Introduction: (Names can change, I just put whoever for now)

All: Our names are Paige, Matt, Isaac, Ryan, and JT and we dissected the inkjet printer.

In our slides, we make the assumption that water and ink have similar enough fluid properties that they are equivalent, so we use water to walk through relevant ideas.

Capillary Action Slide

Ryan: The governing fluid principle of the inkjet printer is **capillary action.**

Capillary action is how a liquid can move through small spaces without an applied force. This happens because of **Adhesion, Cohesion, and Surface Tension**

Adhesion is the liquid being attracted to the solid surface

Cohesion is the liquid attracted to itself

Surface tension is the liquid surface acting similar to a stretch skin

Matt: In the slide, the images demonstrate **Wetting and Non-wetting** with Water and Mercury

A surface is **Wetting** if a liquid spreads out instead of beading when placed on the surface

A surface becomes wetting when **adhesion becomes stronger than cohesion**

- Liquid attracted to the surface rather than itself
- **Surface tension** is overcome and the liquid spreads
- Liquid climbs the walls if surface is wetting

A surface becomes non-wetting when **cohesion is stronger than adhesion**

- Liquid is attracted to itself more than the surface
- **Surface tension** keeps the liquid surface rounded
- Liquid pulls away from the walls if surface is non-wetting

Something we will talk about later is the **contact angle** that results from wetting: it is the angle that forms where a liquid meets the solid surface

Governing Equations Slide

Paige: With that brief introduction to capillary action, I am going to walk you through one of the governing equations, Laplace Pressure

The General Laplace Pressure equation is given by $\Delta p = \gamma\kappa$

- Δp is the pressure difference between water and air, the fluids on either side of the surface.
- Gamma is the surface tension value of a liquid
- Kappa is the curvature given by $\frac{1}{r_1} + \frac{1}{r_2}$, where r_1 and r_2 are radii in perpendicular principle directions

When the model is static, we can assume it is a perfect sphere where r_1=r_2=r so that $\Delta p = \frac{2\gamma}{r}$.

However, because the drop is not a perfect sphere when getting dispensed out of the inkjet, we have to account for the different radii as it is a dynamic model.

We will go more in depth about this later, but the overarching idea is that the bulge has a small delta p compared to the tail, causing an induced force that wants to push the tail back into the bulge to create a perfect sphere. The thermal actuator pressure has to overcome this Laplace pressure (and viscous losses), and when it does enough work the droplet becomes free.

In this model, it is assumed that there are no viscous losses to simplify the model.

When the droplet is free from the main fluid, we can then reassume it is a perfect sphere where r_1=r_2=r so that $\Delta p = \frac{2\gamma}{r}$.

Using this equation, delta p is inversely proportional to r: $\Delta p \sim \frac{1}{r}$ so if you cut the radius in half, the laplace pressure doubles for the static model.

There is an equation that describes the laplace pressure given a contact angle with a container of diameter d; we can do this because it is a static model (r_1+r_1 = r) and we only care about the vertical surface tension force at the wall, as this is where the capillary action force acts on the fluid. Cosine gives us the vertical component for this surface tension and the equation for the capillary pressure becomes $\Delta p = \frac{2\gamma\, cos(\theta)}{r}$.

Isaac: Another equation that governs the inkjet printer is the Navier Stokes equation. This equation is written as $\rho(\frac{\partial v}{\partial t} + v \cdot \nabla v) = - \nabla p + \mu \nabla^2 v$ and is basically newtons 2nd law for fluids
Essentially this says: the ink accelerates because of pressure forces and is resisted by viscous forces.

On the LHS, $\rho(\frac{\partial v}{\partial t} + v \cdot \nabla v)$

- Rho is the density and tells us how hard something is to accelerate
- $\frac{\partial v}{\partial t}$means how fast the velocity at a point is changing with time
- $v \cdot \nabla v$ measures how velocity changes as ink moves

- Putting it together:

On the RHS, $-\nabla p + \mu\nabla^2 v$

- $-\nabla p$ means fluid flows from high pressure to low pressure
  - In the inkjet, pressure comes from laplace equation that holds the ink in place, the thermal bubble that drives ejection and the bubble collapse that drives refilling
- $\mu\nabla^2 v$ represents the friction within the ink

Paige or Matt: The final equation that governs the inkjet printer is the Washburn equation

$$L = \sqrt{\frac{\gamma dt \cos\theta}{4\mu}}.$$

L - the length water penetrates to
The constant pressure difference generates a pressure gradient that decreases with time

This applies to the refill mechanism of printers. This helps estimate How quickly a nozzle can refill after firing. Additionally, it is utilized to ensure ink will not spontaneously drip.

IF refill is too slow, there will be missing dots, faint printing, streaking, or nozzle starvation. If capillarity is too strong, ink may drool out of the nozzle.

Inkjet Dispensing Process Slide

JT: Now, I am going to explain how each of these governing equations applies to the inkjet printer alongside illustrations at each point

1. Resting State
2. Thermal Actuator turns on
3. Capillary Barrier is overcome
4. Surface Tension creates a droplet
5. Bubble collapses and the pressure decreases
6. The chamber refills and reset