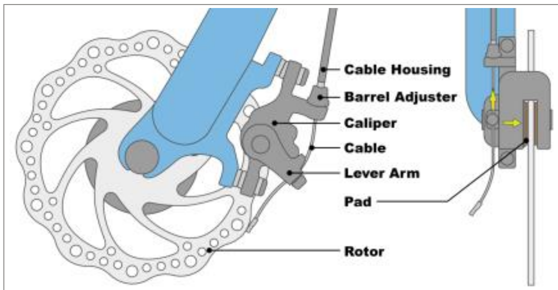
Bike brakes

Monday, January 6, 2025 9:10 PM

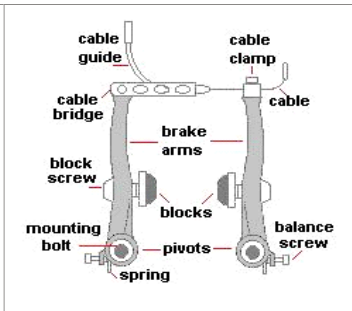
Bike Brakes Learning objectives

- Understand the role of bike brakes in cycling safety and performance.
- Identify the types of bike brake systems (rim brakes, disc brakes, drum brakes).
- Explore the materials used in brake pads and rotors.
- Explain why ceramic composites are used in high-performance brake systems.
- Compare the properties of metals, ceramics, and composites in brake components.
- Discuss the thermal properties of brake materials and their role in preventing brake fade.
- Identify common failure modes of bike brakes (e.g., brake fade, rotor warping).
- Discuss real-world applications and advanced designs.

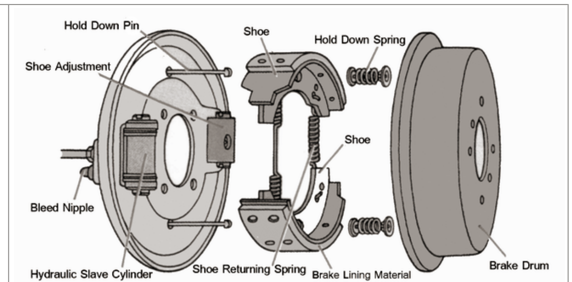
Brake Anatomy



https://cyclingsavvy.org/wp-content/uploads/2024/06/mechanical-brake-diagram.jpg



https://upload.wikimedia.org/wikipedia/commons/3/33/Brake_Drawing_3.jpg



https://4mechtech.blogspot.com/2014/10/drum-brake-service.html

- **Brake Lever:** Transmits force from the rider's hand to the braking mechanism.
- **Caliper:** Houses the brake pads and applies pressure to create friction.
- **Brake Pads:** The components that make contact with the rotor or rim to generate stopping power.
- **Rotor (Disc Brakes):** A circular disc attached to the wheel that the pads clamp onto to slow the bike.
- **Housing and Cables:** Transfer force from the lever to the caliper (in mechanical systems).

Roles of the Brake

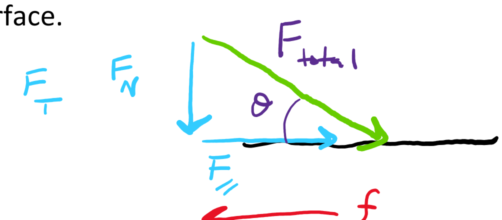
- Provide mechanism for deceleration. Should be consistent whether fast or slow, wet or dry, new or old
- Convert kinetic energy to thermal energy via friction

$PE = mgh$

$70kg \cdot 6.6 \times 10^{-11} \frac{m^3}{kg\, s^2} \cdot 1200m$

Scientific Terms

- **Friction** (f): A force that opposes motion when two surfaces are in contact.
  - Depends on which materials are in contact (coefficient of friction μ), surface roughness, and the **normal force** (N) which is the force acting perpendicular to the contact surface.
  - $f = \mu N$
- **Kinetic Energy** (KE): The energy an object has due to its motion
  - Depends on the mass of the object (m) and it's velocity (v)
  - $KE = \frac{1}{2}mv^2$



