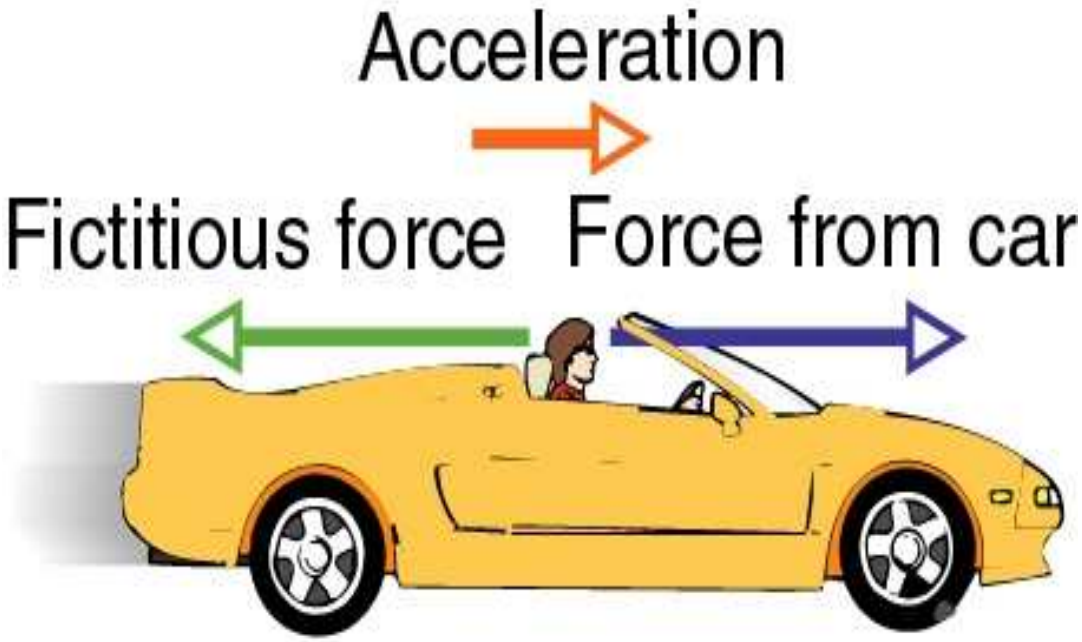
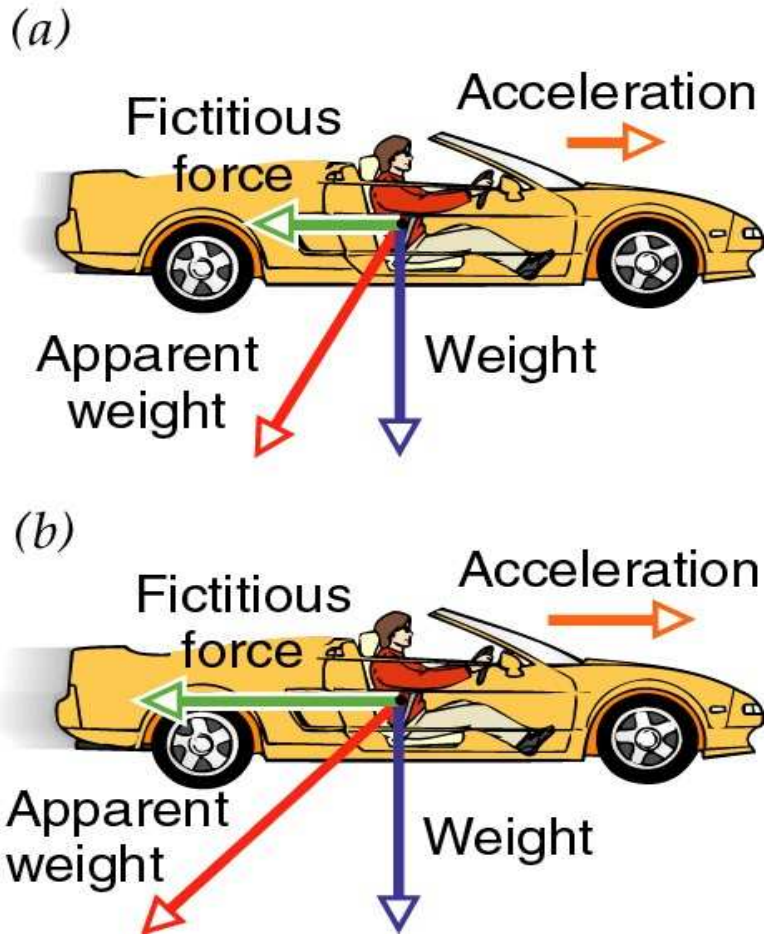
Experiencing Acceleration: The backward force you feel when your car accelerates is caused by your body's inertia.

