



# Fictitious Forces

January 26, 2026

## Introduction

Newton's second law  $F = ma$  only holds when the reference frame is inertial, i.e. the observer is not accelerating. For a non-inertial frame, apply any necessary fictitious forces, and proceed to work as if the frame was inertial.

**Fictitious Force:** An apparent force is appears when working with a non-inertial frame of reference. When added in addition to real forces (which are the same in any frame),  $F = ma$  becomes valid.

- Negative signs are included because if the reference frame is accelerating, the objects within the reference frame will appear to be accelerating in the opposite direction.
- In an inertial frame, there are no fictitious forces..

There are four types of fictitious forces, translational, centrifugal, coriolis, and azimuthal:

$$ma = F_{real} + F_{translational} + F_{centrifugal} + F_{coriolis} + F_{azimuthal}$$

Depending on the acceleration of the reference frame, if we add all the necessary terms above, you can then use  $F = ma$  as in an inertial frame.

**Translational force:** If the observer has a linear acceleration  $a_{frame}$ , then:

$$\mathbf{F}_{translational} = -m\mathbf{a}_{frame}$$

opposite the direction of the acceleration  $a_{frame}$ .

**Centrifugal force:** If the observer (reference frame) is rotating about a point with angular velocity  $\omega$ , then an object at radius  $r$  will experience a fictitious force:

$$\mathbf{F}_{centrifugal} = -mv^2/r = -m\omega^2\mathbf{r}$$

pointing radially outward.

**Coriolis force:** If the observer is rotating about a point at angular velocity  $\omega$ , and an object moves with velocity  $v$  parallel to the plane of rotation, then:

$$\mathbf{F}_{coriolis} = -2m\boldsymbol{\omega} \times \mathbf{v}$$



with direction determined by the cross product  $\boldsymbol{\omega} \times \boldsymbol{v}$  (use right hand rule) and thus always perpendicular to  $\boldsymbol{v}$ .

**Azimuthal fictitious force:** If the observer is rotating about a point at angular acceleration  $\alpha$  and radius  $r$ , then:

$$\boldsymbol{F}_{\text{azimuthal}} = -m\boldsymbol{\alpha} \times \boldsymbol{r} = -m\boldsymbol{a}_{\text{tangential}}$$

opposite the direction of the tangential acceleration.

**\*\*Stick with one reference frame when solving problems, as switching will result in extra-neous forces. Fictitious forces should only be used when the reference frame is accelerating (don't use on physics class FRQs!!)**

#### Practice Problems

**A passenger, sitting on a high speed train with all windows closed, has a bowl of thin soup on the table in front of him. The train is moving in a circular track at constant speed. The passenger faces the engine at the front of the train and the center of the track is to the left of the passenger. The sketch below shows the cross section of the bowl when being cut with a vertical plane passing through the center of the track. Which sketch below best represents the level of the soup in the bowl?**

- a. A
- b. B
- c. C
- d. D
- e. E



**A mass  $m$  hangs from a massless spring connected to the roof of a box of mass  $M$ . When the box is held stationary, the mass-spring system oscillates vertically with angular frequency  $\omega$ . If the box is dropped falls freely under gravity, how will the angular frequency change?**

- (A)  $\omega$  will be unchanged
- (B)  $\omega$  will increase
- (C)  $\omega$  will decrease
- (D) Oscillations are impossible under these conditions
- (E)  $\omega$  will increase or decrease depending on the values of  $M$  and  $m$



At  $t = 0$ , a 100 g ball is thrown upward with initial speed  $v = 2$  m/s in an open-platform elevator which is moving downward with  $v = 3$  m/s and accelerating downward with an acceleration of magnitude  $a = 3$  m/s<sup>2</sup>. A drag force with magnitude  $F_{\text{drag}} = 0.8$  N acts on the ball.

- (a) What is the net force on the ball in the frame of the elevator after it has been thrown?
- (b) What is the net force on the ball in the frame of a person standing on the ground after it has been thrown?

