1. Mind Map: Rolling Without Slipping

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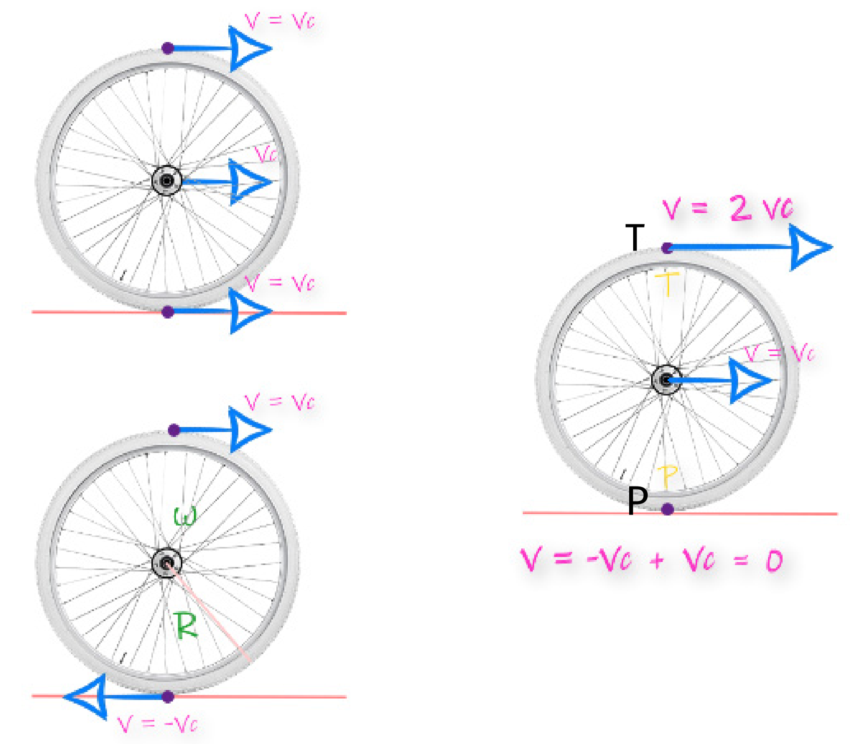
- **Rolling Without Slipping**
  - The Concept
    - Think of (1) Smooth motion without slipping, sliding, or bouncing. (2) No relative motion between the rolling object and the surface.
      - e.g., bicycle wheels, bowling balls, rolling cans
    - Made of 2 Types of Motions
      - Translation (center of the wheel moves in a straight line)
      - Rotation (wheel spinning around its axis)
      - Translation + Rotation = Rolling
  - Diving Deeper
    - Center (O) and Contact Point (P)
      - Center of wheel (O) moves at speed v_*center of mass*
      - Contact point (P) also moves forward at v_*com*
    - Geometry of rolling
      - Distance moved by COM in time t is s. Point P also moves the same distance s in an arc. Therefore $s = \theta R$ (eq. 1)
      - Differentiation (eq. 1)
        - $ds/dt = v_{com}$
        - $d\theta/dt = \omega$
        - $v_{com} = \omega R$
    - Condition for Rolling without Slipping
      - $v_{com} = \omega R$
    - Example of Rolling WITH Slipping
      - Racer accelerating: $\omega R > v_{com}$
      - Evidence of Rolling with Slipping: Smoke due to friction and heating.
  - Key Observations
    - Bottom point (P): Rotational tangential velocity cancels the forward translation velocity. Momentarily stationary (v=0)
      - Zero velocity ensures no skidding
    - Top point (T): Moving at $2\,v_{com}$
    - Time exposure image of a rolling wheel: spokes at top blurred (high velocity). Bottom spokes visible (low vel.)



