Section 9.3

- Vertical Circular Motion

So far, in describing the motion of an object in a circle, we have ignored the effect of the force of gravitation.

Think about a roller coaster going around a loop. Because of the force of gravity, the speed of the coaster in the circular path is not constant. The coasters car accelerated on the downward path and decelerates on the upward part.

The speed is a minimum at the top of the loop and a maximum at the bottom of the loop.

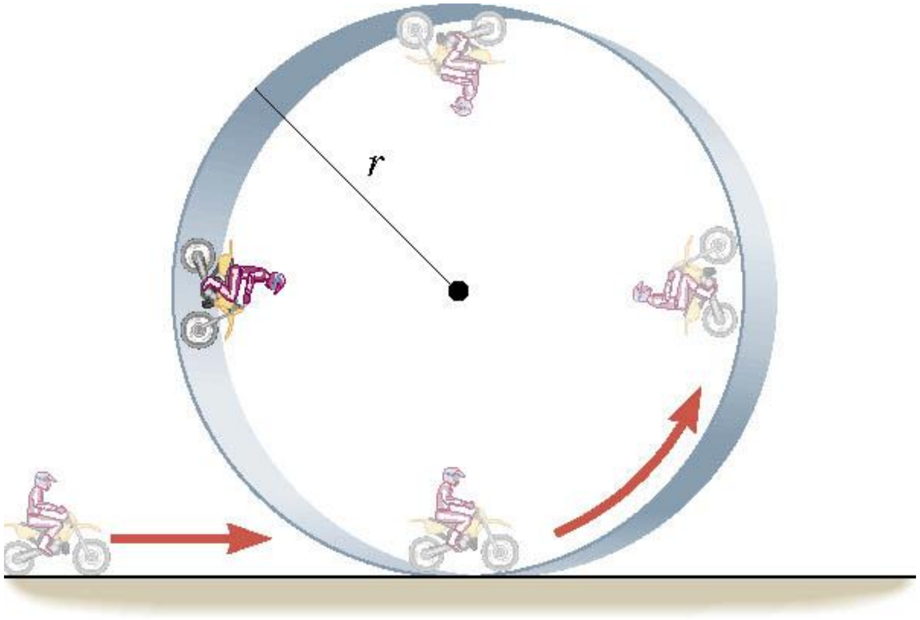
Loop-the-Loop

- As the car or motorcycle goes around loop, the normal force (F_N) is the apparent weight of the person on the motorcycle. This changes as they move around the loop.

- The force you feel, your apparent weight, is the magnitude of the contact force that supports you.

Loop-the-Loop

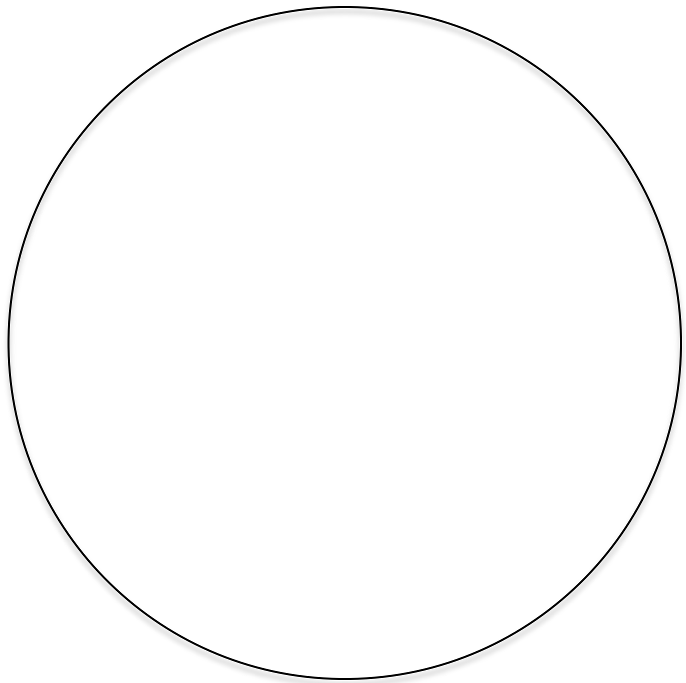
- The apparent weight can be found in four places easily.
- Let's think about a free-body diagram and use Newton's 2nd Law at each location.



