+66.4)/9.3)+\exp(-(V+81.6)/13)}$
- Hodgkin and Huxley potassium current: $I_{HH,K} = g_\mathrm{hhK} \cdot n^4 \cdot (V - V_K)$
  - $\frac{dn}{dt}(V) = \frac{200}{7} \cdot (n_\infty(V) - n)/\tau_n(V)$
  - $\alpha_n(V) = -0.01 \cdot (V + 35.7)/[\exp(-0.1 \cdot (V + 35.7)) - 1]$
  - $\beta_n(V) = 0.125 \cdot \exp(-(V + 45.7)/80)$
  - $n_\infty(V) = \frac{\alpha_n(V)}{\alpha_n(V)+\beta_n(V)}$
  - $\tau_n(V) = \dfrac{1}{\alpha_n(V) + \beta_n(V)}$
- Hodgkin and Huxley sodium current: $I_{HH,Na}(V) = g_\mathrm{Na} \cdot m_\infty^3 \cdot (0.85 - n) \cdot (V - V_\mathrm{Na})$
- Persistent sodium current: $I_{NaP}(V) = g_{NaP} \cdot m_{\infty,Nap}^3 \cdot (V - V_\mathrm{Na})$
- Leak Current: $I_L(V) = g_\mathrm{Leak} \cdot (V - V_\mathrm{Leak})$