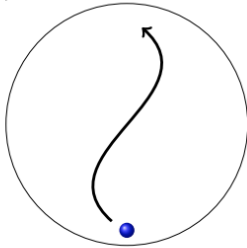
A collision occurs between two masses. In each inertial reference frame, one can compute the change in total momentum  $\Delta \mathbf{P}$  and the change in total kinetic energy  $\Delta K$  due to the collision. Which of the following is true?

- (A)  $\Delta \mathbf{P}$  and  $\Delta K$  do not depend on the frame.
- (B)  $\Delta \mathbf{P}$  and  $\Delta K$  do not depend on the frame for perfectly elastic collisions, but  $\Delta \mathbf{P}$  may depend on the frame for inelastic collisions.
- (C)  $\Delta \mathbf{P}$  and  $\Delta K$  do not depend on the frame for perfectly elastic collisions, but  $\Delta K$  may depend on the frame for inelastic collisions.
- (D)  $\Delta \mathbf{P}$  and  $\Delta K$  do not depend on the frame for perfectly elastic collisions, but both may depend on the frame for inelastic collisions.
- (E)  $\Delta \mathbf{P}$  and  $\Delta K$  may both depend on the frame, for both perfectly elastic and inelastic collisions.

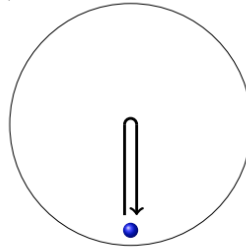


A child in a circular, rotating space station tosses a ball in such a way so that once the station has rotated through one half rotation, the child catches the ball. From the child's point of view, which plot shows the trajectory of the ball? The child is at the bottom of the space station in the diagrams below, but only the initial location of the ball is shown.

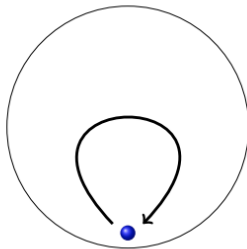
(A)



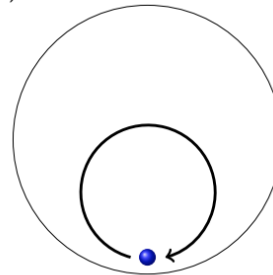
(B)



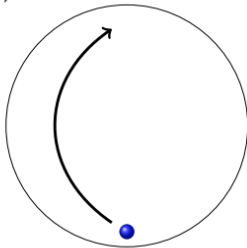
(C)



(D)

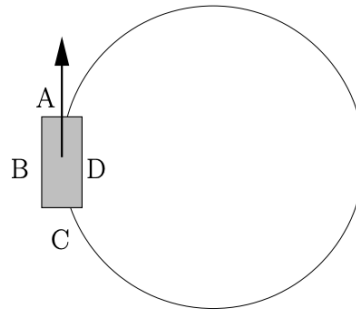


(E)





A balloon filled with helium gas is tied by a light string to the floor of a car; the car is sealed so that the motion of the car does not cause air from outside to affect the balloon. If the car is traveling with constant speed along a circular path, in what direction will the balloon on the string lean towards?



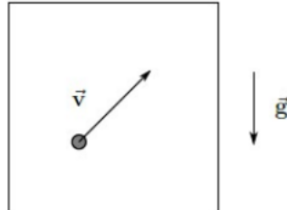
- (A) A
- (B) B
- (C) C
- (D) D
- (E) Remains vertical

Earth rotates with angular frequency vector  $\vec{\omega}$ . Objects moving on Earth experience a Coriolis force  $\vec{F}_c = -2m\vec{\omega} \times \vec{v}$ . When a ball is dropped from a tower, it falls almost straight down, but is deflected by the Coriolis force a distance  $x$  to the East. If the ball is thrown vertically from the bottom of the tower so that it reaches the top of the tower at the apex of its flight, how much and in what direction is it deflected by the Coriolis force before it hits the ground?