Loop-the-Loop – Positions

Position #3

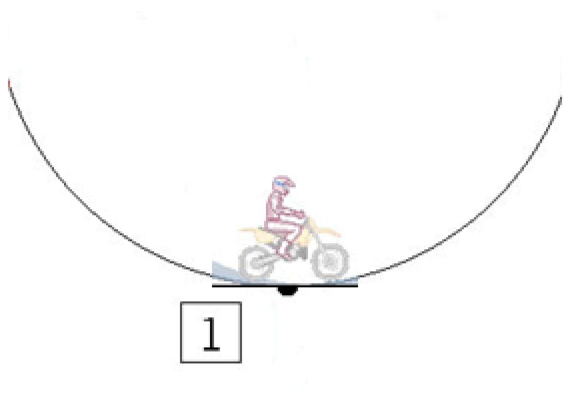
Position #4

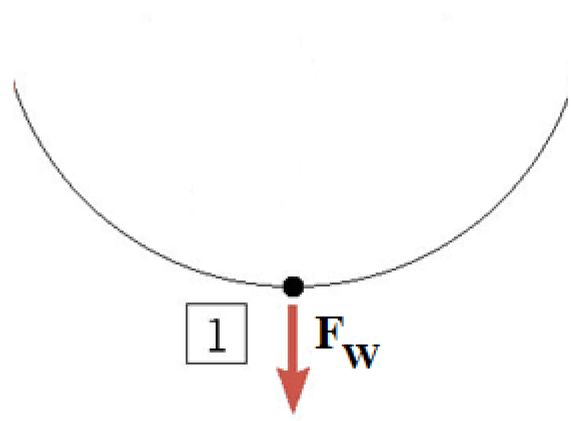


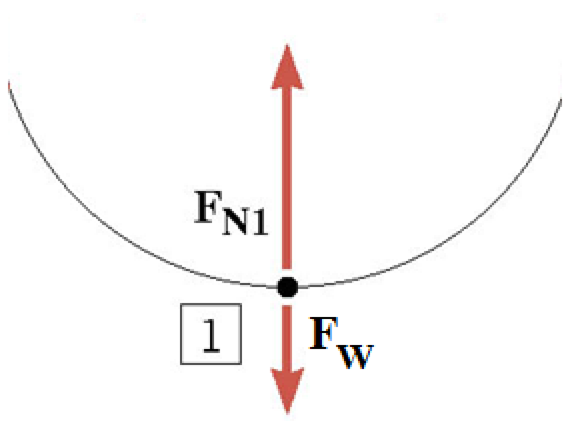
Position #2

Position #1

Loop-the-Loop – Position #1





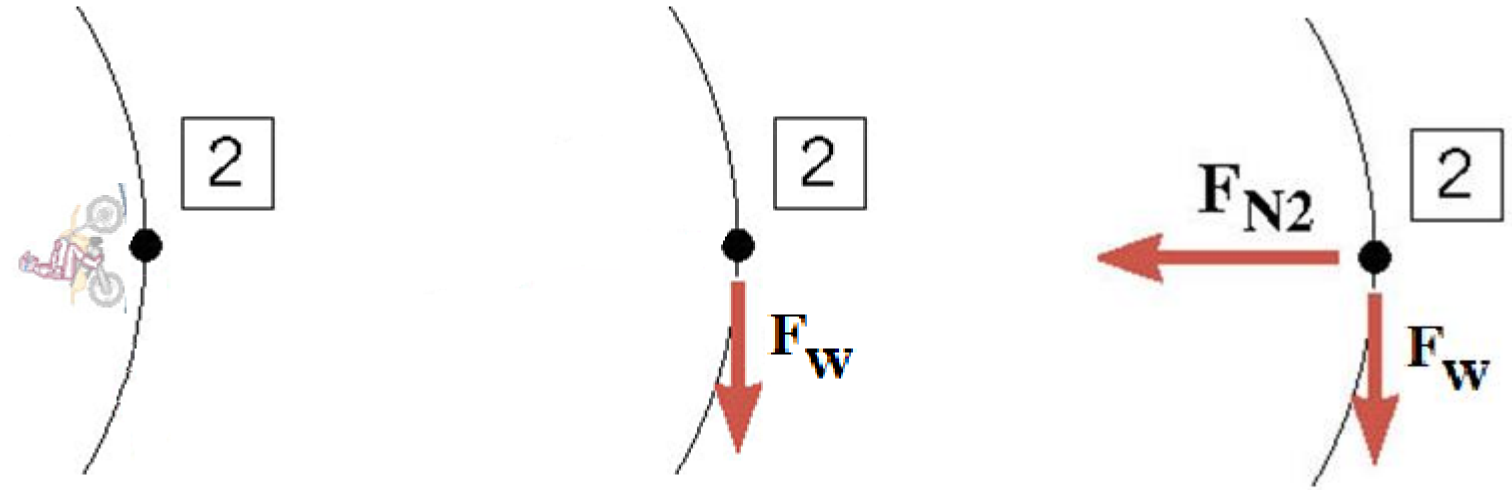


$F_C = ma_c$

$F_{N1} - F_W = ma_c$

$F_{N1} = ma_c + F_W$

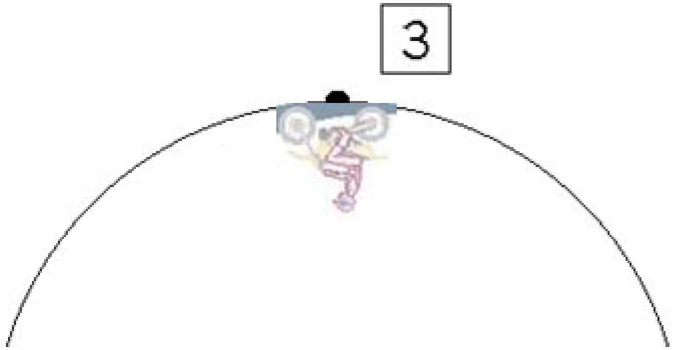
Loop-the-Loop – Position #2

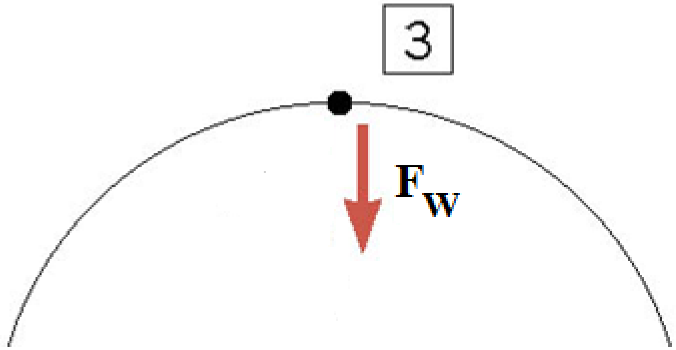


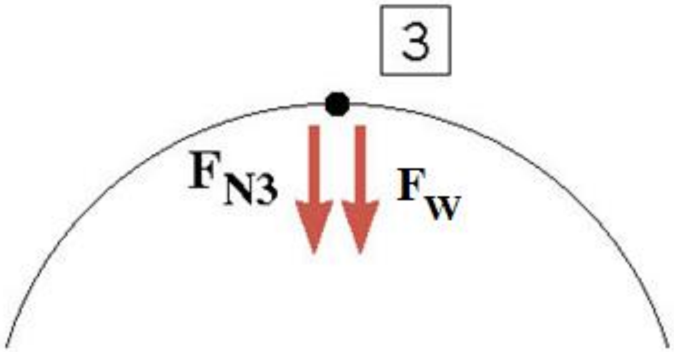
$F_C = ma_c$

$F_{N2} = ma_c$

Loop-the-Loop – Position #3





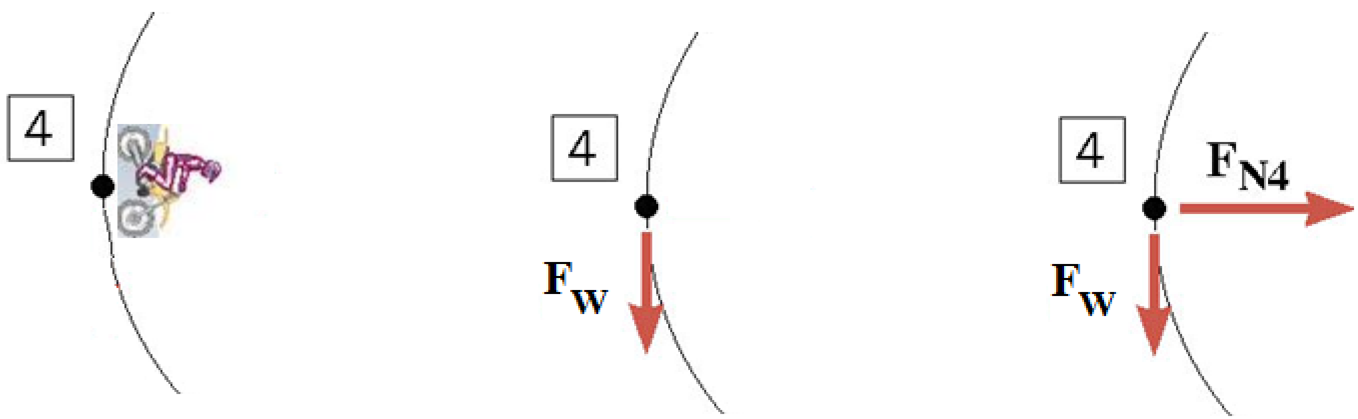


$F_C = ma_c$

$F_{N3} + F_W = ma_c$

$F_{N3} = ma_c - F_W$

Loop-the-Loop – Position #4