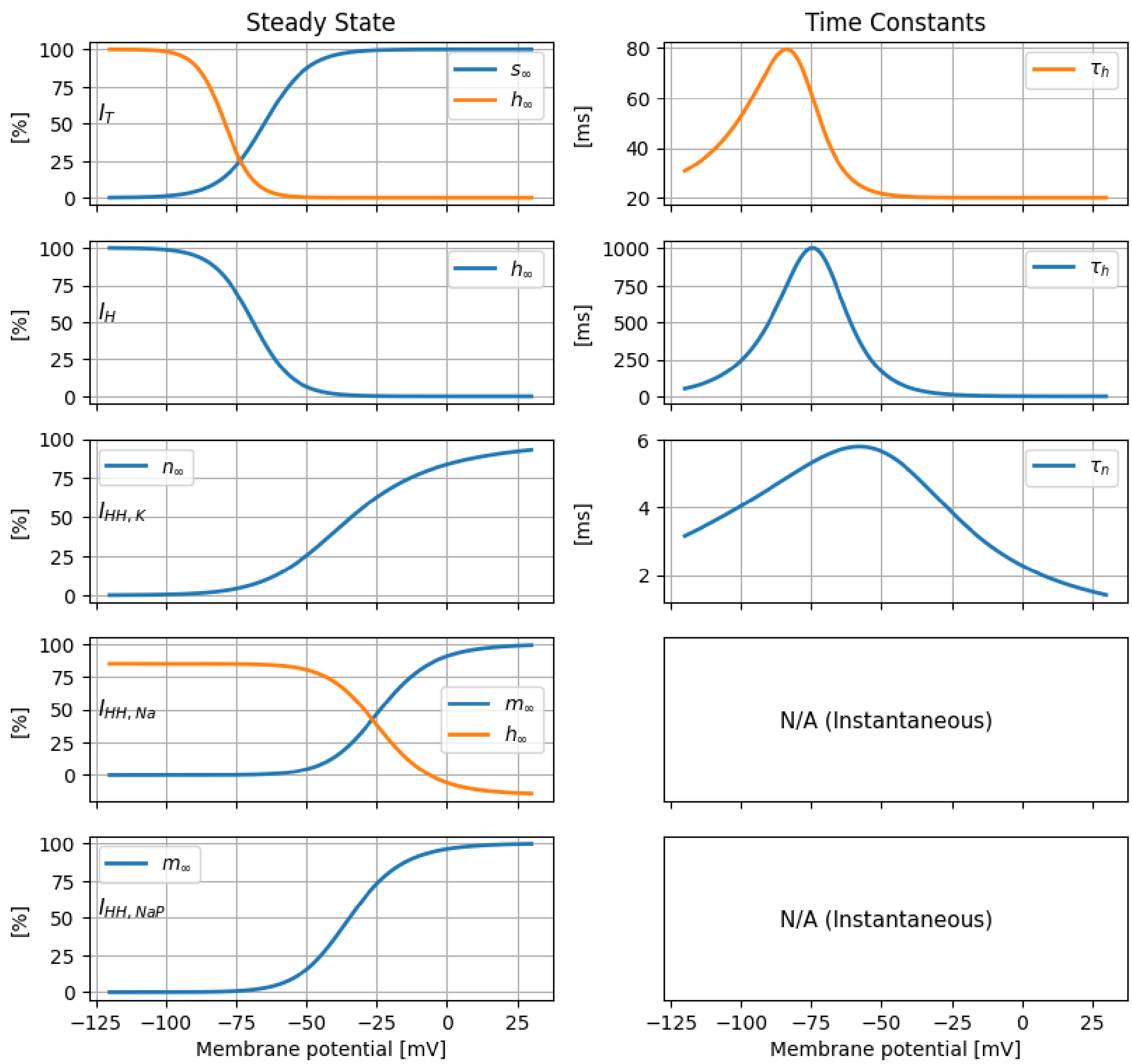

Figure 1: Wang: Steady state activation and inactivation functions, and corresponding time constants. Note, that the negative values of the $I_{HH,Na}$ inactivation gate results from the simplification of the dynamics by assuming litear relationship between the inactivation gate of the HH sodium and activation gate of HH potassium channels (Wang 1994).

Dafault parameters: $c_{\text{Membr}} = 1\ \mu F/cm^2$, $g_T = 1\ mS/cm^2$, $v_{Ca} = 120\ mV$, $g_{\text{G}} = 0.04\ mS/cm^2$, $v_{\text{G}} = -40\ mV$, $g_{\text{HHK}} = 30\ mS/cm^2$, $v_K = -80\ mV$, $g_{\text{Na}} = 42\ mS/cm^2$, $v_{\text{Na}} = 55\ mV$, $g_{\text{NaP}} = 9\ mS/cm^2$, $g_{\text{Leak}} = 0.12\ mS/cm^2$, $v_{\text{Leak}} = -70\ mV$, $I_{\text{ext}} = -1.6\ \mu A/cm12$,

1.2 Goldman et. al. 2001

The model and parameters adapted from (Franci, Drion, and Sepulchre 2018). The model contains six types of currents (i.e. currents passing through particular ion channel):

- Fast sodium current ($\mathrm{INa_T}$): $I_{\mathrm{NaT}} = g_{\mathrm{nat}} \cdot m^3 \cdot h \cdot (V - V_{\mathrm{Na}})$
  - $\frac{dm}{dt} = \frac{m_\infty(V) - m}{\tau_m(V)}$
  - $m_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+25.5}{-5.29}\right)}$
  - $\tau_m(V) = 1.32 - \dfrac{1.26}{1 + \exp\left(\frac{V+120}{-25}\right)}$
  - $\frac{dh}{dt} = \frac{h_\infty(V) - h}{\tau_h(V)}$
  - $h_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+48.9}{5.18}\right)}$
  - $\tau_h(V) = \dfrac{0.67}{1 + \exp\left(\frac{V+62.9}{-10}\right)} \cdot \left(1.5 + \dfrac{1}{1 + \exp\left(\frac{V+34.9}{3.6}\right)}\right)$
- T-type calcium current: $I_{\mathrm{CaT}}(V) = g_{\mathrm{cat}} \cdot m^3 \cdot h \cdot (V - V_{\mathrm{Ca}})$
  - $\frac{dm}{dt} = \frac{m_\infty(V) - m}{\tau_m}, \quad m_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+27.1}{-7.2}\right)}$
  - $\tau_m(V) = 21.7 - \dfrac{21.3}{1 + \exp\left(\frac{V+68.1}{-20.5}\right)}$
  - $\frac{dh}{dt}(V) = \frac{h_\infty - h}{\tau_h}, \quad h_\infty = \dfrac{1}{1 + \exp\left(\frac{V+32.1}{5.5}\right)}$
  - $\tau_h(V) = 105 - \dfrac{9.8}{1 + \exp\left(\frac{V+55}{-16.9}\right)}$
- Slow calcium current: $I_{\mathrm{CaS}}(V) = g_{\mathrm{cas}} \cdot m^3 \cdot h \cdot (V - V_{\mathrm{Ca}})$
  - $\frac{dm}{dt} = \frac{m_\infty - m}{\tau_m}, \quad m_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+33}{-8.1}\right)}$
  - $\tau_m(V) = 1.4 + \dfrac{7}{\exp\left(\frac{V+27}{10}\right) + \exp\left(\frac{V+70}{-13}\right)}$
  - $\frac{dh}{dt}(V) = \frac{h_\infty(V) - h}{\tau_h(V)}, \quad h_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+60}{6.2}\right)}$
  - $\tau_h(V) = 60 + \dfrac{150}{\exp\left(\frac{V+55}{9}\right) + \exp\left(\frac{V+65}{-16}\right)}$