- (a)  $4x$  West
- (b)  $2x$  West
- (c)  $x$  West
- (d) 0
- (e)  $x$  East

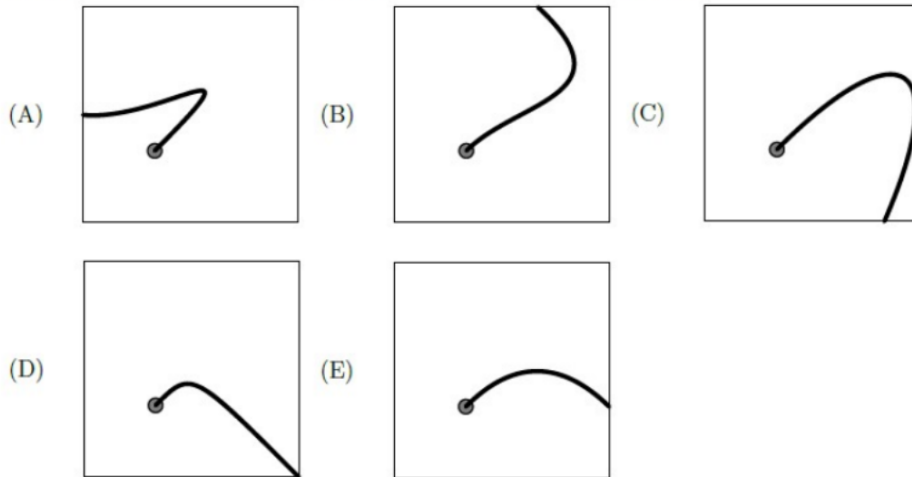


Consider a particle in a box where the force of gravity is down as shown in the figure.

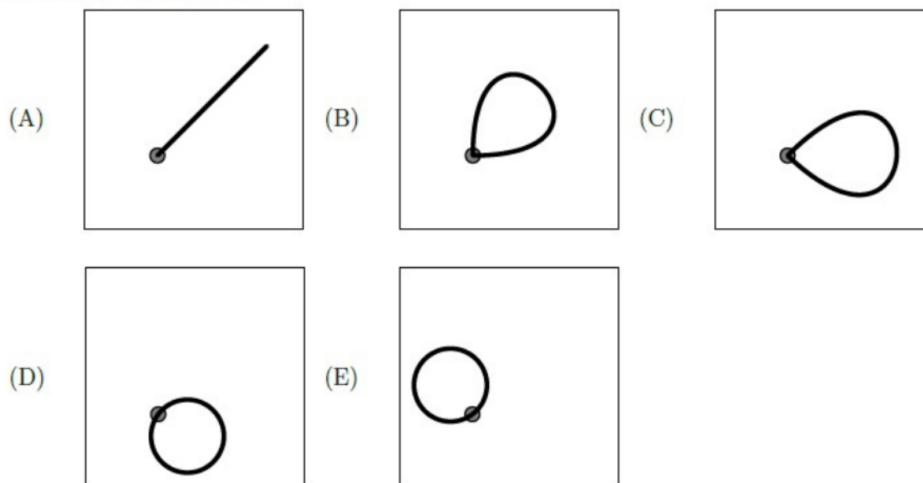


The particle has an initial velocity as shown, and the box has a constant acceleration to the right.

5. In the frame of the box, which of the following is a possible path followed by the particle?



If the magnitude of the acceleration of the box is chosen correctly, the launched particle will follow a path that returns to the point that it was launched. In the frame of the box, which path is followed by the particle?





A unicyclist goes around a circular track of radius 30 m at a (*amazingly fast!*) constant speed of 10 m/s. At what angle to the left (or right) of vertical must the unicyclist lean to avoid falling? Assume that the height of the unicyclist is much smaller than the radius of the track.

- (A)  $9.46^\circ$
- (B)  $9.59^\circ$
- (C)  $18.4^\circ$
- (D)  $19.5^\circ$
- (E)  $70.5^\circ$

A block floats partially submerged in a container of liquid. When the entire container is accelerated upward, which of the following happens? Assume that both the liquid and the block are incompressible.

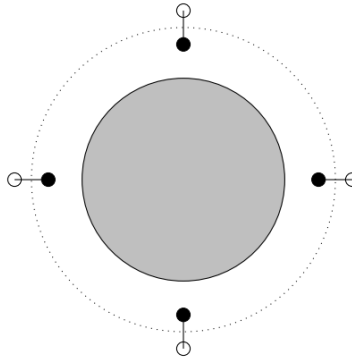
- (A) The block descends down lower into the liquid.
- (B) The block ascends up higher in the liquid.
- (C) The block does not ascend nor descend in the liquid.
- (D) The answer depends on the direction of motion of the container.
- (E) The answer depends on the rate of change of the acceleration



If a longjumper can jump 8 meters at the north pole, how far can he jump at the equator? Assume that  $g_{\text{eff}}$  is 0.5% less at the equator than at the north pole (although this is only approximate). Ignore effects of wind resistance, temperature, and runaways made of ice.

