Relating microscopic charge movement to macroscopic currents: the Ramo-Shockley theorem applied to ion channels

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Running title: Gating Charge and Ramo-Shockley

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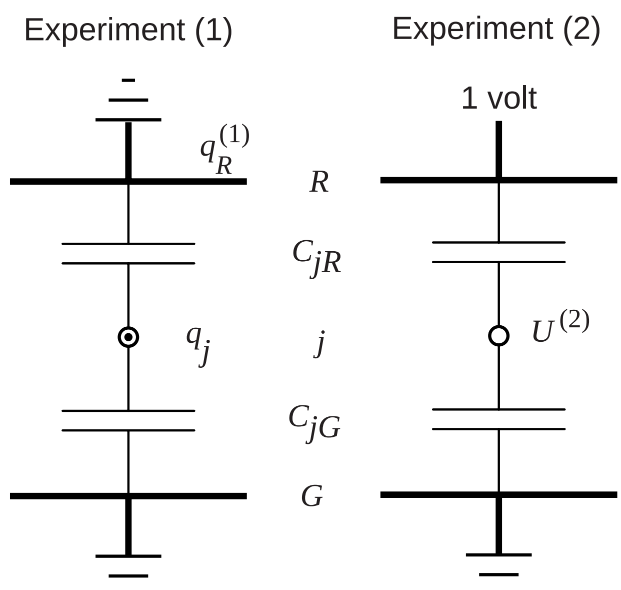
Figure Captions

Figure 1. Equivalent circuits for the two thought experiments used to derive the Ramo-Shockley theorem (see text).

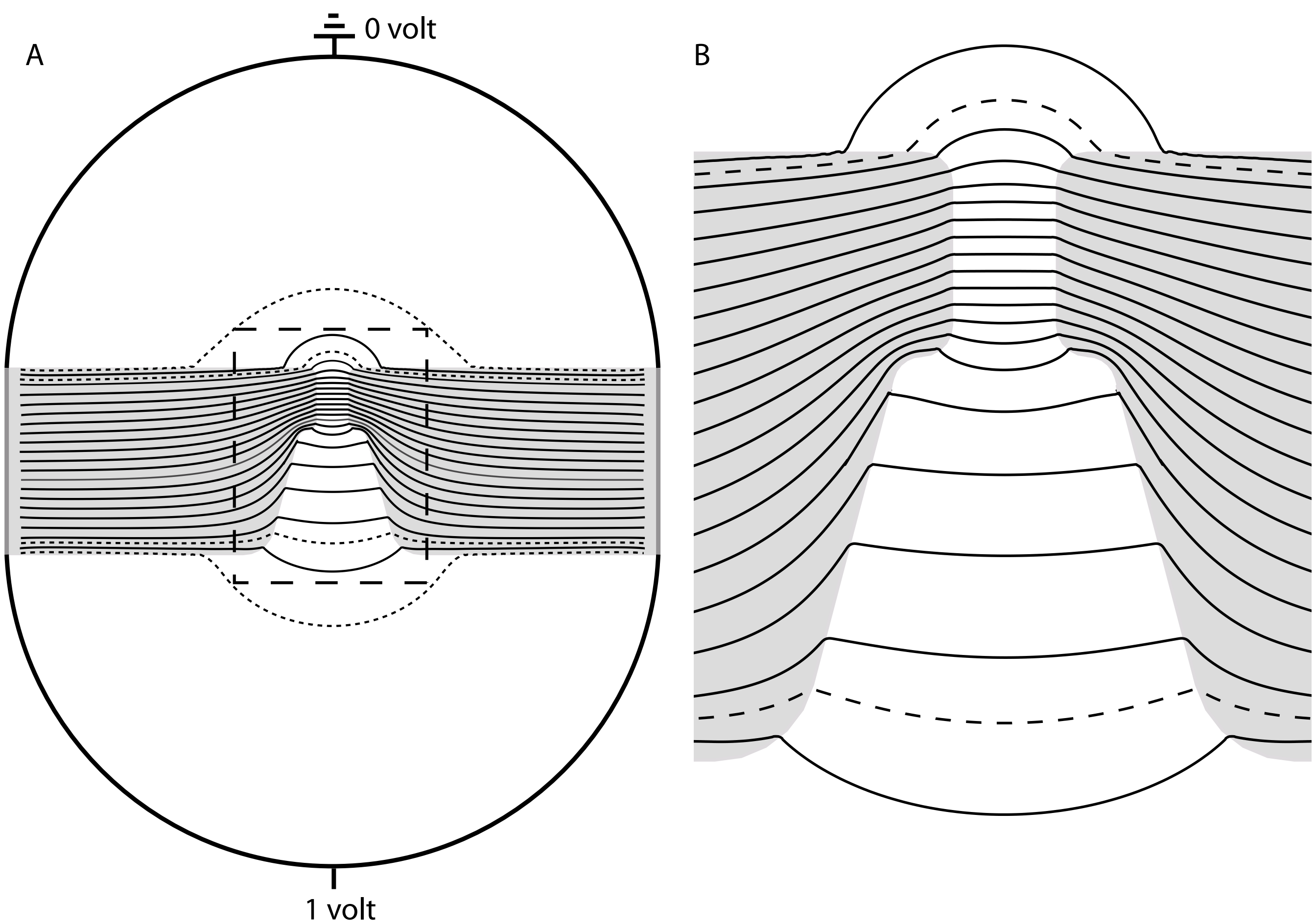
Figure 2. Mapping geometric coordinates to electrical coordinates. A conductive pore provides an aqueous bridge through the membrane (qualitatively similar to the open pore of a K channel (Jiang et al., 2003)). The domain (*panel A*, drawn to scale) is a generalized cylinder (maximal radius 5 nm, length 13 nm) and is shown in an axial cross-section; the highlighted part in A is shown at larger scale in *panel B*. Electrodes bound the two hemispherical baths. The top (external) electrode is grounded, whereas the bottom (internal) electrode is maintained at 1 volt. Isopotential lines are shown at 50 mV intervals (*solid lines*); some intermediate isopotentials corresponding to 25 mV intervals are also included (*dashed lines*). The isopotential lines also mark surfaces of constant "electrical coordinate" (with respect to the grounded electrode), corresponding to intervals of 0.05 (or 0.025). The dielectrics are described by dielectric coefficients of 80 (bath solutions and pore, *unshaded*) and 2 (lipid and channel, *shaded in gray*). At the lateral boundary of the membrane (*dark gray lines)*, a linearly varying potential is imposed