Chapter 3.3



Feeling of apparent weight: Caused your body's reaction to the push that the seat is exerting to push your body forward when being accelerated.

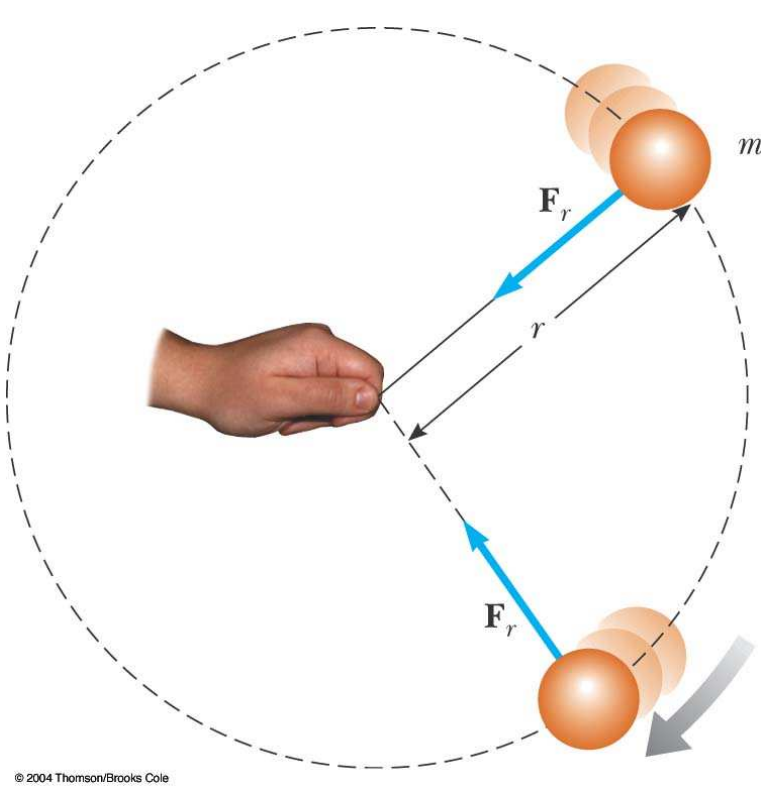


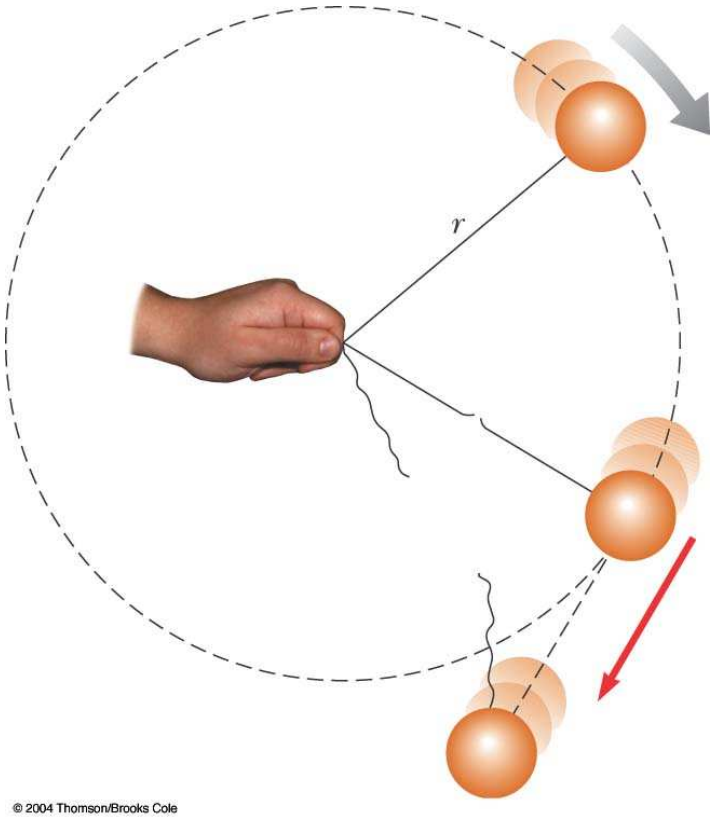
Astronauts at take off feel as if their apparent weight has increased by 200 to 400 percent depending on the acceleration of the vehicle by the launch rockets.

