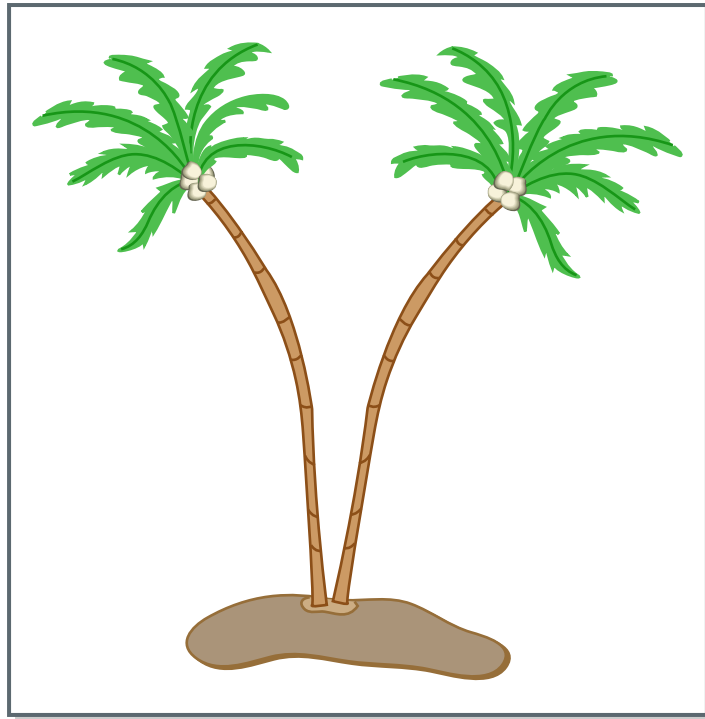


# The Growth and Strength of Trees and Palms

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Cheryl Kwinn and Olga Wichrowska

Figures by MIT OCW.



# How Do Trees Grow?

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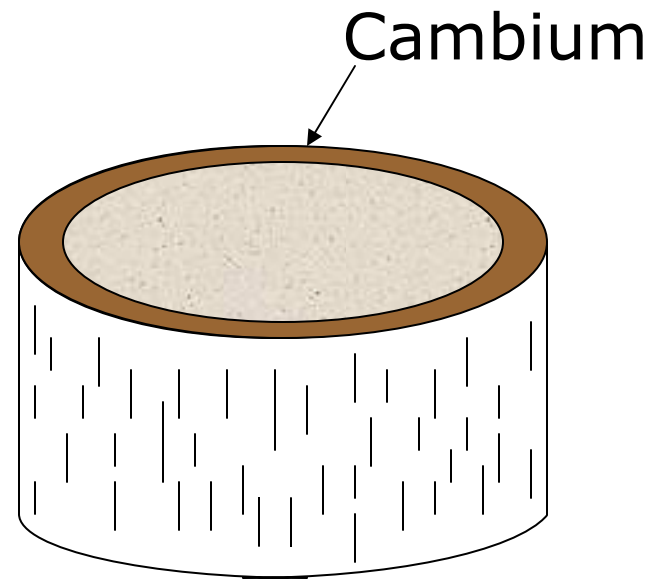
Deciduous and evergreen (coniferous) trees start out very thin and grow layers of cells around the trunk to get wider as they get older.

Photo removed for copyright reasons.

# How Do Trees Grow?

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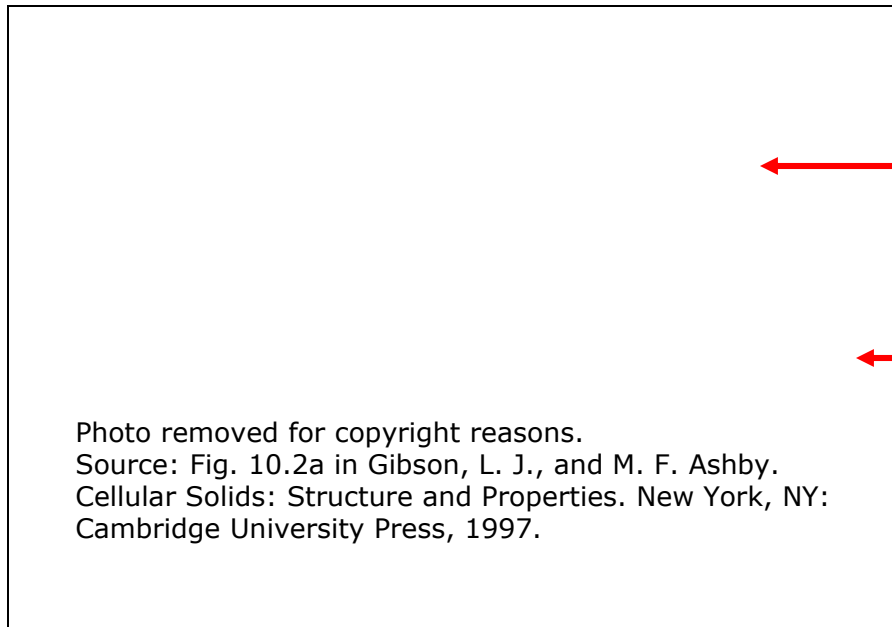
New cells grow from the cambium, a layer just beneath the bark of the tree