Figure 3. Mapping geometric coordinates to electrical coordinates. An S4 helix segment spans the membrane through a "gating pore" (as envisioned by Bezanilla (2002)). Two

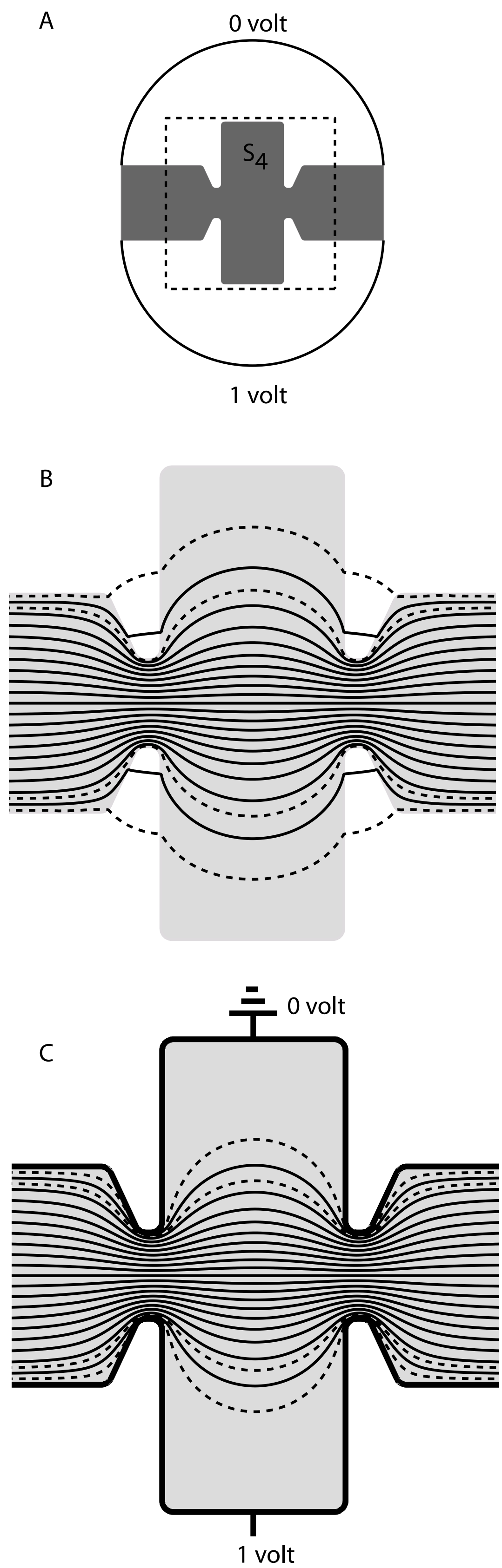
different electrode arrangements are used. One arrangement includes bath solutions between the membrane and electrodes (*panel A*, c.f. Fig. 2); *panel B* shows an enlargement of the region bounded by the *dashed line* in A. In the other arrangement, the electrodes cover membrane and protein like a thin metal foil (*panel C*). Isopotential lines are shown at 50 mV intervals (*solid lines*); some intermediate isopotentials corresponding to 25 mV intervals are also included (*dashed lines*). The dielectrics are described by dielectric coefficients of 80 (bath solutions, *unshaded*) and 2 (lipid and channel, *shaded in gray*).



Experiment (1)
Experiment (2)
1 volt
$q_R^{(1)}$
R
C_{jR}
q_j
j
$U^{(2)}$
C_{jG}
G



A
0 volt
1 volt
B


A
0 volt
S4
1 volt
B
C
0 volt
1 volt