A rocket ship orbiting the earth in a circular orbit is falling towards the earth (centripetal acceleration), so is the astronaut. There is no net force the astronaut feels with respect to the space ship – he is weightless !

Artificial gravity can be generated in a space ship by spinning it rapidly.

Acceleration in circular motion:





- ***Uniform circular motion*** occurs when an object moves in a circular path with a constant speed
- An acceleration exists since the *direction* of the motion is changing
  - This change in velocity is related to an acceleration
- The velocity vector is always tangent to the path of the object

In such motion, the object has a constant angular velocity with respect to its axis of rotation. The relation between its linear velocity and its angular velocity is

Linear speed = radius x angular speed
Angular speed = (2 pi radians) / (period of revolution)

$$\omega = \frac{2\pi}{T} \text{ and } v = R\omega$$

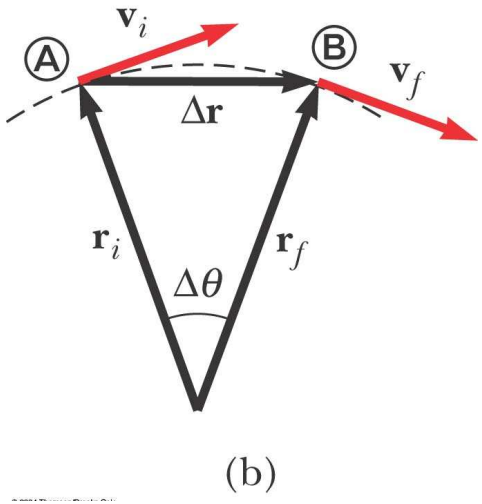
Changing Velocity in Uniform Circular Motion

- The change in the velocity vector is due to the change in direction

angle turned : $\Delta\theta = \dfrac{\Delta s}{r}$

distance covered: $\Delta s = v\,\Delta t$

- The vector diagram shows $\Delta\mathbf{v} = \mathbf{v}_f - \mathbf{v}_i$



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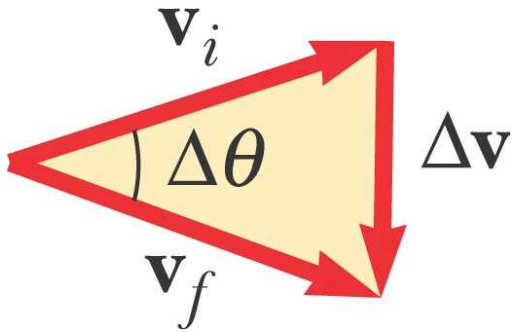


$$\Delta\theta = \frac{\Delta v}{v}$$

Centripetal acceleration: $\vec{a}_c = \frac{\Delta \vec{v}}{\Delta t}$

the change in $\vec{v}$ is due to the angle turned: $\Delta\theta$
and $\Delta \vec{v} = v\,\Delta\theta$ in magnitude

Now we can express : $\Delta\theta = \frac{\Delta s}{r}$

Where Δs is the arc length covered in Δt
which is $\Delta s = v\,\Delta t$

hence $a_c = \frac{\Delta v}{\Delta t} = v\frac{\Delta\theta}{\Delta t} = v\frac{\frac{\Delta s}{r}}{\Delta t}$

which is $= \frac{v}{r}\left(\frac{\Delta s}{\Delta t}\right)$

using $\frac{\Delta s}{\Delta t} = v$

we get $a_c = \frac{v^2}{r}$

Centripetal Acceleration

- The acceleration is always perpendicular to the path of the motion
- The acceleration always points toward the center of the circle of motion
- This acceleration is called the ***centripetal acceleration -towards the center.***

$$a_c = \frac{v^2}{r}$$

- The magnitude of the centripetal acceleration vector is given by

$$a_C = \frac{v^2}{r}$$

- The direction of the centripetal acceleration vector is always changing, to stay directed toward the center of the circle of motion

Centripetal Force: $$F_c = M\frac{v^2}{r}$$

Directed towards the center.