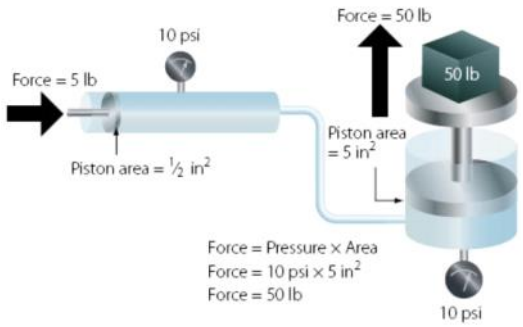
- **Thermal Energy**: The total energy of all the particles in a substance due to their random motion.
  - An object at a higher temperature has more thermal energy than a lower temperature object
- **Hydraulic Forces**: Forces transmitted through a fluid (like in hydraulic brakes).
  - Pascal's Law states "A change in pressure in a confined fluid is transmitted equally in all directions"
  - $F_1 A_1 = F_2 A_2$

$\sin\theta = \frac{F_N}{}$

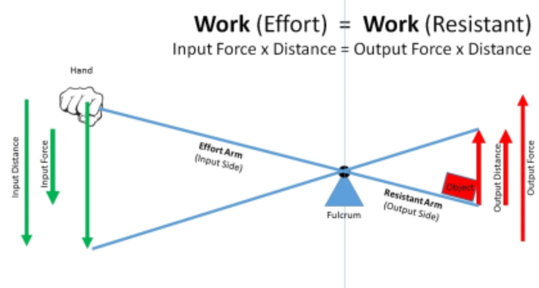
Force = 50 lb

$\sin \theta = \frac{\sim}{F_{total}}$

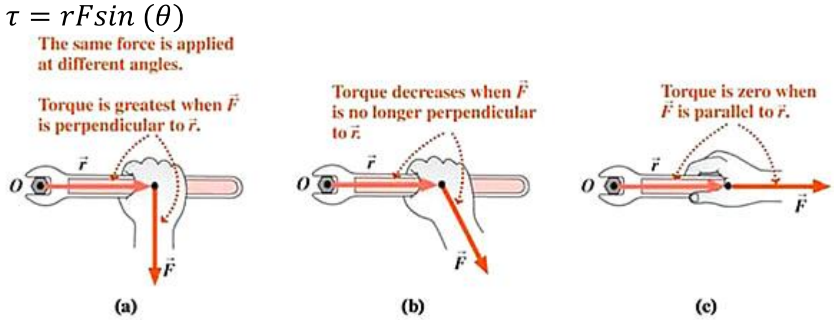
$F_N = F_{total} \cdot \sin(\theta)$

- 

  http://avstop.com/ac/Aviation_Maintenance_Technician_Handbook_General/3-30.html

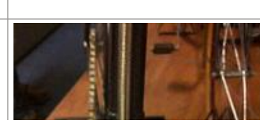
- **Levers and mechanical advantage** (MA): A lever is a rigid bar that rotates around a pivot point (fulcrum) to amplify force.
  - $MA = \frac{Load}{effort} = \frac{Effort\ arm\ length}{Load\ arm\ length}$
  - 

  https://vhmsscience.weebly.com/uploads/1/2/7/6/12762866/5053269_orig.jpg
- **Torque** (τ): A measure of the force causing an object to rotate.
  - Depends on the distance from the point of rotation (r, "pivot point"), F the force applied, and θ the angle between the force and the lever arm
  - $\tau = rF\sin(\theta)$



  - https://www.engineering.com/wp-content/uploads/2024/04/torque2.jpg
- **Heat capacity** (C_p): The amount of heat energy (Q) required to raise the temperature of a substance by 1 degree Celsius.
  - $Q = mC_p\Delta T$
- **Hardness**: a materials resistance to local plastic deformation (scratching)
- **Thermal conductivity** (κ): a measure of how well a material transfers heat
  - $Q = \frac{\kappa A \Delta T}{d}$
  - Q is heat transfer rate, A is cross sectional area, ΔT is the temperature difference, d is the thickness

History of bike brakes

Even the first laufmaschine had a pivoting metal shoe on the rear wheel that could provide braking	
Spoon brakes (aka plunger brakes) - Used on penny farthing bikes all the way through safety	

bicycles
- Pad was leather or rubber on a metal shoe or spoon pressed onto the top of the front tire (onto the rubber, not the rim)
- Very sensitive to road condition like wet vs dry
- Degrades tire rapidly
- Remained until 1930s for adult bikes, 1950s on kid bikes
- Front tire only

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcROpkxf3P1g1UGrNIQXhkEOh3Qs3uClxmjjLw&s

