Water Molecules
Polar Molecule
Size Matters
Vapor

Liquid
### Moisture Transport in Porous Media

<table>
<thead>
<tr>
<th>Phase</th>
<th>Transport Process</th>
<th>Driving Potential</th>
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<td>Surface Tension</td>
<td>Surface Energy</td>
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<tr>
<td></td>
<td>Momentum</td>
<td>Kinetic Energy</td>
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Monolayers of adsorbed water increase with increasing RH
Monolayers flow along surface following concentration gradient
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William Thomson
William Thomson – Lord Kelvin
Kelvin Equation

\[ \ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT} \]
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]

\[ P_{\text{cap}} \]

\[ P_0 \]

\[ \Delta z \]

\[ \frac{2 \sigma \cos \theta}{r} \]

\[ g \rho \Delta z \]

\[ \text{ambient pressure} \]

\[ \text{pressure} \]
Capillary rise versus diameter

![Graph showing the relationship between capillary rise and diameter in inches. The x-axis represents the diameter in inches ranging from 0.00 to 0.10, while the y-axis represents the capillary rise in inches ranging from 0 to 100. The graph has a steep curve, indicating a significant decrease in capillary rise with an increase in diameter.]
Surface area vs. particle size
From Straube & Burnett, 2005
Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

Figure 1b. Brick, sintered clay, porosity 40 per cent.
Capillary break on exterior foundation wall

Capillary break under slab

Capillary break on top of footing
Siding Laps
FILM OF WATER ON SURFACE OF SIDING

WATER FILM DRAWS UP BETWEEN LAPS OF SIDING BY CAPILLARY SUCTION

BUILDING PAPER

SHEATHING
Curvature ("meniscus")

Small pore

Large pore
Ballast (rock, pavers, earth)

Filter fabric

Extruded polystyrene insulation

Sloped concrete topping; slope minimum 2% to drains

Concrete structural deck

Drainage gap, i.e., drainage mat or grooved insulation

Fully-adhered roof membrane
Concrete curb or paver

Planting medium

Gravel

Drainage space

Filter fabric

Root barrier

Sloped concrete topping

Concrete structural deck

Water retention layer/vent and drainage layer

Insulation

Drainage space

Roof membrane (water control layer/drainage plane)
Really Heavy Pink Stuff

Liquid Waterproofing over Concrete Deck
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Capillarity + Salt = Osmosis

- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling
Building Science Corporation

Evaporation

Water with salt in solution travels in porous material via capillary flow to surface where evaporation occurs.

Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues.

Water rushes to dilute concentration of salt leading to potentialy huge hydrostatic pressures.

Surface breaks apart and flakes when hydrostatic pressure due to “osmosis” exceeds cohesive strength of material.

"Spalling"
Pressures

- Diffusion Vapor Pressure: 3 to 5 psi
- Capillary Pressure: 300 to 500 psi
- Osmosis Pressure: 3,000 to 5,000 psi
Freeze-Thaw Damage
Freeze-Thaw Damage
Freezing Temperatures
Water
Susceptible Brick
More Osmosis
Vapor diffusion

Top of membrane is wet
Vapor diffusion

Pore condensation dissolves minerals creating solute
Paver Water Beds!
Need To Do An Aside…Necessary For A Segway
Relative Humidity
Vapor Pressure
90°F 50% RH
75°F 50% RH
60°F 50% RH
45°F 50% RH
30°F 50% RH
Heating

35°F
90% RH

70°F
30% RH
Sorption
Sorption isotherm for several building materials [Kumaran 2002]
From Straube & Burnett, 2005
BET Theory
BET Theory
Stephen Brunauer
Paul Emmett
Edward Teller
Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2005
Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

**Sorption Curve**

Regimes of moisture storage in a hygroscopic porous material
From Straube & Burnett, 2005

- A: Single-layer of adsorbed molecules
- B: Multiple layers of adsorbed molecules
- C: Interconnected layers (internal capillary condensation)
- D: Free water in Pores, capillary suction
- E: Supersaturated Regime
A - Single-layer of absorbed molecules
B - Multiple layers of absorbed molecules
C - Interconnected layers (internal capillary condensation)
D - Free water in pores, capillary suction
E - Supersaturated regime

Relationship between Dry Cup and Wet Cup
Adapted from Joy & Wilson, 1963
**Water Vapor Permeance vs. Relative Humidity**

- **Dry cup limits**
- **Wet cup limits**

**Mean Relative Humidity, %**

**Water Vapor Permeance, US perms**

- $\mu_1 = \text{Dry cup permeance}$
- $\mu_2 = \text{Wet cup permeance}$
Average sorption isotherm for wood as a function of temperature

From Straube & Burnett, 2005
Truss bows upward

Bottom chord shrinks

Top chord lengthens

Top chord lengthens
Bead of adhesive

18"

Bead of adhesive

Continuous bead of drywall adhesive required here

Clips may also be used

Continuous bead of drywall adhesive required here
Slotted anchor at non-bearing walls