Making a tight high speed turn involves lots of acceleration and a large centripetal force.

Direction of centripetal force is continuously changing although its magnitude is a constant for uniform circular motion.

Newton's Law of Universal Gravitation

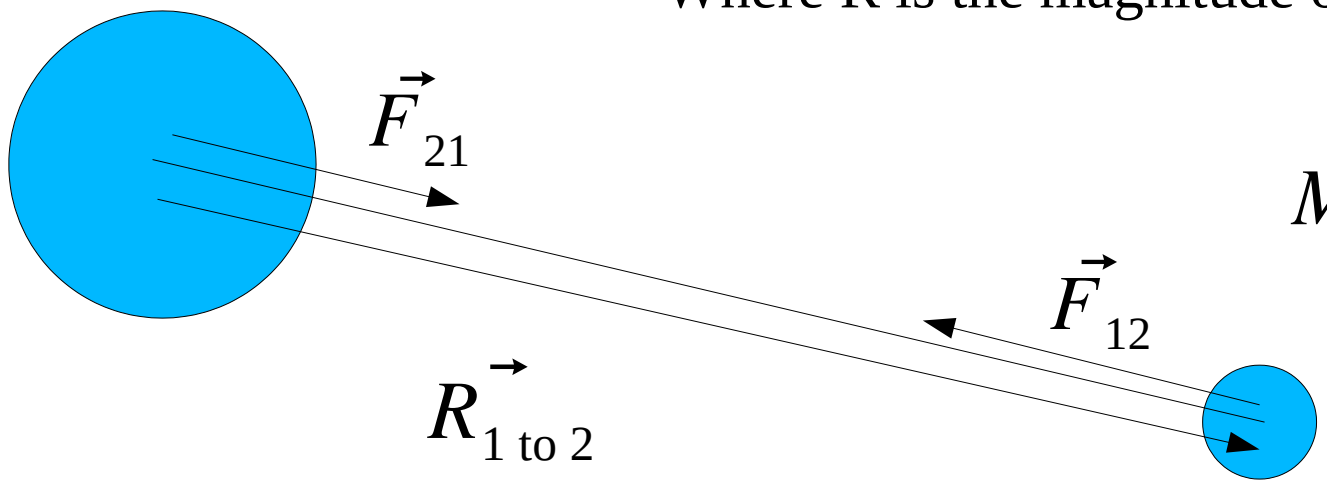
- This is an example of an ***inverse square law***
  - The magnitude of the force varies as the inverse square of the separation of the particles
- The law can also be expressed in vector form

$$\mathbf{F}_{12} = -G\frac{m_1 m_2}{r^2}\hat{\mathbf{r}}_{12}$$

$$\vec{F}_{12} = -\vec{F}_{21}$$

Magnitude $F_{12} = F_{21} = G\dfrac{M_1 M_2}{R^2}$

Where R is the magnitude of $\vec{R}_{12}$ or $\vec{R}_{21}$



This is an example of a centrally directed force.

Earth does not collapse under its own gravity because outward atomic forces balance the inward gravitational forces

Sun does not collapse because the hydrostatic pressure of its gases, which are at high temperature, balance the inward pull of gravity. The source of energy which provides these high temperatures is nuclear reactions at the center of the sun which transform 4 Hydrogen nuclei into one Helium nucleus.

Neutron stars (stars with nuclear densities) are prevented from collapsing by quantum pressure.