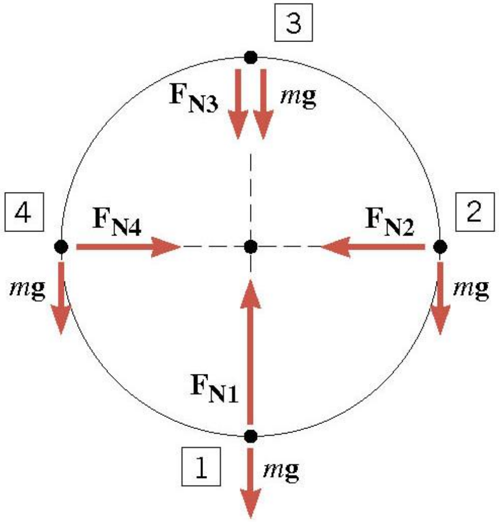


$$F_C = ma_c$$

$$F_{N4} = ma_c$$

Minimum Speed – (Top of Loop)

- *Must have minimum speed at top of loop*
- $F_{N3} + F_w = ma_c$
  - ✓ *Lowest speed :* $F_{N3} = 0$
  - ✓ $F_W = mg$
  - ✓ $mg = ma_c$



$$mg = \frac{mv^2}{r}$$

$$\boxed{V_{min} = \sqrt{g\,r}}$$

MASS…No Effect!!!!!!!!!

<u>Example #1:</u>

A 60 kg person moves along the loop of a roller coaster with a radius of 15 meters and a circular speed of 22 m/s.

a. **What is the apparent weight of the person at the <u>top</u> of the loop?**
b. **What is the apparent weight of the person at the <u>bottom</u> of the loop?**
c. **What would be the <u>minimum speed</u> required for the coaster to continue to move at the top of the loop?**

Example #2

A 2 kg rock swings in a vertical circle of radius 8 m. The speed of the rock is 10 m/s.

a. **What is tension in the rope at the highest point?**
b. **What is the tension in the rope at the lowest point?**
c. **What is the minimum speed needed to keep the rock moving at the top of the circle?**

“G” Forces

- A “G”-Force is a way to quantify the sum of all forces on a person.
- We can experience both positive and negative G-forces.
- A “G”-force is the feeling of weightlessness and the feeling of being heavier than you actually are.

“G” Forces

- Positive “G” force is when you fell really heavy (when you get pushed into the seat while on a roller coaster).