- A-type potassium current: $I_A(V) = g_a \cdot m^3 \cdot h \cdot (V - V_K)$
  - $\frac{dm}{dt} = \frac{m_\infty(V) - m}{\tau_m(V)}, \quad m_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+27.2}{-8.7}\right)}$
  - $\tau_m(V) = 11.6 - \dfrac{10.4}{1 + \exp\left(\frac{V+32.9}{-15.2}\right)}$
  - $\frac{dh}{dt} = \frac{h_\infty(V) - h}{\tau_h(V)}, \quad h_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+56.9}{4.9}\right)}$
  - $\tau_h(V) = 38.6 - \dfrac{29.2}{1 + \exp\left(\frac{V+38.9}{-26.5}\right)}$
- Calcium-dependent potassium current: $I_{KCa}(V) = g_{\text{kca}} \cdot m^4 \cdot (V - V_K)$
  - $\frac{dm}{dt} = \frac{m_\infty(V) - m}{\tau_m(V)}$
  - $m_\infty = \left(\frac{[Ca]}{[Ca]+3}\right) \cdot \frac{1}{1+\exp\left(\frac{V+28.3}{-12.6}\right)}$
  - $\tau_m = 90.3 - \dfrac{75.1}{1 + \exp\left(\frac{V+46}{-22.7}\right)}$
- Delayed rectifier potassium current: $I_{KDR}(V) = g_{\text{kd}} \cdot m^4 \cdot (V - V_K)$
  - $\frac{dm}{dt} = \frac{m_\infty(V) - m}{\tau_m(V)}$
  - $m_\infty(V) = \dfrac{1}{1 + \exp\left(\frac{V+12.3}{-11.8}\right)}$
  - $\tau_m(V) = 7.2 - \dfrac{6.4}{1 + \exp\left(\frac{V+28.3}{-19.2}\right)}$
- Leak current: $I_{\text{leak}}(V) = g_{\text{leak}} \cdot (V - V_{\text{leak}})$
- Calcium dynamics:

$$\frac{d[Ca]}{dt} = \frac{-9.4 \cdot (I_{\text{CaT}} + I_{\text{CaS}}) - [Ca] + 0.05}{200}$$

Parameters Goldman 1: $g_{\text{nat}} = 700\ mS/cm^2$, $V_{\text{Na}} = 50$ mV, $g_{\text{cat}} = 7\ mS/cm^2$, $g_{\text{cas}} = 10.5\ mS/cm^2$, $V_{\text{Ca}} = 80$ mV, $g_a = 225\ mS/cm^2$, $g_{\text{kca}} = 25\ mS/cm^2$, $g_{\text{kd}} = 80$, $V_K = -80\ mS/cm^2$, $g_{\text{leak}} = 0.1\ mS/cm^2$, $V_{\text{leak}} = -50$ mV, $I_{\text{app}} = 2\ \mu A/cm^2$, $c_m = 1\ \mu F/cm^2$

Parameters Goldman 2: $g_{\text{nat}} = 1200\ mS/cm^2$, $V_{\text{Na}} = 50$ mV, $g_{\text{cat}} = 10\ mS/cm^2$, $g_{\text{cas}} = 8\ mS/cm^2$, $V_{\text{Ca}} = 80$ mV, $g_a = 10\ mS/cm^2$, $g_{\text{kca}} = 40$, $g_{\text{kd}} = 100$, $V_K = -80$ mV, $g_{\text{leak}} = 0.1$, $V_{\text{leak}} = -50$ mV, $I_{\text{app}} = 2\ \mu A/cm^2$, $c = 1\ \mu F/cm^2$