1897 Duck brakes
- Twin friction rollers pressed against the front tire
- Longer lever, more force, better stopping power

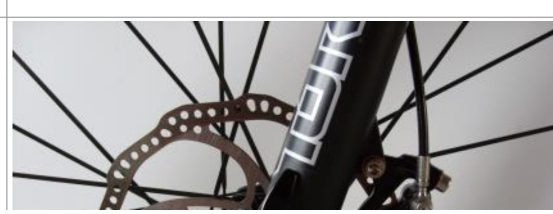
https://infolific.com/images/bicycling/duck-brake.png

Rim brakes
- Friction force is applied directly to the rotating rim material instead of the tire.
- Leather, rubber, or cork mounted on a metal shoe actuated by a cable connected to a lever.
- Cheap, easy to maintain, mechanically simple, strong, light weight compared to disk options
- Perform poorly on wet rims, uneven braking or unwanted friction if the rim is even slightly bent, clogging with snow or mud, uneven wear on pad, potential damage to rim, less mechanical advantage on wide rims/tires, drift over time causing non-centering
- Still extensively used on road bikes

Many different varieties!
- Stirrup brakes, Single pivot side pull, dual pivot side pull, direct mount, center pull caliper brakes, u brakes cantilever brakes, V brakes, roller cam brakes, delta brakes, hydraulic brakes,

https://en.wikipedia.org/wiki/Bicycle_brake

1890s Disc brakes
- Metal disc called a rotor mounted to the hub so it rotates with the wheel.
- Calipers attached to the fork press a pad against the rotor
- Mechanical force via cable or hydraulic

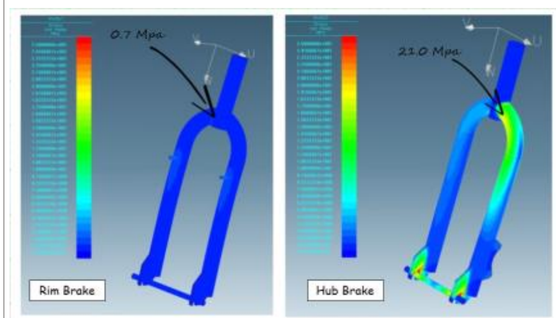


- Adjustment necessary during life of pad so the distance from pad to rotor maintains constant so you have same brake lever "throw"
  - Adjustment can be self-adjusting or manual
- Pads retract when not in use while they lightly brush on vehicles (resistance more important on bikes and faster response valued in vehicles)

Benefits:
- Equal performance most conditions because
- Braking surface further from contamination that accumulates on rim
- Better heat dissipation
- Holes in rotor allow water and mud a path to escape from under pads
- Discs and pads are small so we can use denser, but stronger materials without major weight gain from the rim overall
- Can use even with a buckled wheel
- Disc is easier and cheaper to replace than rim
- Same performance for any tire width
- No issues with bike suspension
- Able to swap wheel sizes

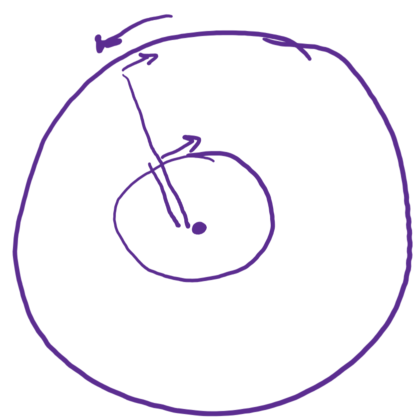
Downsides:
- Hub must be built to accept the disc, fork must be built to accept the caliper.
  - Usually means the wheel is slightly "dished" to make room for disc which leads to less strength
- Smaller torque arm since disc is closer to the hub
- Torque must be transmitted to tire through the myriad rim components (spokes, flanges, etc)
- Bending moment is produced on the fork itself so fork must be overengineered to resist deformation (one study showed 30x more stress!)
- Heat build up is confined to a smaller area
  - If material heats up too much, it will boil brake fluid!
  - Bigger discs, less of a problem
- Get in the way of pannier racks

https://upload.wikimedia.org/wikipedia/commons/thumb/2/21/BrakeDiskVR.JPG/1920px-BrakeDiskVR.JPG



https://www.rodfordbuilt.co.uk/technical/2016/1/19/brakes-forks-and-braking-forks

$$\tau = F \cdot r \cdot \sin(\theta)$$



Drum Brakes
- Shoes are mounted inside the rotating hub and expand to press against the braking surface.
- Consistent braking in any conditions since drum is enclosed within the hub
- Heaving, more complicated, and weaker than rim brakes
- Don't typically allow quick release axels for wheel changes (brake cable and axle must both be disconnected)
- Torque arm must be mounted on frame or fork

https://upload.wikimedia.org/wikipedia/commons/thumb/e/e8/Pashley_Poppy_Drum_Brakes_01.jpg/1920px-Pashley_Poppy_Drum_Brakes_01.jpg