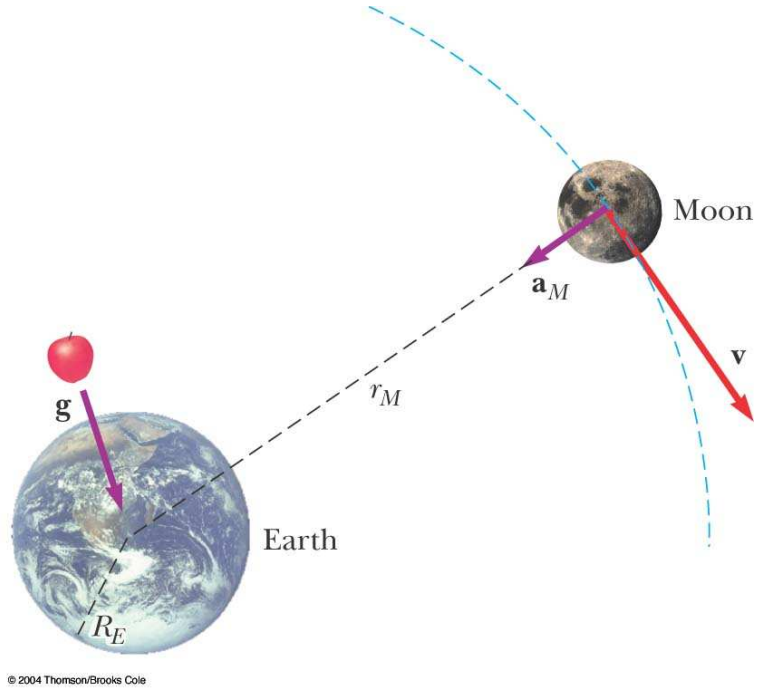
Next we estimate some centripetal accelerations of celestial bodies moving in nearly circular orbits: the moon around the earth and the earth around the sun.

Centripetal Acceleration

- The Moon experiences a centripetal acceleration as it orbits the Earth

$$a_M = \frac{v^2}{r_M} = \frac{\left(2\pi r_M / T\right)^2}{r_M}$$

$$= \frac{4\pi^2 r_M}{T^2}$$



Mean distance of moon from earth: $R_m = 384\,404\,km = 3.84\,10^8\,m$

period of revolution $T = 29\,days = 29\,x\,86400\,s = 2.5\,10^6$

Centripetal acceleration of the moon $a_c = \frac{4\pi^2 R_m^2}{T^2 R_m} = 2.44\,10^{-3}\,m\,s^{-2}$

Similar calculation for pull of the Sun on earth

distance ' $R = 1.44\,10^{10}\,m$

Period of revolution $T = 3e7\,s$

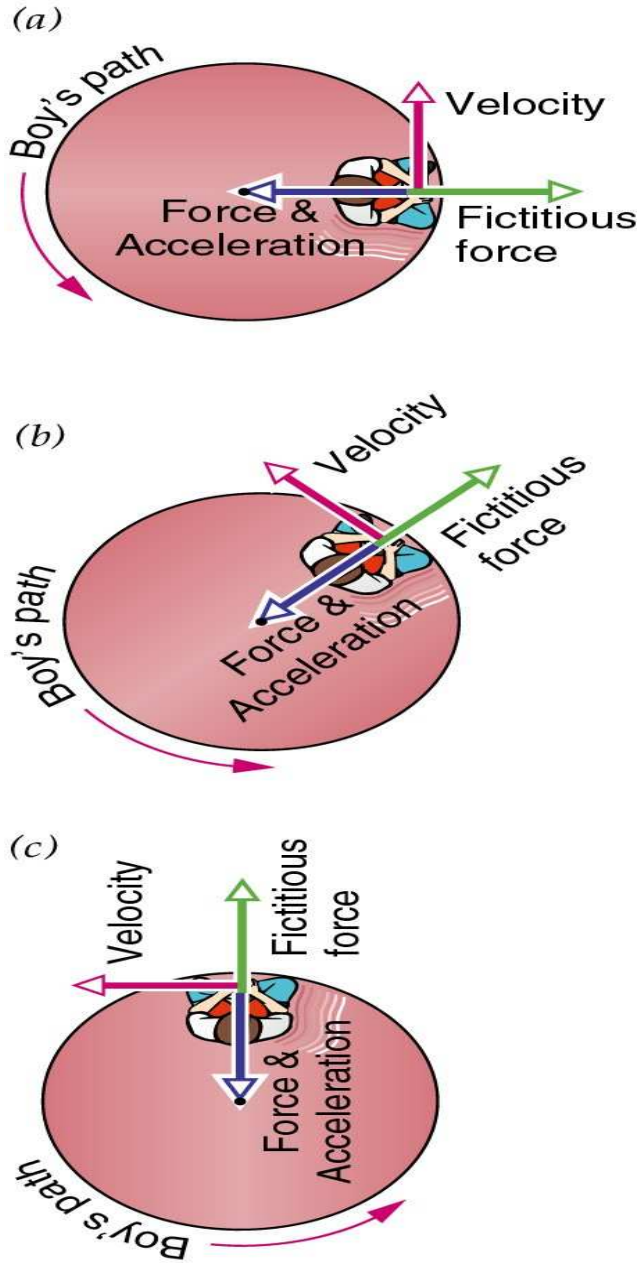
acceleration $= 6.31\,10^{-4}\,m\,s^{-2}$