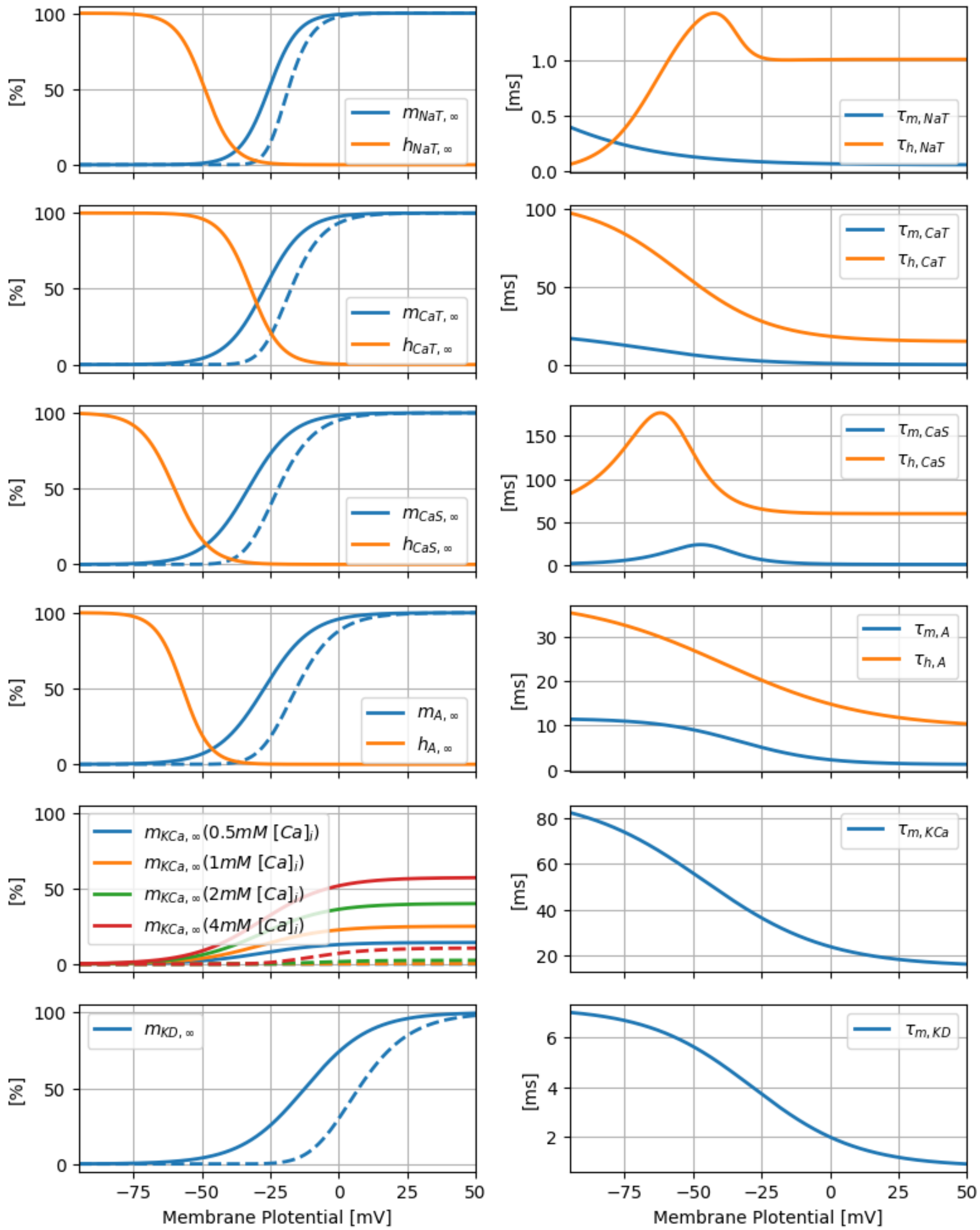

Figure 2: Godlman: Steady state activation and inactivation functions, and corresponding time constants Parameters adapted from (Franci, Drion, and Sepulchre 2018).

1.3 Park et. al. 2021

The model and parameters adapted from (Park, Rubchinsky, and Ahn 2021). The model incorporates following currents:

- Leak current: $I_L = g_L(V - V_L)$
- Spike-generating potassium current: $I_K = g_K n^4(V - V_K)$
- Spike-generating sodium current: $I_{\text{Na}} = g_{\text{Na}}\, m^3 h(V - V_{\text{Na}})$
- Persistent sodium current: $I_{\text{NaP}} = g_{\text{NaP}}(V - V_{\text{Na}})$
- Calcium-dependent potassium current: $I_{\text{AHP}} = g_{\text{AHP}}\, r^2(V - V_K)$
- Hyperpolarization-activated Cyclic Nucleotide-gated (HCN) current: $I_{\text{HCN}} = g_{\text{HCN}} f(V - V_{\text{HCN}})$
- A-type potassium current: $I_A = g_A a^2 b(V - V_K)$
- T-type low-threshold calcium current: $I_{\text{CaT}} = g_{\text{CaT}}\, p^2 q(V - V_{\text{Ca}})$
- n L-type high-threshold calcium current: $I_{\text{CaL}} = g_{\text{CaL}}\, c^2 d_1 d_2(V - V_{\text{Ca}})$

where

$$\frac{dx}{dt} = \frac{x_\infty(V) - x}{\tau_x(V)}, \quad x \in \{m, h, n, f, a, b, p, q, c, d_1\}, \tag{2}$$

$$\frac{dx}{dt} = \frac{x_\infty([\text{Ca}]) - x}{\tau_x(V)}, \quad x \in \{r, d_2\}, \tag{3}$$

$$\frac{d[\text{Ca}]}{dt} = \frac{\epsilon}{2F}(-I_T - I_{\text{CaL}}) - K_{\text{Ca}}[\text{Ca}], \tag{4}$$

$$
\begin{aligned}
x_\infty(V) &= \left[1+\exp\left(\frac{V-\theta_{\infty,x}}{\sigma_{\infty,x}}\right)\right]^{-1}, \quad x\in\{m,h,n,f,a,b,p,q,c,d_1\},\\
x_\infty([\mathrm{Ca}]) &= \left[1+\exp\left(\frac{[\mathrm{Ca}]-\theta_{\infty,x}}{\sigma_{\infty,x}}\right)\right]^{-1}, \quad x\in\{r,d_2\},\\
\tau_x(V) &= \tau_{0,x}+\tau_{1,x}\left[1+\exp\left(-\frac{V-\theta_{1,x}}{\sigma_{1,x}}\right)\right]^{-1}+\tau_{2,x}\exp\left(\frac{V-\theta_{2,x}}{\sigma_{2,x}}\right),\\
&\qquad x\in\{m,h,n,r,a,b,p,q,c,d_1,d_2\},\\
\tau_f(V) &= \tau_{0,f}+\tau_{1,f}\left[\exp(\theta_{1,f}+\sigma_{1,f}V)+\exp(\theta_{2,f}+\sigma_{2,f}V)\right]^{-1}.
\end{aligned}
$$

Gate	θ_∞	σ_∞	τ_0	τ_1	τ_2	θ_1	σ_1	θ_2	σ_2
m	-40.00	-8.00	0.2	3.0	0	-53.00	-0.70	0.00	0.00
h	-45.50	6.40	0.0	24.5	1.0	-50.00	-10.00	-50.00	20.00
n	-41.50	-14.00	0.0	11.0	1.0	-40.00	-40.00	-40.00	50.00
r	0.17	-0.08	2.0	0.0	0.0	0.00	0.00	0.00	0.00
f	-75.00	5.50	0.0	1.0	1.0	-14.59	-0.086	-1.87	0.08
a	-45.00	-14.70	1.0	1.0	0.0	-40.00	-0.50	0.00	0.00
b	-90.00	7.50	0.0	200.0	1.0	-60.00	-30.00	-40.00	10.00
p	-56.00	-6.70	1.0	0.33	200.0	-27.00	-10.00	-102.0	15.00
q	-85.00	5.80	0.0	400.0	100.0	-50.00	-15.00	-50.00	16.00
c	-30.60	-5.00	45.0	10.0	15.0	-27.00	-20.00	-50.00	15.00
d1	-60.00	7.50	400.0	500.0	1.0	-40.00	-15.00	-20.00	20.00
d2	0.20	0.02	3000.0	0.0	0.0	0.00	0.00	0.00	0.00

Table 1: Park: Gating parameters for each variable.