# How Do Trees Grow?

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The new cells that are grown in the spring have thin walls while those that are grown in the summer have thick walls



← Spring growth  
Thin walls

← Summer growth  
Thick walls

# How Do Trees Grow?

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- This alternating band of thin and thick walled cells gives the characteristic “growth ring”
- One new growth ring is added each year



Photo courtesy of Dr. Henri D. Grissino-Mayer.  
Used with permission.  
From <http://web.utk.edu/~grissino/gallery.htm>



## How Do Trees Grow?

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- Older, taller trees have larger diameter trunks, so that the trunk can support the increasing weight of the tree.



# How Do Palms Grow?

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- In contrast to other trees, palms trunks do not increase in diameter as they age.

Photo removed for copyright reasons.  
Palm trees in strong wind.



# Palms

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- How does the palm stem support an increasingly heavier and taller tree?
- How do palms maintain stability and strength?





# Palms

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- The palm stem is a radially *gradient structure*.
- Although the palm stem diameter stays constant, the distribution of material inside the stem changes. As the palm grows taller, it increases the density of the material towards its periphery.



# To Clarify: Cross Section of Palm Stem

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Diagram removed for copyright reasons.

Source: Rich, PM. Bot.Gazette 148 (1987): 42-50.



# Palm Stem Cells

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The cell walls in the young palm stem are thin walled (and lower density).

The cells in the old palm stem are thicker walled (and higher density), creating a more rigid structure.

Cells  
from a  
young  
stem

Two photos removed for copyright reasons.  
Source: Rich PM. Amer J. Botany 74 (1987): 792-802.

Cells  
from an  
old  
stem



## Palm Stems

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- The increased density of the cells towards the periphery of the stem increases the bending stiffness and strength of the palm stem



# Demonstration

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- Obtain sheets three different densities of foam (e.g a flexible polyethylene should work well)
- Obtain one foam that is the average density of the three above
- Make one cylinder with the three different densities of foam, placing the densest foam on the outside, the intermediate density in the middle and the lowest density on the inside (this then mimics the structure of palm)
- Make a second cylinder of the same length and diameter with the average density foam.
- Load both cylinders in bending - the palm-like one will deflect less than the uniform one



# Model Descriptions

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- 1<sup>st</sup> model
  - **Purpose:** Show the strength and flexibility of the tube with the radial gradient. Explain how the varying densities give support where needed most- compare to palm
  - **Supplies needed:** 3 foams with different densities, clear outer plastic tube
  - **Directions:** Fill the clear plastic tube with the three foams such that the most dense foam is the outermost shell, the least dense foam as the core, and the last foam between the two.
- 2<sup>nd</sup> model
  - **Purpose:** Show how the tube with one density can bend/fold easily. Compare with the strength and flexibility of the 1<sup>st</sup> model.
  - **Supplies needed:** clear plastic tube, 1 foam with density the average density of the three from the first model
  - **Directions:** Fill the tube with the foam

# Model Images: Model 1

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Top View:



Most Dense ( $TM_3$ )



Less Dense ( $TM_2$ )

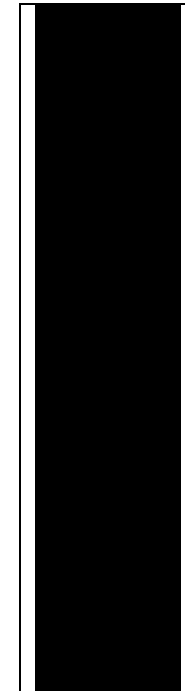


Least Dense ( $TM_1$ )



Side View:

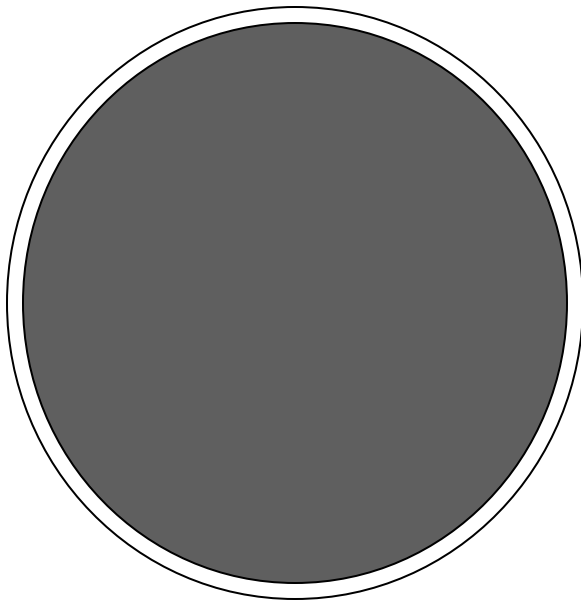
Push Load




# Model Images: Model 2

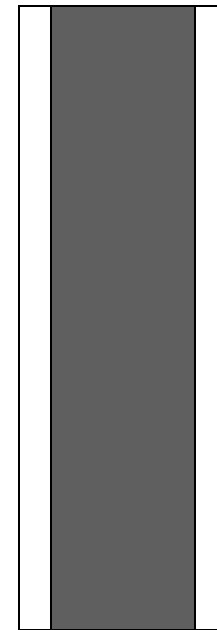
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Top View



Side View

Push Load 



Average Foam  
Density ( $\rho_a$ ) 





## Optional Models:

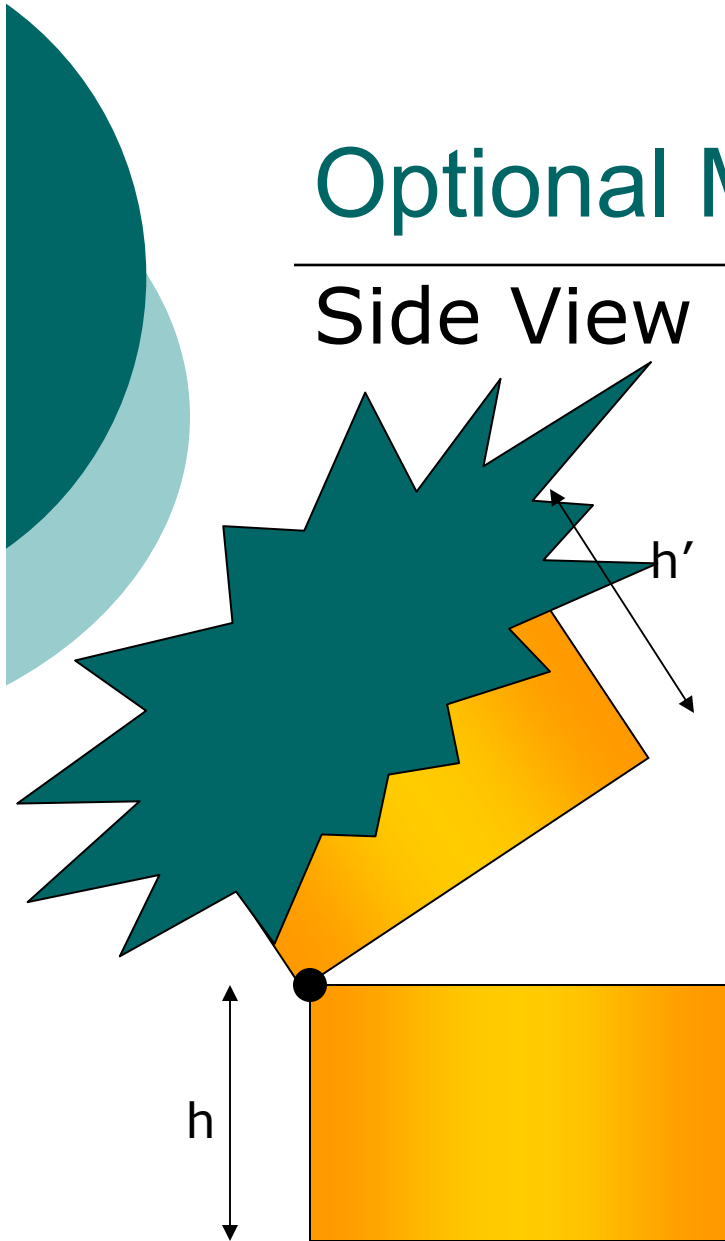
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- **Purpose:** Show how the palm density changes while diameter remains constant throughout life of palm tree
- **Supplies Needed:** 3 foams with different densities, 3 outer shells to replicate palm exterior (three varying heights, diameter constant)
- **Directions:** Fill the three outer shell replicas with the different foams. The smallest height (year 1) will have mostly  $TM_1$ , small ring of  $TM_2$ , smaller  $TM_3$ . The taller height (year 5) will have less  $TM_1$  and more of  $TM_2$  and  $TM_3$ . The tallest height (year 10) will have distinct ring of  $TM_3$ , a larger ring of  $TM_2$ , and a small core of  $TM_1$ . Cut each replica the same height (h) from the bottom, such that a hinge would attach the two pieces together for viewing.