Racing car in a circular track of radius = 500 m

Speed of the racing car 150 mph = 66.7 m/s^2

Acceleration = 8.89 m/s^2 !!

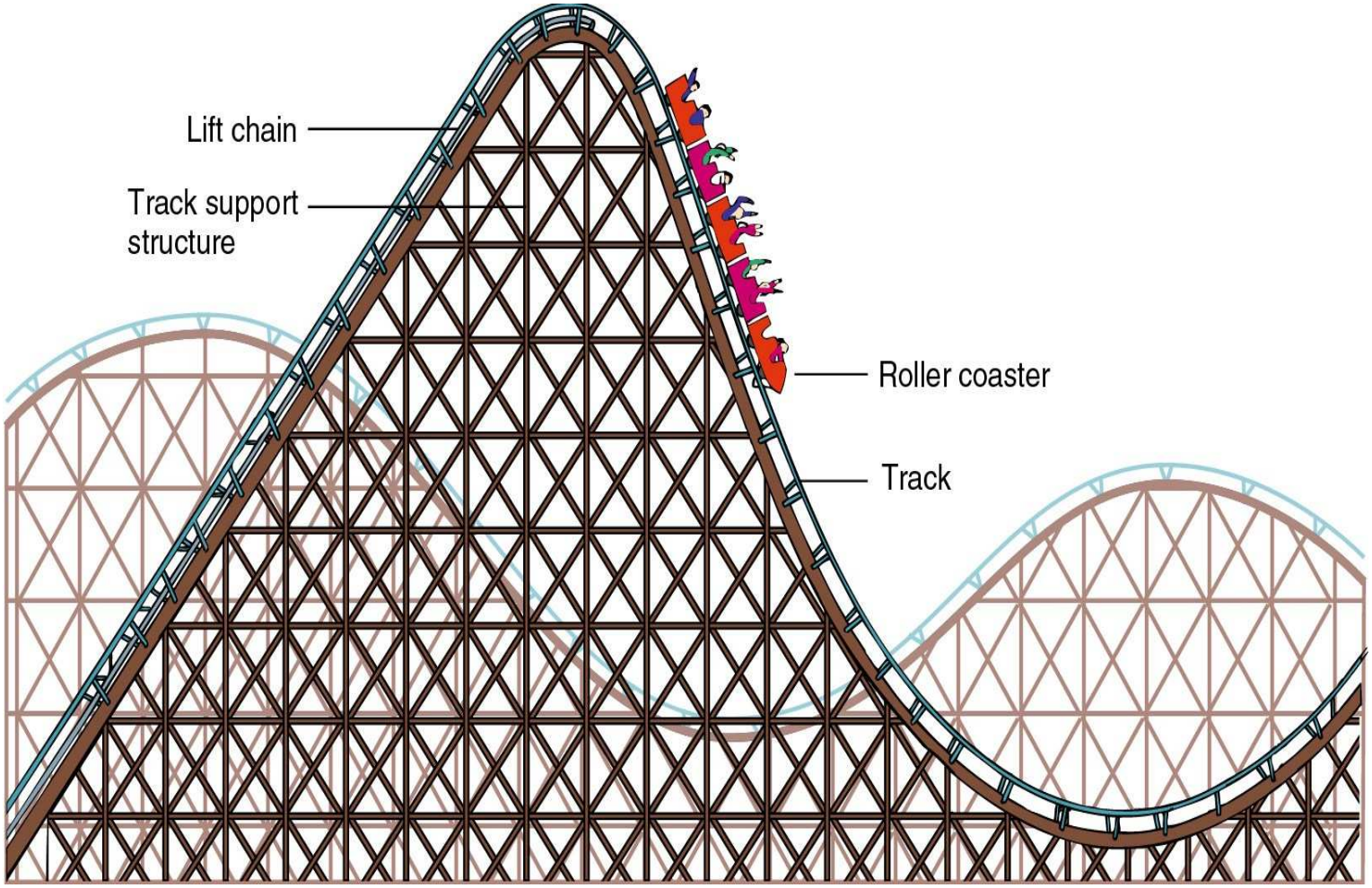
Why does the racing car track have to be 'banked' ?