1898 Coaster Brake -Pedal backwards brake	 https://upload.wikimedia.org/wikipedia/commons/thumb/3/35/R%C3%BCcktrittbremse_geschnitten.jpg/330px-R%C3%BCcktrittbremse_geschnitten.jpg

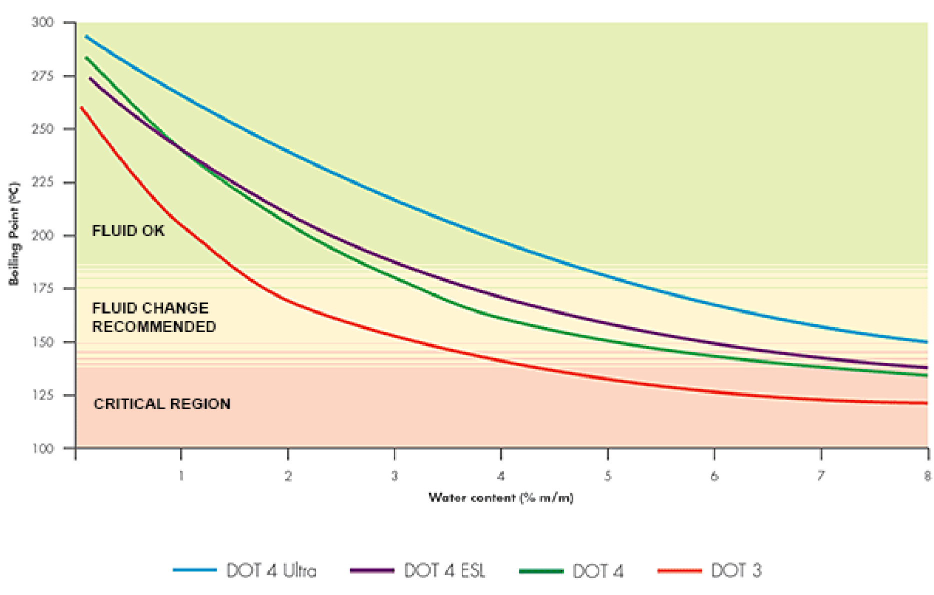
Brake failure

- Brake fade
  - Vented rotors
- Brake warping
- Wear

Brake materials

- Cable
  - Stainless steel
    - High stiffness means better response, but also less flexible in routing to the brake.
    - High strength unlikely to yield
  - Coated steel (Teflon or polymer coatings)
    - Coatings reduce friction prevent corrosion and improve responsiveness
- Brake Fluid
  - Mineral oil (noncorrosive, but lower boiling point ~180C)
  - DOT glycol ether compounds. 70-80% glycol ether as solvents, 20-30% polyethylene or other lubricants
    - (corrosive to paint, higher boiling point ~230C)
    - Hygroscopic (it absorbs water) which degrades performance