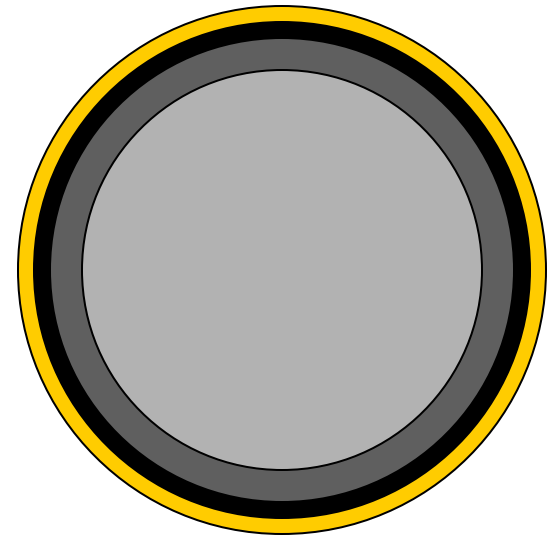
# Optional Model Images: Year 1

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Side View



Interior View



Most Dense ( $\text{TM}_3$ )



Less Dense ( $\text{TM}_2$ )



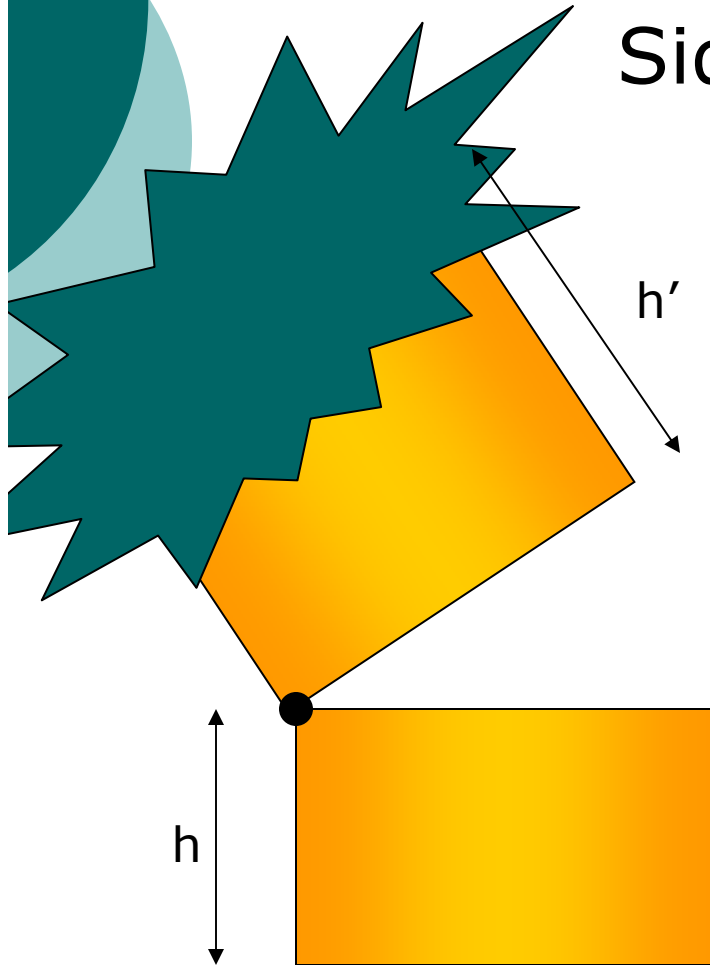
Least Dense ( $\text{TM}_1$ )



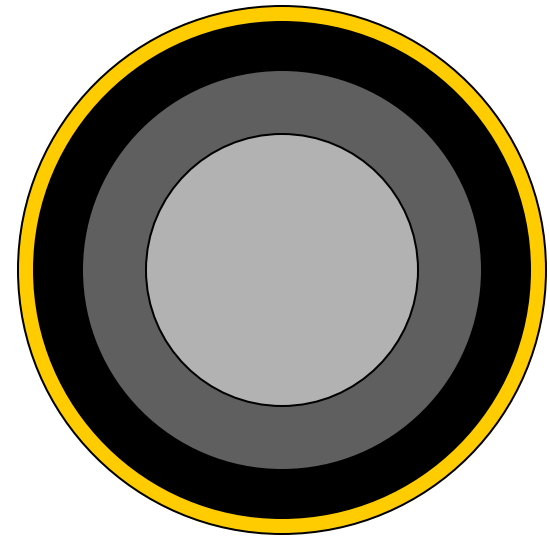
# Optional Model Images: Year 5

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Side View



Interior View



Most Dense ( $TM_3$ )