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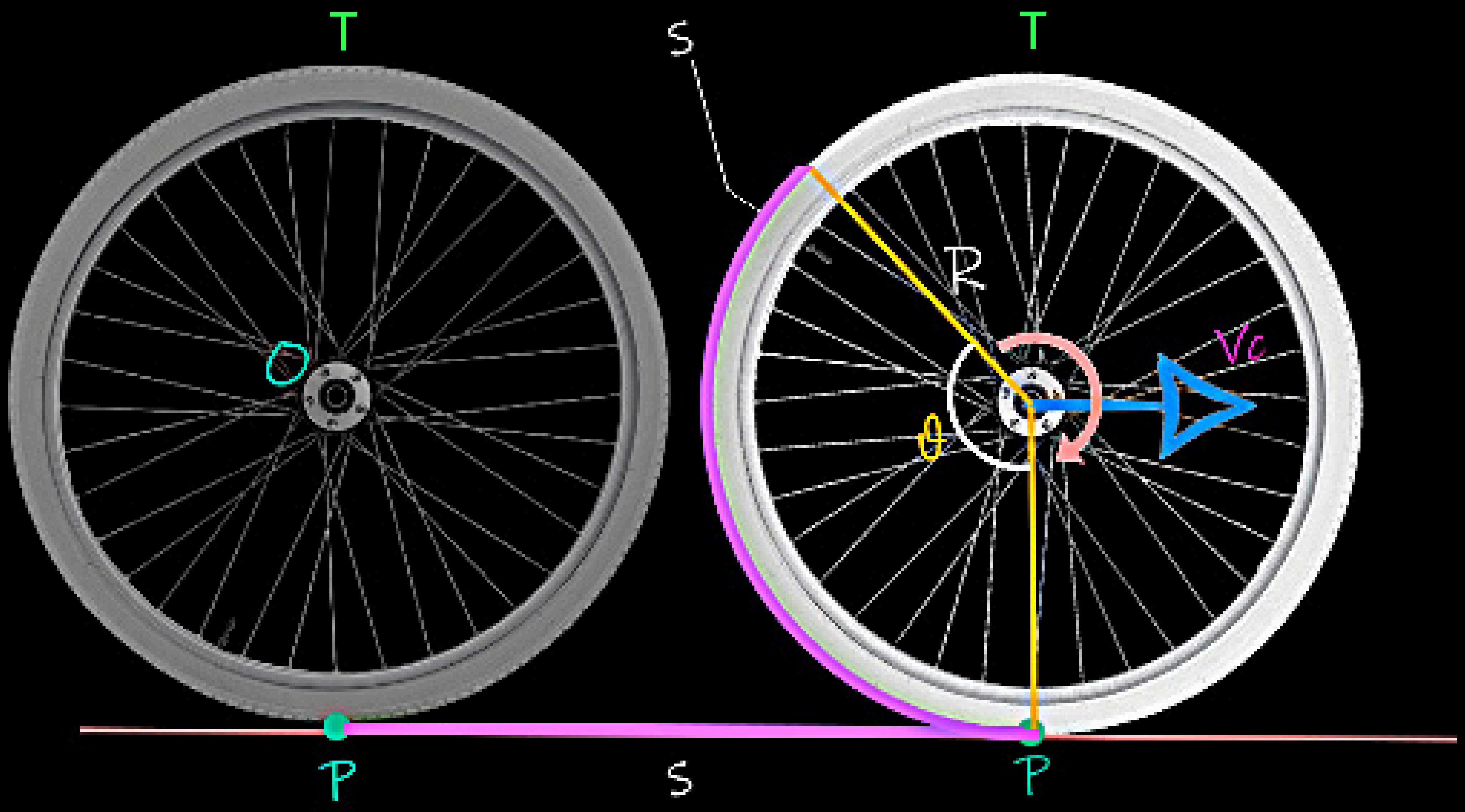