The impact of water content on Shell DOT brake fluid boiling point

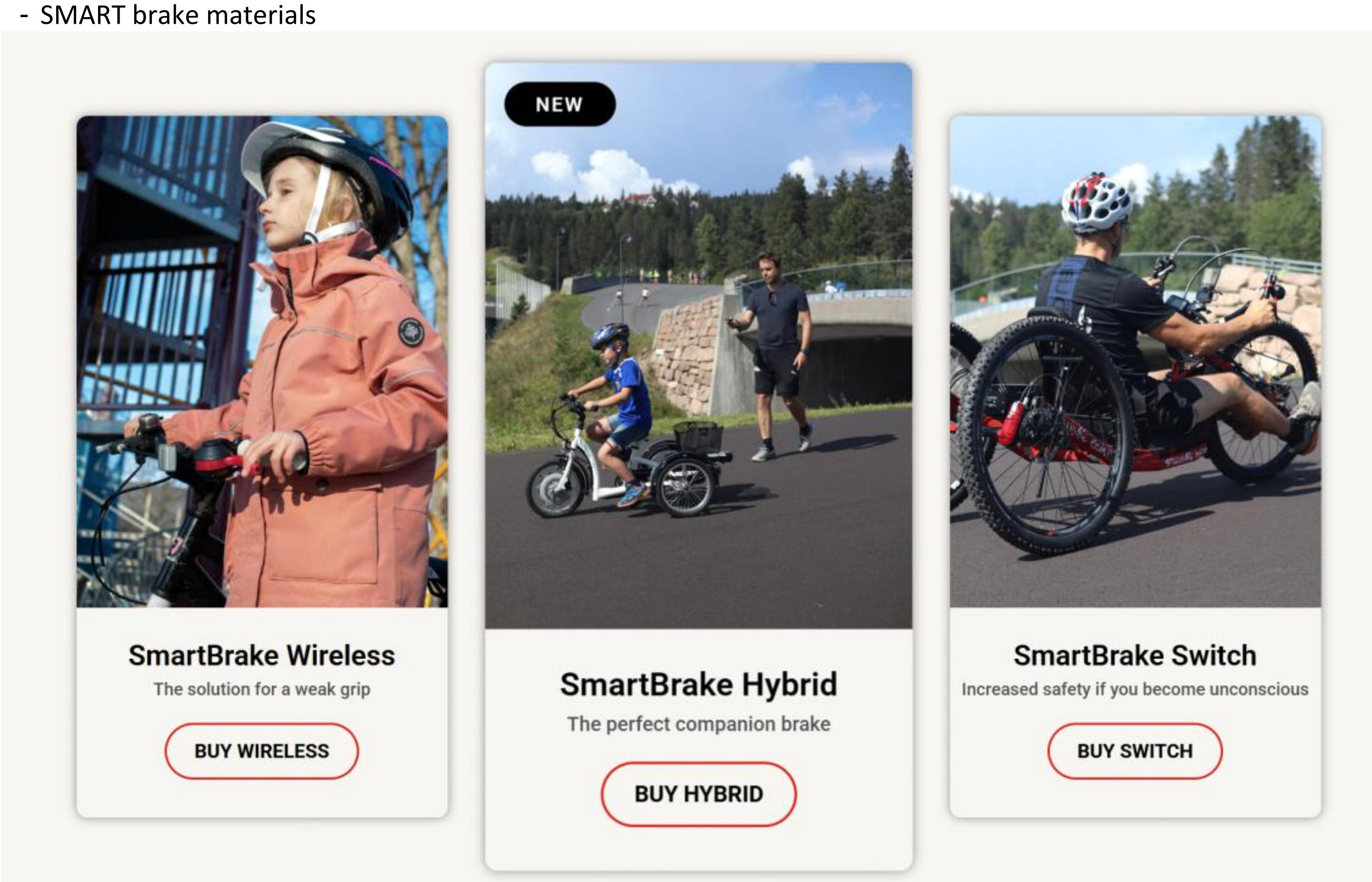
  - 

  - Need to match fluid to seal choice to avoid swelling/leaking. Boiling point is highly susceptible to water content from air etc

- Pad
  - Polymers like kevlar or carbon fiber in a resin binder
    - Quiet, smooth braking, faster wearing, less effective wet, high temperature degradation
  - Metal powders bonded together (copper or steel)
    - Good durability and heat resistance, noisier, harsher on discs
  - Ceramics like silicon carbide or aluminum oxide
    - Lightweight, heat resistant, quiet, expensive, prone to cracking
- Disc
  - Stainless steel or "high carbon steel" (more on this next module)
    - Excellent strength and wear resistance, high thermal conductivity, higher density, high wear
  - Aluminum with a steel braking surface (composite design)
    - Lightweight, but overheats faster
  - Ceramic composite like Reinforced carbon-carbon (carbon fibers in a graphite matrix), ceramic matrix composites (fibers with the matrix made of ceramics)
    - Highest performance
    - Combine ceramic with metal matrix for excellent thermal resistance and reduced weight.

Future of brakes

- SMART brake materials



- Self-healing ceramics
- Adaptive braking via shape memory alloys
- Recycling of worn brakes
- Sensors for monitoring wear and thermal performance