Less Dense ( $TM_2$ )



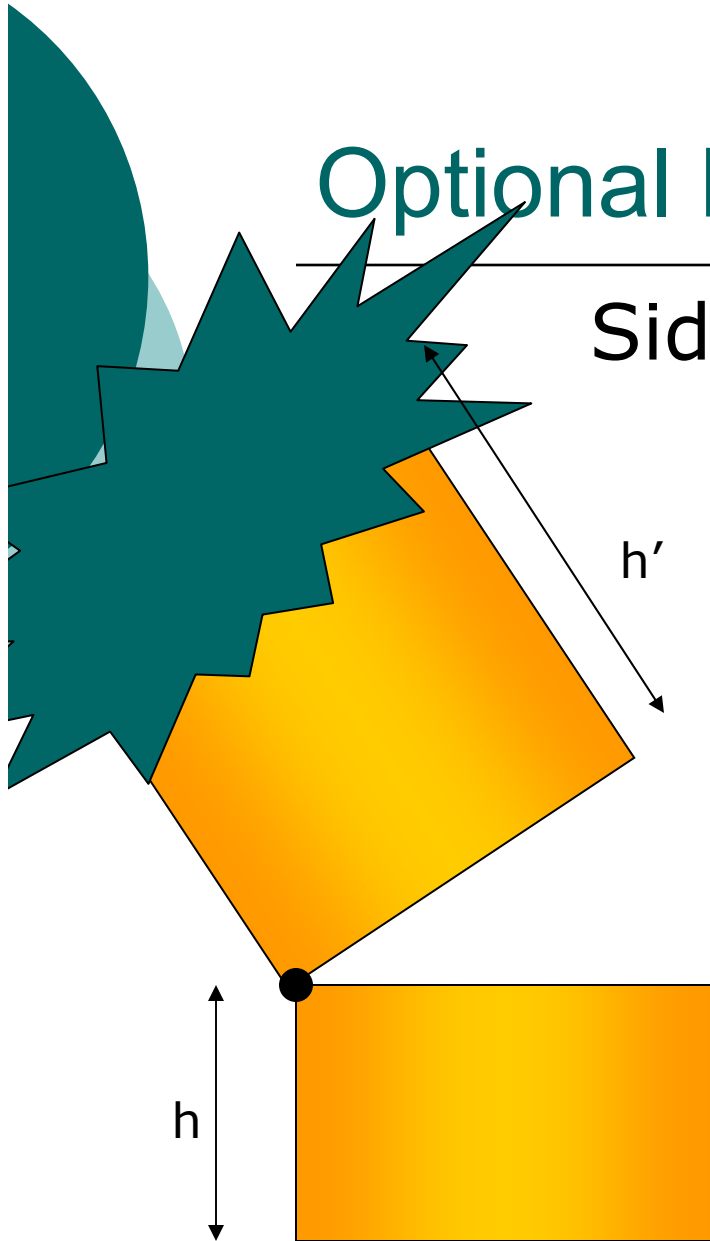
Least Dense ( $TM_1$ )



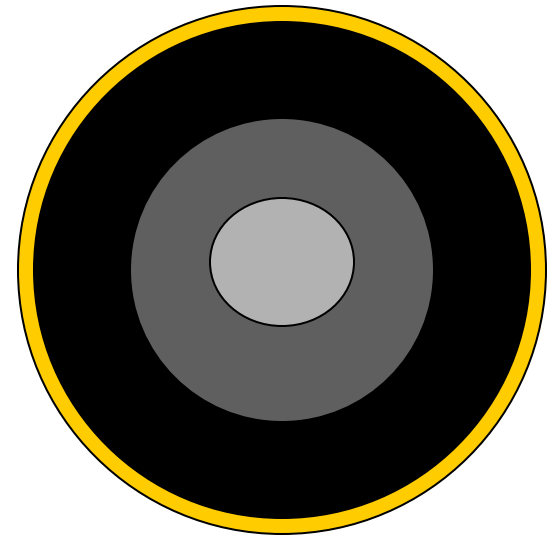
# Optional Model Images: Year 10

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Side View



Interior View



Most Dense ( $TM_3$ )



Less Dense ( $TM_2$ )



Least Dense ( $TM_1$ )

