

# Bicycles

Turn off all electronic devices

## Observations about Bicycles

They are hard to keep upright while stationary  
 They stay upright easily while moving forward  
 They require leaning during turns  
 They can usually be ridden without hands

## 5 Questions about Bicycles

1. Why is a stationary tricycle so stable?
2. Why is stationary bicycle so unstable?
3. Why does a moving tricycle flip during turns?
4. Why must you lean a bicycle during turns?
5. Why can you ride a bicycle without hands?

## Question 1

Q: Why is a stationary tricycle so stable?

A: The tricycle is in a stable equilibrium

A system with a stable equilibrium has restoring influences

- that tend to restore the system to equilibrium following a disturbance

An upright tricycle and rider are in a stable equilibrium

- The tricycle's three contact points with the ground define a base of support
- The upright pair's center of gravity is above that base of support
- and tipping the tricycle raises that center of gravity,
- which increases the pair's gravitational potential energy.
- They accelerate in the direction that reduces their total potential energy,
- so they tend to return to the equilibrium—the stable equilibrium.

A tricycle is statically stable (stable at rest)

## Question 2

Q: Why is stationary bicycle so unstable?

A: The bicycle is in an unstable equilibrium

A system with an unstable equilibrium has leaving influences

- that tend to make the bicycle leave equilibrium following a disturbance

An upright bicycle and rider are in an unstable equilibrium

- The bicycle's two contact points with the ground define a line of support
- The upright pair's center of gravity is above that line of support,
- but tipping the bicycle about the line lowers their center of gravity,
- and decreases the pair's gravitational potential energy.
- They accelerate in the direction that reduces their total potential energy,
- so they tend to tip away from the equilibrium—the unstable equilibrium.

A bicycle is statically unstable (unstable at rest)

## Question 3

Q: Why does a moving tricycle flip during turns?

A: Inertial effects overwhelm its static stability

The tricycle's wheels accelerate toward the inside of a turn

- but rider tends to coast forward because of inertia,
- so the tricycle and rider begin to tip toward the outside of the turn.
- Restoring influences arise and tend to restore the pair to equilibrium.

If the turn's acceleration too rapid,

- the inertial effects will overwhelm the restoring influences,
- so tricycle and rider tip over toward the outside of the turn.
- The tricycle drives out from under their center of gravity

A tricycle is dynamically unstable (unstable in motion)

### Question 4

Q: Why must you lean a bicycle during turns?

A: To balance inertial effects with static instability

If the rider turns without tipping the bicycle

- inertial effects dominate and they tip over toward the outside of the turn.

If the rider tips the bicycle without turning

- leaning effects dominate and they tip over in the direction of the initial tip.

If the rider tips the bicycle toward the inside of the turn

- inertial effects can cancel leaning effects,
- so the rider and bicycle remain at a steady tip throughout the turn.

A bicycle is dynamically stable (stable in motion)

### Question 5

Q: Why can you ride a bicycle without hands?

A: It automatically steers under center of gravity

When a bicycle tips, its front wheel automatically steers toward the tip

- It steers in the direction of the tip,
- so that the bicycle tends to drive back under the pair's center of gravity
- and tends to restore the pair to its unstable equilibrium.
- The bicycle automatically recovers from a tip.

The tipped bicycle's automatic steering involves two effects

- the fork pivots toward the tip so as to reduce the total potential energy
- the ground's torque on the spinning wheel makes it pivot toward the tip
  - The ground's torque does an angular impulse on the tipped wheel,
  - so the wheel precesses—its rotational axis shifts and it pivots toward the tip.

### Summary about Bicycles

Tricycles

- have static stability
- but inertial effects can flip tricycles during turns
- have poor dynamic stability

Bicycles

- are statically unstable
- can tip during turns to avoid flipping
- automatically steer back to unstable equilibrium
- have remarkable dynamic stability