Translocation of Nutrients in the Phloem: Poiseuille's Equation

# Introduction

Plant biologists spent many decades trying to understand the mechanisms behind transport of nutrients through seive tubes in the phloem. Proponents of mass transport believed the gradient of solute concentration along seived tubes would create a gradient of turgor pressure. The pressure gradient could be quite small (0.020 MPa per meter) but still be enough to drive the flow of nutrients (see [**Dixon's Paradox**](http://www.tiem.utk.edu/~gross/bioed/webmodules/dixonsparadox.htm)). However, the idea of mass transport seemed too simplistic for many plants whose cell-to-cell pressure gradient or speed of transfer did not match that predicted by Dixon's equation.

# Importance

The pressure gradient along the length of a plant is related to the width of the sieve tubes as well as the viscosity of the solution. We can use an equation to calculate expected pressure gradients and compare these results with those of mass transport.

# Questions

How is the pressure gradient affected by the size of sieve tubes? How does this cast doubt on the idea of mass transport?

# Variables

|  |  |
| --- | --- |
| dP/dl | change in pressure across a small distance dl (MPa/m) |
| v | viscosity of the solution (poise) |
| s | speed of transfer (cm/s) |
| r | radius of seive tube (cm) |

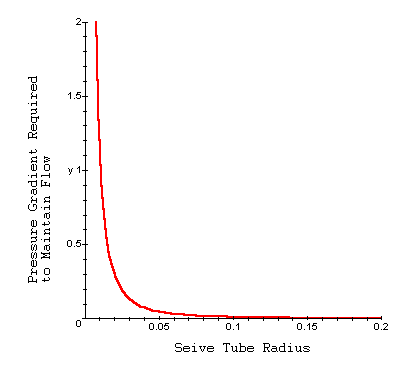
# Methods

The Poiseuille equation cast doubts on the feasibility of mass transport. This equation assumes that the pressure gradient (dP/dl) created by differences in carbon concentration between phloem cells depends on the width of those cells and the viscosity of the solution. A useful form of this equation is:

|  |  |
| --- | --- |
|  | LaTeX Code: \[ \frac{dP}{dl} = \frac{8vs \times 10^{-5}}{r^2} \] |

 where v is the viscosity of the solution (around 0.015 poise), s is the speed of transfer (cm/s), and r is the radius of the tube (cm).

If we graph dP/dl as a function of r, we can assess how the pressure gradient required to maintain mass transfer varies with size of the seive tubes.



# Interpretation

For plants with wide seive tubes (2.5 to 5 m), only small differences in internal pressure are needed to drive the flow. This favors the idea of mass transport which assumes small differences in carbon concentration can drive the transfer of nutrients. However, a great majority of plants have very small seive tubes (0.5 m) and seive pores (0.07 m) and require very large pressure gradients (from 0.04 to 4 MPa per meter) for flow to occur at a speed of around 100 cm/hour. This does not match the idea of mass transfer.

If the cell to cell pressure gradient in plants is not large enough to drive flow, than what is driving nutrient transport? Milburn (1974) showed the pressure gradient appeared unrelated to the gradient of solute concentration as proponents of mass transport believed. The pressure near leaf sources fell dramatically from 1.6 MPa to 1.2 MPa right below the leaves, remained constant down the length of the plant, and again dropped dramatically to 0.6 MPa just above the roots. Consequently, the pressure gradient from source to sink would be sufficient to drive flow, but not the negligible pressure gradient in-between.

# Conclusion

Proponents of mass transport generally tested their theory with plants with wide sieve tubes. The concentration gradient between cells was quite small, but enough to drive the flow of nutrients. However, most plants have much smaller sieve tubes and would require much larger pressure gradients between cells in order to drive flow. Poiseuille's equation quantified how the pressure gradient is related to seive tube size and raised questions about the feasibility of mass transfer.

# Source

M. J. Canny. 1984. *Translocation of nutrients and hormones, p. 277-296 in Advanced Plant Physiology*. M. B. Wilkins, ed. Pitman Publishing Limited, Marshfield, MA

J. A. Milburn. 1974. Phloem transport in Ricinus. Concentration gradients between source and sink. *Planta 117*:303-319

# About this Resource

This material was originally distributed as part of “Alternative Routes to Quantitative Literacy for the Life Sciences[[1]](#endnote-1)” - National Science Foundation Award DUE-9752339 to the University of Tennessee, Knoxville for August 1, 1998 - July 31, 2000. Principal Investigator: Louis J. Gross. Co-Principal Investigators: Beth C. Mullin and Susan E. Riechert.

This material is now being revised as part of the “Resources for Improving Quantitative Skills in Community College Biology[[2]](#endnote-2)” project. As part of that project is also aligned with the OpenStax Biology Textbook[[3]](#endnote-3).

It is published using the QUBES Open Education Resources publishing platform[[4]](#endnote-4).

1. http://www.tiem.utk.edu/~gross/bioed/ [↑](#endnote-ref-1)
2. https://qubeshub.org/community/groups/quantbioatcc/ [↑](#endnote-ref-2)
3. https://openstax.org/details/books/biology-2e [↑](#endnote-ref-3)
4. https://qubeshub.org/qubesresources/publications/1075/ [↑](#endnote-ref-4)