$s = \theta R$

$ds/dt = (d\theta/dt)R$

$V_c = \omega R$

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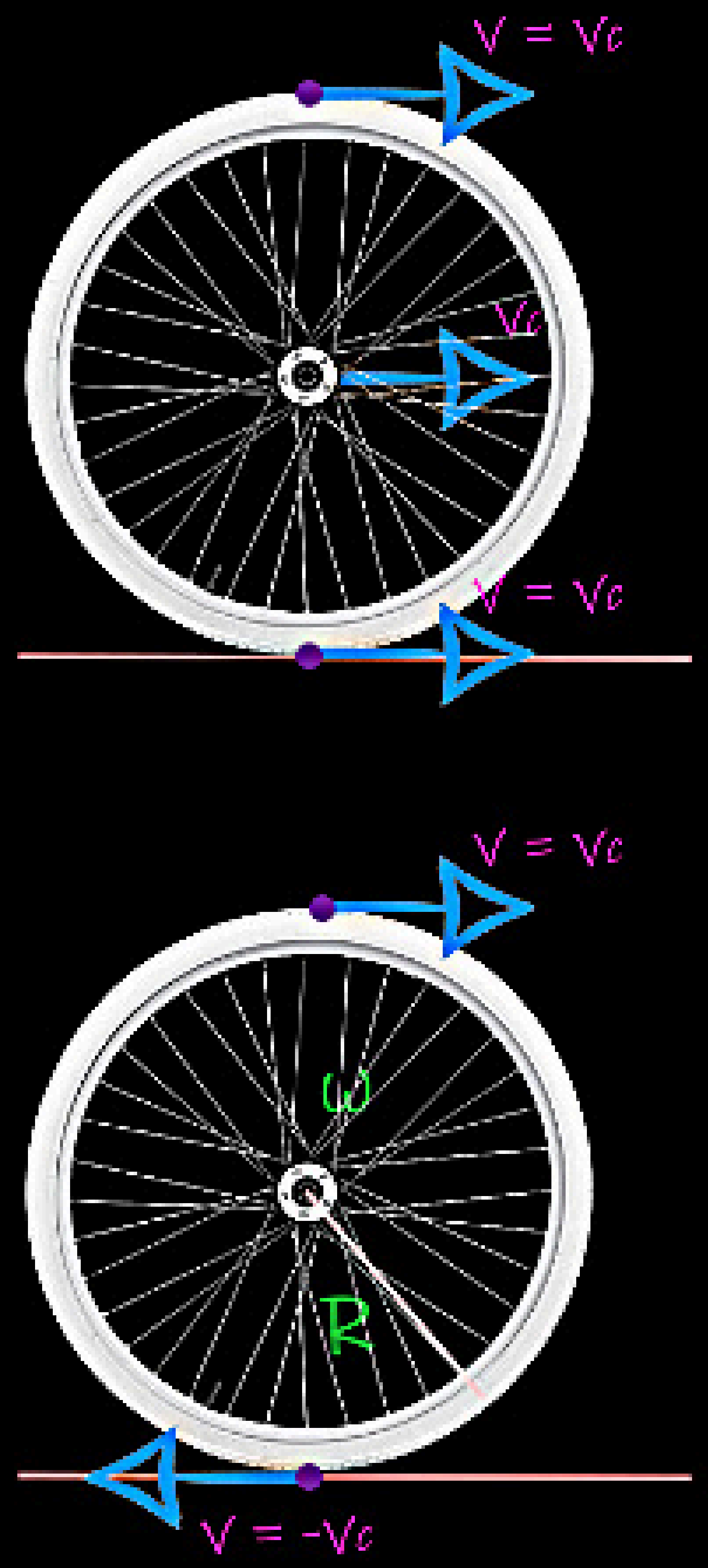
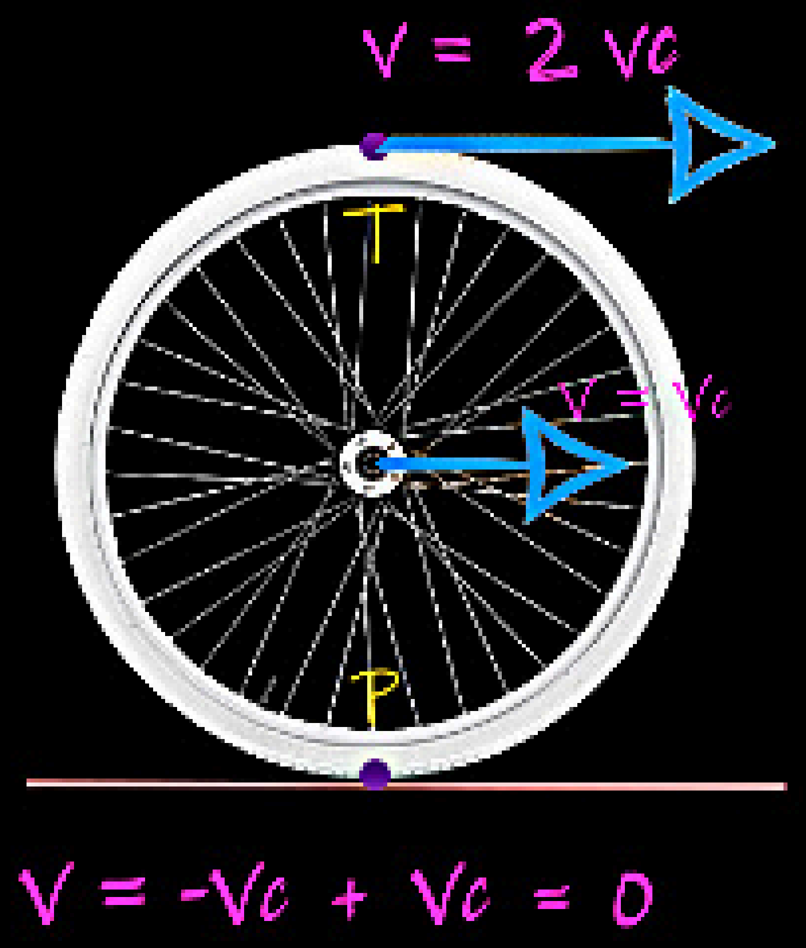


