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 outside of turn.

If the rider tips the bicycle without turning

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

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

- inertial effects can cancel leaving 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, it 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