Drywall clips

Float drywall at wall corners
Water Vapor Permeance of MemBrain™ Smart Vapor Retarder, Primed and Painted Gypsum Board, Unpainted Gypsum Board and Asphalt-Coated Kraft Paper

- MemBrain™ Smart Vapor Retarder
- Primed & Painted Gypsum Board
- Unpainted Gypsum Board
- Asphalt-Coated Kraft Paper

Mean Relative Humidity, %

Water Vapor Permeance, US perms
Water Vapor Permeance of WRB's
Laws of Thermodynamics
Zeroth Law – Equal Systems
First Law - Conservation of Energy
Second Law - Entropy
Third Law – Absolute Zero
2nd Law of Thermodynamics
In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius
Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less
Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion
Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Vapor Diffusion
Thermodynamic Potential
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DIFFUSION

Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly

AIR TRANSPORT

Higher Air Pressure

Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly

Lower Air Pressure
How Does Wetting Occur?
- "non-wettable" surface
- water repellant surface
- hygrophobic surface
- water more attracted to itself than to surface
- surface energy of water greater than surface energy of surface
- water "beads up"
- "greasy" surface
- high contact angle $\theta$

- "wettable" surface
- non-water repellant surface
- hygroscopic surface
- water more attracted to surface than itself
- surface energy of surface greater than surface energy of water
- water "spreads out"
- "non-greasy" surface
- low contact angle $\theta$
Non-wetting
$\theta > 90^\circ$

Partial wetting
$\theta = 90^\circ$

Wetting
$\theta < 90^\circ$

Perfect wetting
$\theta = 0^\circ$
Premier House Wrap by CS Fabric Int'l
- Air and Moisture Barrier
- Tear Resistant
- Easy Installation
- Meets all national building codes
- National ES Report No. NER-655
Premier HouseWrap by CS Fabric Int'l

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<tr>
<td>Water (20 C)</td>
<td>73 dynes/cm</td>
</tr>
<tr>
<td>Water (100 C)</td>
<td>59 dynes/cm</td>
</tr>
<tr>
<td>Epoxy</td>
<td>46 dynes/cm</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>31 dynes/cm</td>
</tr>
<tr>
<td>Soapy water</td>
<td>30 dynes/cm</td>
</tr>
<tr>
<td>Paraffin wax</td>
<td>25 dynes/cm</td>
</tr>
<tr>
<td>Silicone</td>
<td>24 dynes/cm</td>
</tr>
<tr>
<td>Teflon</td>
<td>18 dynes/cm</td>
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When Phases Change
Dewpoint (50% RH, 70°F)

Location of condensation and frost

Exterior sheathing

0°F

70°F
Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005
The inside face of the exterior sheathing is the condensing surface of interest.

- Wood-based siding
- Building paper
- Exterior sheathing
- R-19 cavity insulation in wood frame wall
- Gypsum board with any paint or wall covering

The diagram illustrates the temperature variation throughout the year with specific dew point temperatures at different relative humidities. The potential for condensation is indicated by the shaded area.

- Dew point temp. at 50% R.H., 70°F
- Mean monthly outdoor temperature
- Dew point temp. at 35% R.H., 70°F
- Dew point temp. at 20% R.H., 70°F

The graph shows the temperature in °F over the months from April to May.
The inside face of the insulating sheathing is the condensing surface of interest.

Wood-based siding

R-7.5 rigid insulation

R-13 cavity insulation in wood frame wall

Gypsum board with any paint or wall covering

Mean monthly outdoor temperature

Dew point temp. at 35% R.H., 70°F

Insulation/sheathing interface temperature (R-7.5 sheathing, R-13 cavity insulation as shown in adjacent drawing)

Potential for condensation

Month

Temperature (°F)
Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.
Outside

Condensation and frost accumulating on underside of roof sheathing

Attic

Attic insulation

Inside

Dewpoint
Outside

Roof sheathing

Condensation and frost accumulating on underside of roof sheathing

Attic

Condensation and frost accumulating on top of attic insulation

Inside

Attic insulation

Roof sheathing and top of attic insulation are radiation-coupled

Radiation to night sky
The Best For The Last....
Hydrostatic head

Cladding
### Pascals vs. mph

<table>
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<tr>
<th>Pascals (Pa)</th>
<th>mph</th>
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<tbody>
<tr>
<td>50</td>
<td>20 mph</td>
</tr>
<tr>
<td>100</td>
<td>30 mph</td>
</tr>
<tr>
<td>150</td>
<td>35 mph</td>
</tr>
<tr>
<td>250</td>
<td>45 mph</td>
</tr>
<tr>
<td>500</td>
<td>65 mph</td>
</tr>
<tr>
<td>1,000</td>
<td>90 mph</td>
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**Wind Speed (mph) vs. Stagnation Pressure (Pa)**

- **x-axis** (Pa)
- **y-axis** (mph)
Rain Screen
Beer Screen?