Default parameters: $g_l = 0.9$ S/cm^2, $g_k = 57$ S/cm^2, $g_{na} = 45$ S/cm^2, $g_{nap} = 0.003$ S/cm^2, $g_{ahp} = 1$ S/cm^2, $g_{hcn} = 2$ S/cm^2, $g_a = 5$ S/cm^2, $g_{cat} = 20$ S/cm^2, $g_{cal} = 5$ S/cm^2, $V_l = -60$ mV, $V_k = -80$ mV, $V_{na} = 55$ mV, $V_{hcn} = -43$ mV, $V_{ca} = 120$ mV, $I_{\text{app}} = -16$ mA/cm^2,

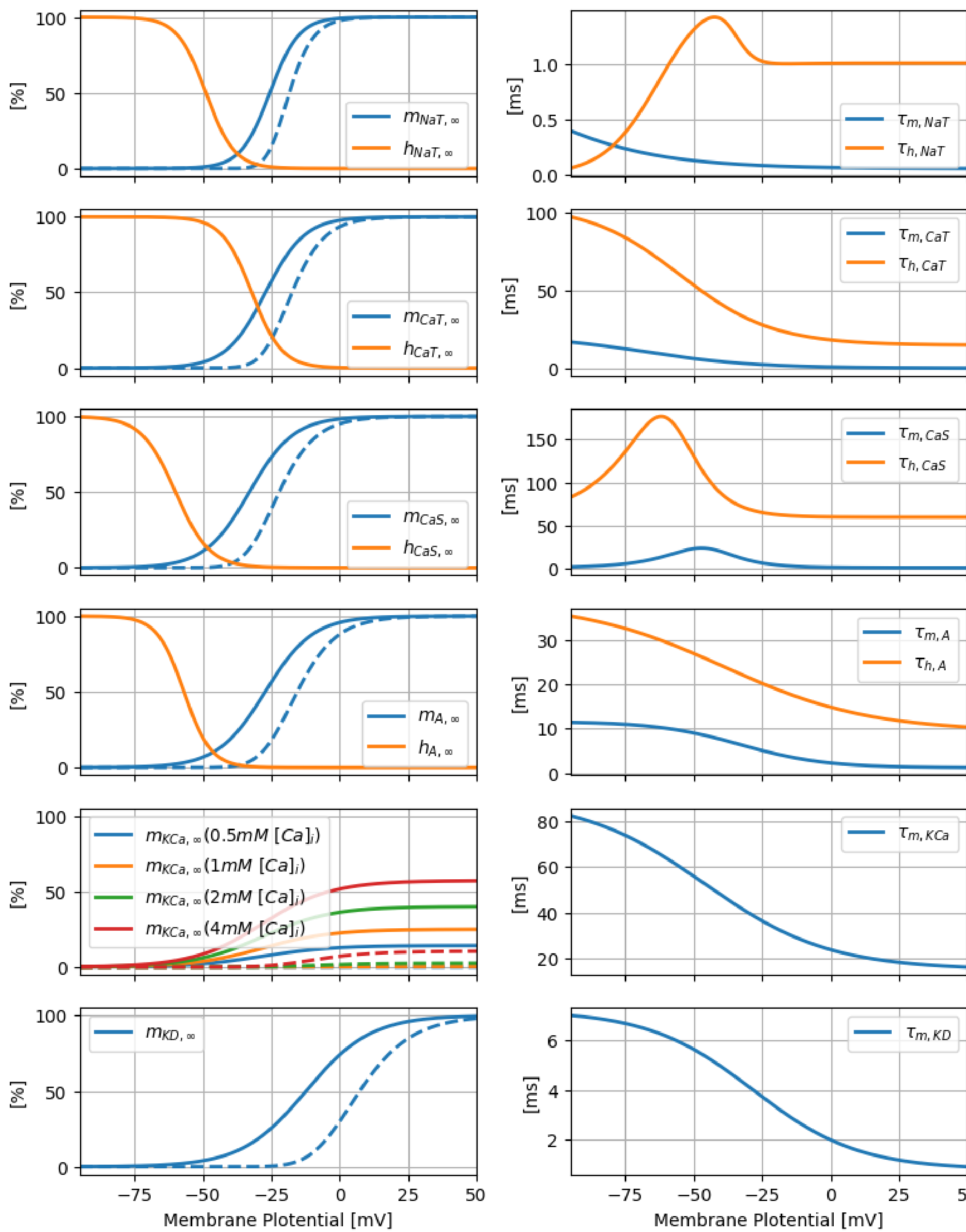

Figure 3: Park: Steady state activation and inactivation functions, and corresponding time constants Parameters adapted from (Park, Rubchinsky, and Ahn 2021).

1.4 EAG Channel

Model	a	d	k
Default (Bronk et al. 2018)	1	0	16.94
Wang 1994	0.01	-35.5	0.2

Table 2: Parameter values for EAG channels used in implemented models.