- Negative “G” force is when you feel weightless (when you feel like you or going to fly out of the seat while on a roller coaster)

“G” Forces

- **The force of gravity when you sit, stand or lie down is 1 G, though the total sum of the forces on you is zero.**

- **If you carry someone of the same weight on your back and walk around, you’re feeling a force of 2 G’s.**

“G” Forces

- A person can experience a maximum of 9 positive G’s before blacking out.

- Some say that a human can experience up to 100 G’s for a fraction of a second (the body compresses a little so it doesn’t feel an instantaneous acceleration).

- Roller coasters typically peak at 5 G’s to ensure safety and comfort.

- At >20 G’s there is a potential for death due to internal injuries (organs are moving around).

“G” Forces

- If you accelerate downwards faster than the rate of natural free fall, you will experience what is known as a negative g-force.

- As you accelerate, the liquid in your body (the blood) moves slower than the solid parts of your body due to the inertia of the blood, often resulting in a feeling of weightlessness.

- An example would be travelling in a car accelerating over the crest of a hill, or riding on a rollercoaster that accelerates downwards.

- Negative g-forces can result in a ‘redout’, where the blood gathers in your head and everything has a slight red tinge, something pilots often experience in high-speed dives.

“G” Forces

- **A person can experience a maximum of 2-3 negative G’s before blood vessels in the eyes rupture. Beyond 2-3 results in brain hemorrhage, and other internal disturbances (marked discomfort).**

Calculating "G" Forces (Thrill Factor)

- The Thrill Factor, will be the value of a_c (Centripetal acceleration) divided by the value of g.

$$g's = \frac{a_C}{9.81m/s^2}$$

- This will actually be an expression of the acceleration experienced by the rider, in multiples of Earth's gravity. This is the quantity commonly referred to as G-force.

Highest G-Force on a Roller Coaster (World)

- **Largest: 6.3 G (World)**
  - Tower of Terror (Gold City Reef), Johannesburg, Gauteng, South Africa

Highest G-Force on a Roller Coaster

Highest G-Force on a Roller Coaster

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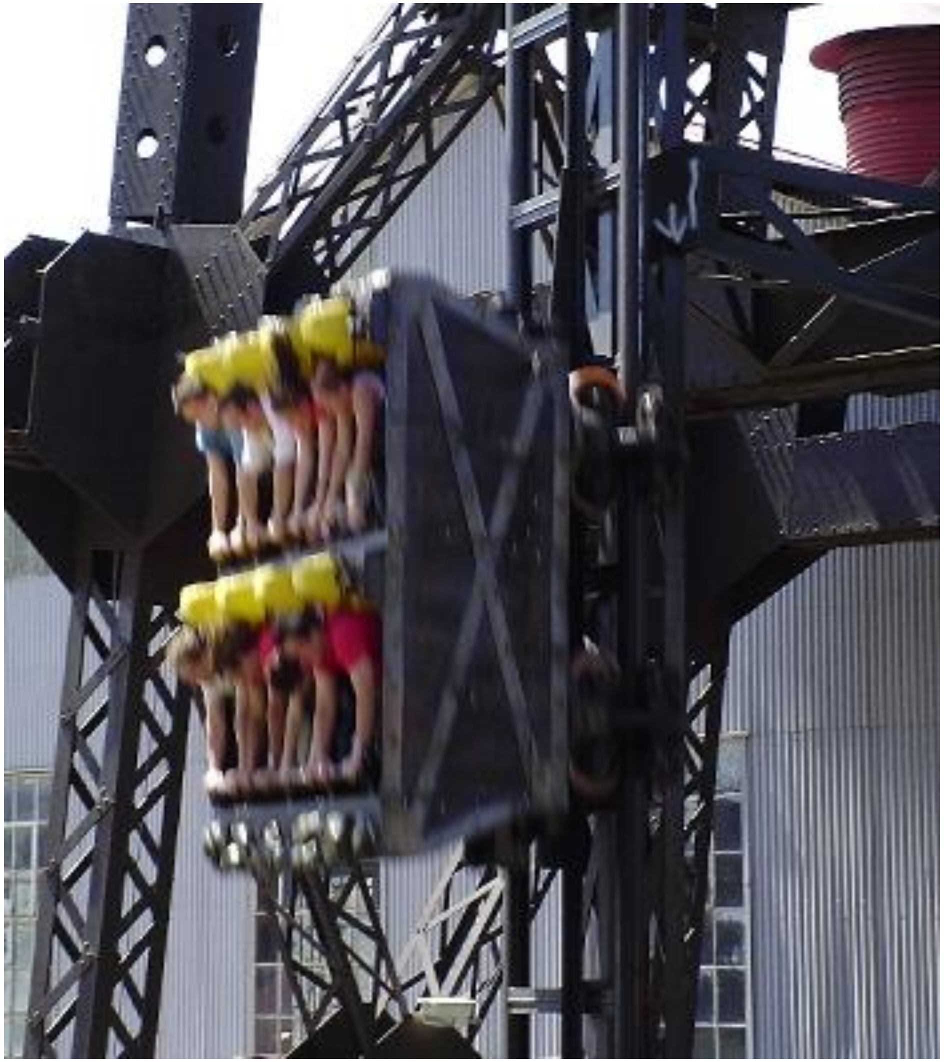
Highest G-Force on a Roller Coaster