Two small, equal masses are attached by a lightweight rod. This object orbits a planet; the length of the rod is smaller than the radius of the orbit, but not negligible. The rod rotates about its axis in such a way that it remains vertical with respect to the planet.

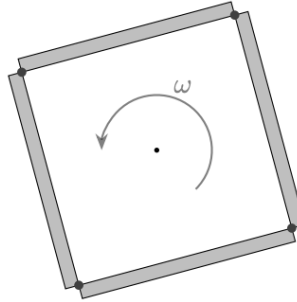
- Is there a force in the rod? If so, is it tension or compression?
- Is the equilibrium stable, unstable, or neutral with respect to a small perturbation in the angle of the rod? (Assume this perturbation maintains the rate of rotation, so that in the co-rotating frame the rod is still stationary but at an angle to the vertical.)



- (A) There is no force in the rod; the equilibrium is neutral.
- (B) The rod is in tension; the equilibrium is stable.
- (C) The rod is in compression; the equilibrium is stable.
- (D) The rod is in tension; the equilibrium is unstable.
- (E) The rod is in compression; the equilibrium is unstable.



Four identical rods, each of mass  $m$  and length  $2d$ , are joined together to form a square. The square is then spun around its center, as shown in the figure, at an angular frequency of  $\omega$ . What is the magnitude of the force that the joints between the rods (at the corners of the square) must bear?



(A)  $m\omega^2 d/2$

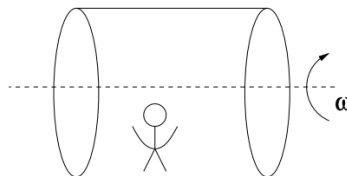
(B)  $m\omega^2 d/\sqrt{2}$

(C)  $m\omega^2 d$

(D)  $\sqrt{2}m\omega^2 d$

(E)  $2m\omega^2 d$

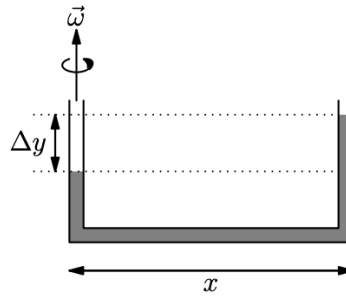
A cylindrical space station produces ‘artificial gravity’ by rotating with angular frequency  $\omega$ . Consider working in the reference frame rotating with the space station. In this frame, an astronaut is initially at rest standing on the floor, facing in the direction that the space station is rotating. The astronaut jumps up vertically relative to the floor of the space station, with an initial speed less than that of the speed of the floor. Just after leaving the floor, the motion of the astronaut, relative to the space station floor,



- (A) always has a component of acceleration directed toward the floor, and they land at the same point they jumped from.
- (B) always has a component of acceleration directed toward the floor, and they land in front of the point they jumped from.
- (C) always has a component of acceleration directed toward the floor, and they land behind the point they jumped from.
- (D) has a component of acceleration directed away from the floor, and they land behind the point they jumped from.
- (E) has a zero acceleration relative to the floor, and the astronaut never reaches the floor again.



A pipe consists of two vertical sections connected by a horizontal section of length  $x$ . The width of the pipe is small compared to the length of the sections of pipe. The pipe spins around one of the vertical sections at angular frequency  $\omega$ . What is the difference in heights of the fluid  $\Delta y$  between the vertical segments of pipe?



- (a)  $\Delta y = \frac{\sqrt{gx}}{\omega}$
- (b)  $\Delta y = \omega \sqrt{\frac{x^3}{g}}$
- (c)  $\Delta y = \frac{1}{2} \frac{\omega^2}{g} x^2$
- (d)  $\Delta y = \frac{\omega^2}{g} x^2$
- (e)  $\Delta y = 2 \frac{\omega^2}{g} x^2$