Background

• Stomata, microscopic pores on a leaf’s surface, regulate the diffusion of CO2 from, and the diffusion of water vapor to, the air.
• Stomata are responsible for fixing essentially all carbon in the biosphere and generating over 90% of the water vapor in the atmosphere over landmasses.
• Exactly how stomata respond to temperature, light intensity, and ambient CO2 and humidity, is still a matter of active debate.
• Most research probing this question focuses on identifying and unraveling complicated biochemical interactions. Recent investigations in our laboratory, however, indicate that much of stomatal behavior can be understood in terms of a simple vapor phase physical model.

Physics

VAPOR PHASE MODEL OF STOMATAL CONDUCTANCE

\[ g_s = \frac{-\Theta \Delta w}{w_s} \]

- \( g_s \): stomatal conductance (aperture)
- \( w_s \): conductance at 100% external humidity
- \( \Theta \): saturated water vapor (WW) concentration inside the leaf
- \( \Delta w \): humidity sensitivity due to resistance to WV diffusion from inside the leaf to the air

MECHANICS

- Stomatal aperture is proportional to the difference in turgor pressures in guard (P_g) and surrounding epidermal (P_e) cells.
- Larger epidermal cells have a mechanical advantage (m).

THERMODYNAMICS

- Chemical potential of water, \( \Psi \), determines direction of water transport:
  - Liquid Phase: \( \Psi = P - \pi = \Theta T \)
    - This yields: \( g_s = \chi (P_g - mP_e) \)
  - Vapor Phase: \( \Psi = \frac{RT}{w_s} \ln \frac{w_s}{w_e} = \chi e^\Theta \)
  - Transport of water vapor is fast compared with hydration of guard cells
  - This leads to equilibrium conditions:
    - Liquid phase potential in the epidermis = liquid phase potential at the evaporation site = vapor phase potential immediately outside the evaporation site
    - Vapor phase potential in the stomatal pore = liquid phase potential in the guard cells
    - And a steady state condition:
      - Vapor phase potential in the stomatal pore = \( \frac{RT}{w_s} \ln \frac{w_s}{w_e} \)
      - Vapor phase potential at the evaporating site
      - Approximations:
        - Liquid phase potential at the evaporation site \( \approx \frac{RT}{w_s} \)
        - Temperature of evaporating site is slightly lower than that of epidermis
          - These yield \( Z \)
          - \( \sigma \) is small (< 0.1)
          - This yields \( \Theta \)

Motivation

1. Isolated stomata (removed from mesophyll cells in leaf interior) respond to air humidity just as they do in intact leaves.¹
2. Isolated stomata don’t respond to light and CO2, but when brought close to, but not in contact with, mesophyll cells they do.²
3. Isolated stomata respond to vapor phase ions.³

References


Conclusion

• Some important aspects of stomatal behavior can be explained through simple mechanics and vapor phase physics. This runs counter to the prevailing tradition in plant physiology that essentially all stomatal behavior is biochemical.
• Some metabolic component to stomatal response is contained in the temperature dependence of \( g_s \). A more complete understanding of this requires additional experiments varying light and CO2, which we are now conducting.