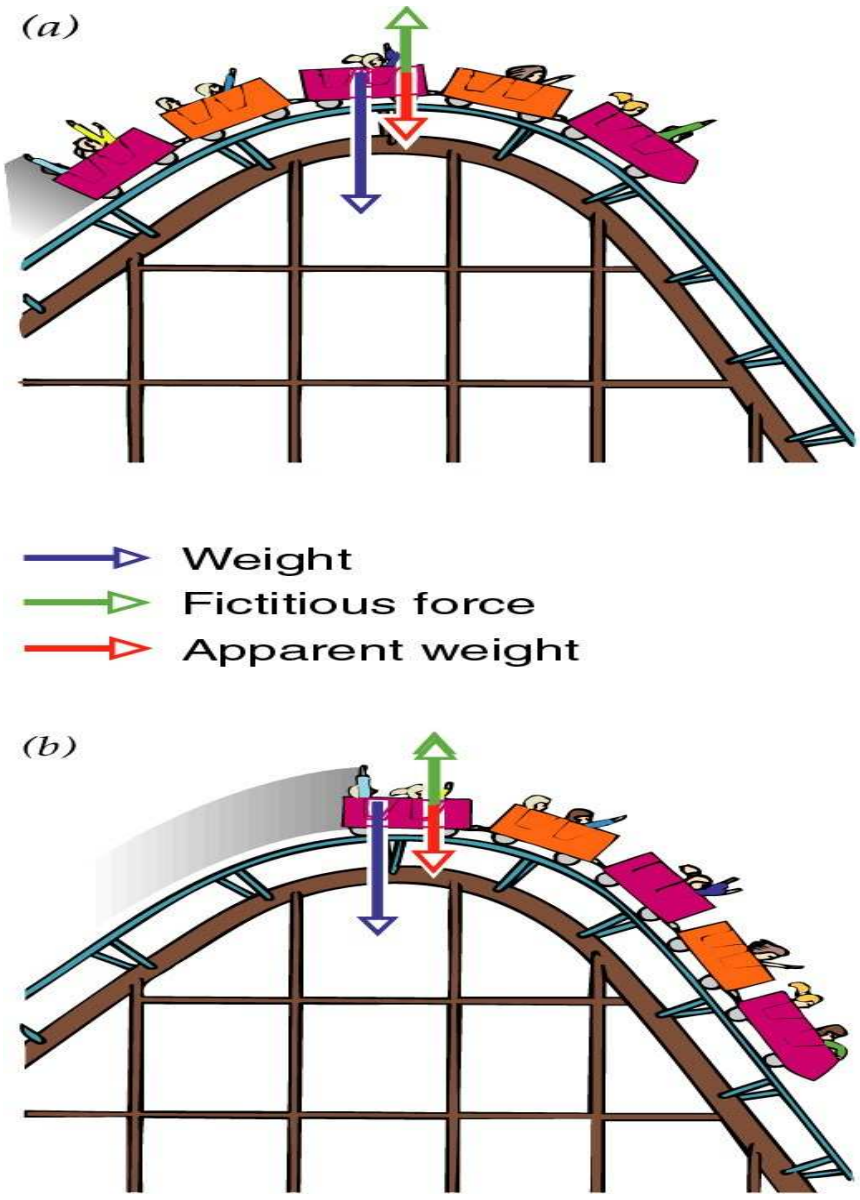


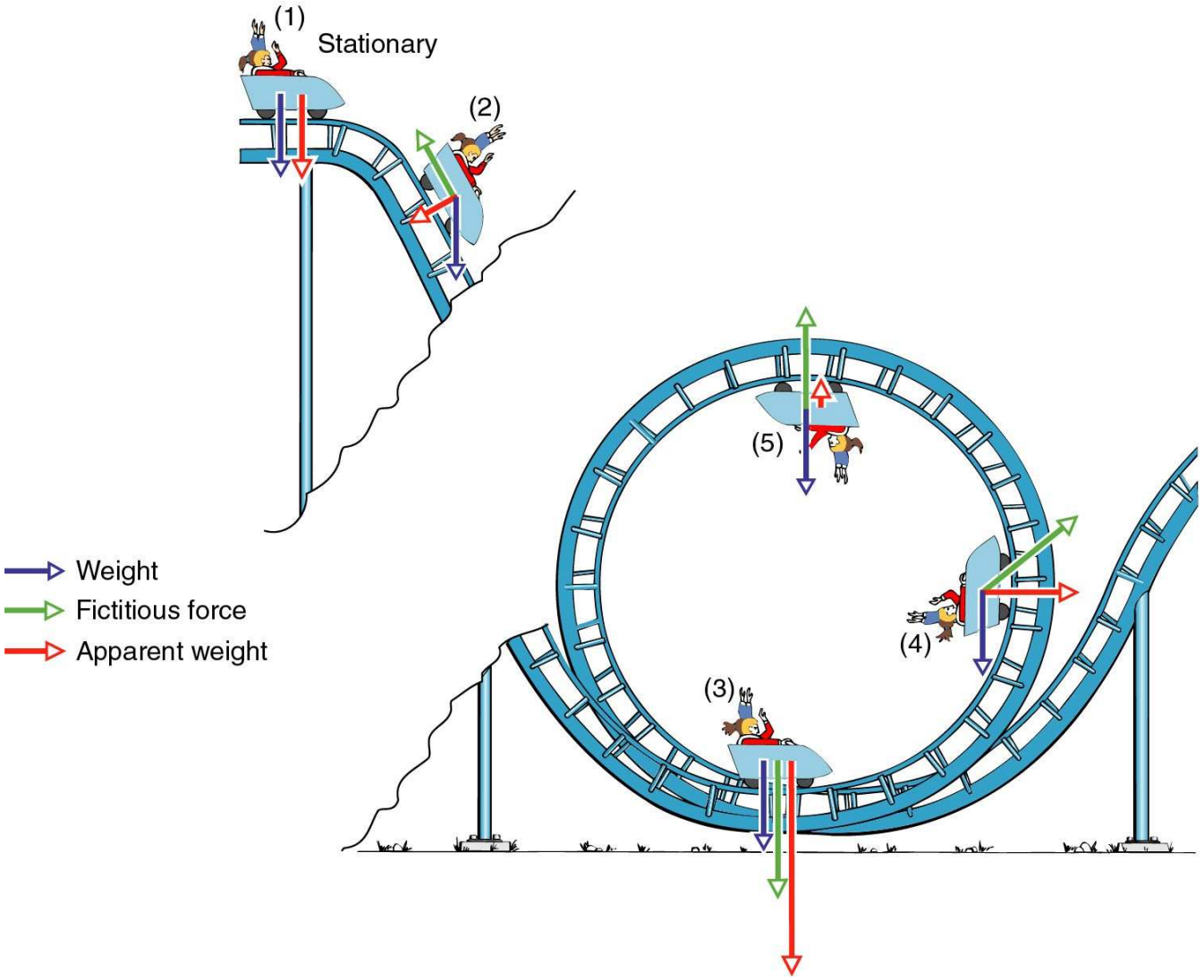
What provides the centripetal force ?

Friction, because if there was no friction boy would not go around in a circle.

The boy ' feels ' a fictitious force outwards.


Lift chain
Track support structure
Roller coaster
Track


(a)
Weight
Fictitious force
Apparent weight
(b)


(1)
Stationary
(2)
(3)
(4)
(5)
Weight
Fictitious force
Apparent weight