Highest G-Force on a Roller Coaster (America)

- Largest: 5.9 G (America)
  - Shock Wave (Six Flags over Texas), Arlington, Texas

Highest G-Force on a Roller Coaster

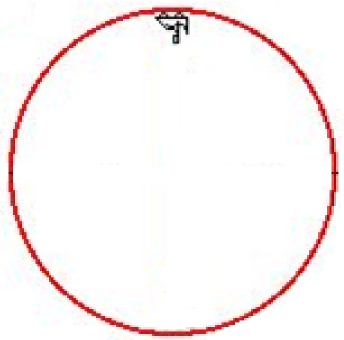
Highest G-Force on a Roller Coaster (Kings Island)

- **Kings Island**
  - Banshee (0-G Turn)
  - The Beast (3.1 G)
  - Vortex (3.9 G)
  - Diamondback (4.2 G)
  - Firehawk (4.3 G)
  - Invertigo (5 G)

"G" forces felt in a loop

- ***g's*** **felt at the top of the loop:**

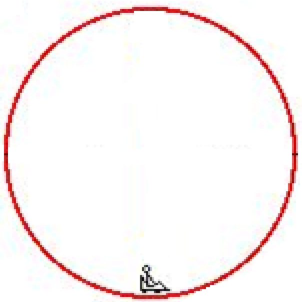
$$g's = \frac{a_C}{9.81 m/s^2} - 1$$



$F_N = ma_c - F_W$

- ***g's*** **felt at the bottom of the loop:**

$$g's = \frac{a_C}{9.81 m/s^2} + 1$$



$F_N = ma_c + F_W$

Example #3

A 1.8 kg stone moves in a vertical circle at constant speed. The stone is attached to a light weight rod 0.5 meters long and makes 0.75 rev/sec.

a. **What is the force exerted by the rod on the stone when it is at the top of the circular path?**
b. **What is the force exerted by the rod on the stone when it is at the bottom of the circular path?**
c. **What is the "G" force at the top of the circular path?**
d. **What is the "G" force at the top of the circular path?**

Example #4

What is the apparent weight of the same 50 kg boy who is now passing over the top of a hill that has a radius of curvature of 21 m and is traveling at a speed of 12 m/s?

Work Problem #1

An amusement park ride spins in a vertical circle. If the diameter of this ride is 5.8 meters, what minimum speed must the ride have so that the 75 kg passenger will remain against the wall when he is in the top position? ***(5.33 m/s)***

Work Problem #2

A 50 kg boy is riding his 1st roller coaster. He encounters the bottom of a small dip having a radius of curvature of 15 m. At the bottom of this dip they are traveling with a speed of 16 m/s and experiencing a much larger than usual normal force.

a. **What is their centripetal acceleration?**
b. **What is the boy's apparent weight?**
c. **How many G's are they experiencing?**