- Velocity vectors at top add up
- Velocity vectors at bottom cancel



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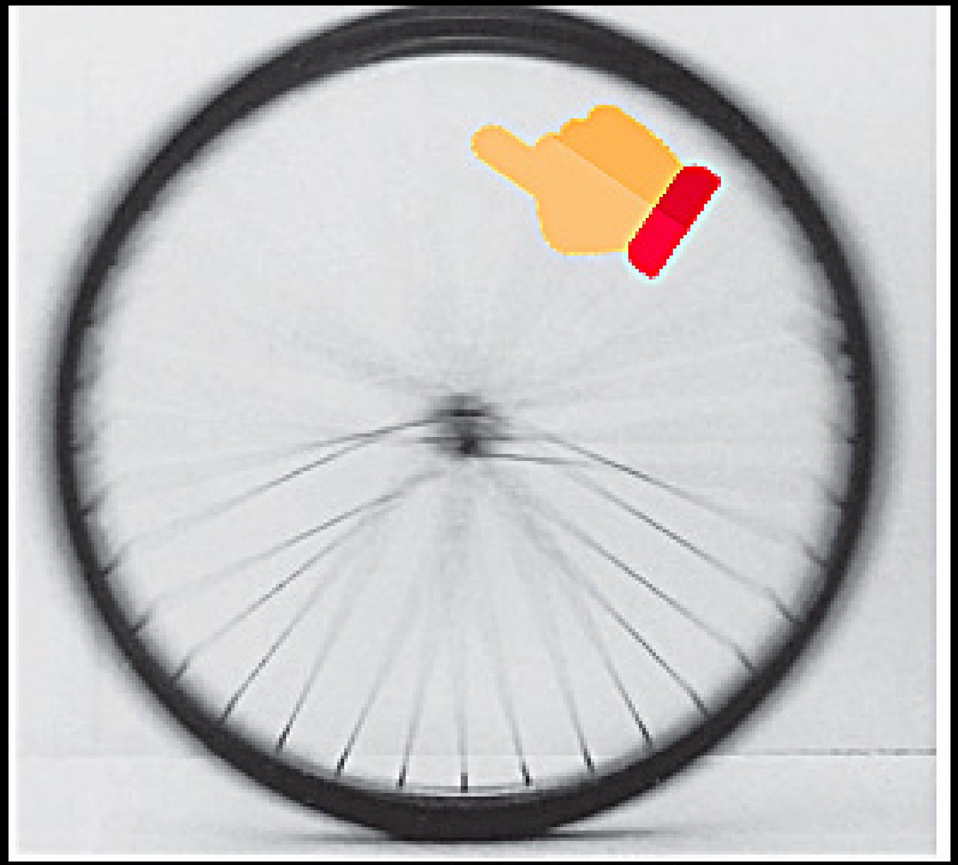

- Spokes in the upper part of the wheel look blurred compared to the lower part
- This indicates higher velocity at the top compared to the bottom