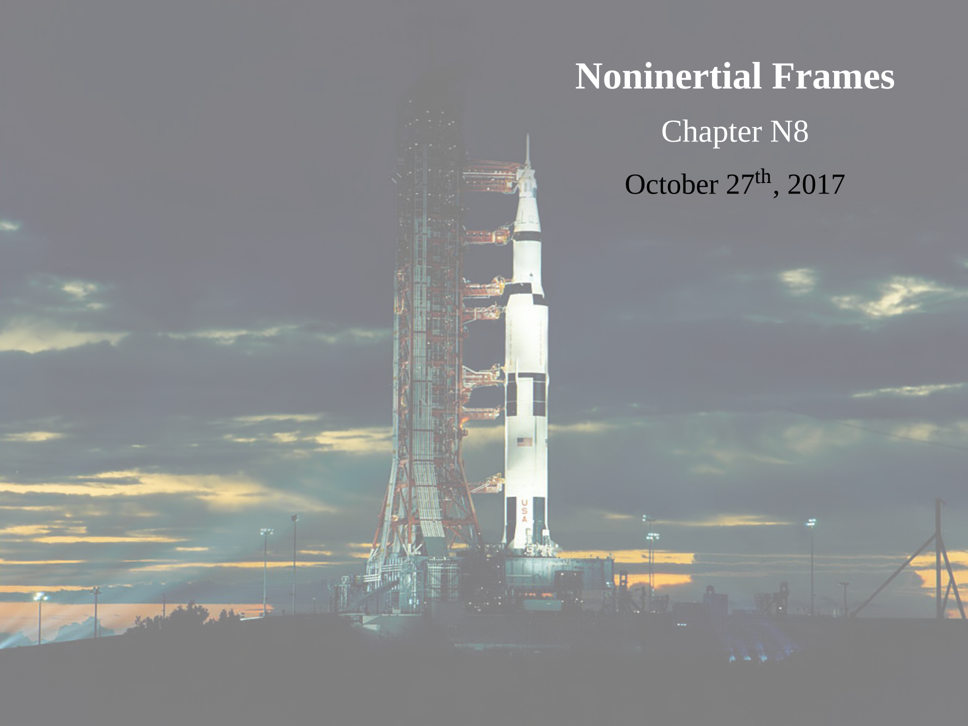

Noninertial Frames

Chapter N8

October 27th, 2017

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- We can infer forces that do not actually exist.
- This chapter helps lay some groundwork for Unit R.

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3. Inertial Reference Frames
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We will show that **these forces are not real forces, they are <u>fictitious forces</u>**

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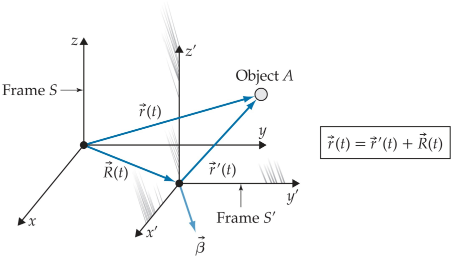

Frame S' is moving at a relative "boost" velocity $\vec{\beta}$ relative to frame S. The position vectors in the two frames at some time t are related by: $\vec{r}(t) = \vec{r}\,'(t) + \vec{R}(t)$.

The Galilean Transformation

$$\vec{r}(t) = \vec{r}\,'(t) + \vec{R}(t)$$

Taking the time derivative of both sides of this equation and solving for the boosted-frame velocity yields:

$$\vec{r}\,'(t) = \vec{r}(t) - \vec{R}(t)$$

$$\vec{v}\,'(t) = \vec{v}(t) - \vec{\beta}(t)$$

This is the **Galilean velocity transformation equation**.

The Galilean Transformation: Example

An airplane flies due east at a speed of 145 km/h relative to the ground. If there is a wind blowing east at 15 km/h, what is the plane's speed relative to the air (this is *air speed*, different from *ground speed*).

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First, we must decide what is frame S and S', and what is β?

We're given the plane's speed relative to the ground, so let this be v in S.

The "boosted" frame is the air frame, which is moving at $\beta =$+15 km/h.

$$\begin{bmatrix} v'_x \\ v'_y \\ v'_z \end{bmatrix} = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} - \begin{bmatrix} \beta_x \\ \beta_y \\ \beta_z \end{bmatrix}$$

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This makes sense intuitively!

The Galilean Transformation: Two-Minute Problem

In a Western movie, a person shoots an arrow backward from a fleeing horse. If the velocity of the horse relative to the ground is 13 m/s west and the arrow's velocity relative to the horse is 38 m/s east, what is the arrow's velocity with respect to the ground?

A. 41 m/s east
B. 41 m/s west
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Horse frame: S', ground frame: S, $\beta = 13$ m/s west$=-13$ m/s $\hat{x}$.
Arrow's velocity in the horse frame (S'): $\vec{v}\,' = 38$ m/s east =38 m/s $\hat{x}$.

$$\vec{v}\,' = \vec{v} - \vec{\beta}$$

$$\vec{v} = \vec{v}\,' + \vec{\beta}$$

$$v_x = v'_x + \beta_x$$

$$= (38 \text{ m/s}) + (-13 \text{ m/s}) = 25 \text{ m/s } (+x = \text{east})$$

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This equation implies that if frame S' moves at a constant velocity with respect to S (so that $\vec{A} = 0$), the object's acceleration is the same in both frames: $\vec{a}\,'(t) = \vec{a}(t)$

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Noninertial Frames $\vec{A} \neq 0$: isolated object will have some nonzero acceleration: $\vec{a}\,' = -\vec{A} \neq 0$ and **Newton's first and second laws do not hold**

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- Now we don't need the magical force—it vanishes if we analyze the situation in an **inertial** reference frame.

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- "Forces" that exist or don't exist depending on one's arbitrary choice of reference frame can't be considered "real".

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- But we can see that this force is not real, and we can understand the movement of objects in circularly accelerating (noninertial) frames without the force, by analyzing the situation in an inertial frame.

Circularly Accelerating Frames

Noninertial Reference Frames

Newton's laws do not apply in noninertial reference frames, and we can explain the motion of objects by observing the system in an inertial reference frame.

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- Say we have a frame S and noninertial frame S' that is accelerating at $\vec{A}$ relative to S. Real forces $\vec{F}_1$, $\vec{F}_2$, …act on an object of mass m. In the noninertial S' frame, the acceleration can be calculated:

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- Call this "force" ($-m\vec{A}$) a **frame-correction force** $\vec{F}_{FC}$ (it's only purpose is to compensate for the noninertial frame). It is proportional to the object's mass, like the gravitational force ($\vec{F}_g = m\vec{g}$).

Two-Minute Problem

A cork floats in an inverted jar sitting on a cart, as shown in the diagram below. If we suddenly accelerate the cart to the right (as shown in the diagram) what will the cork do:

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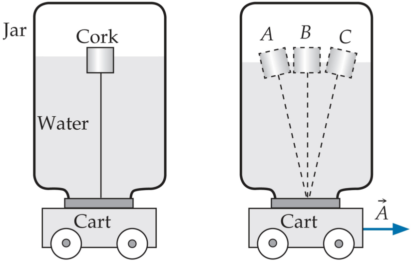

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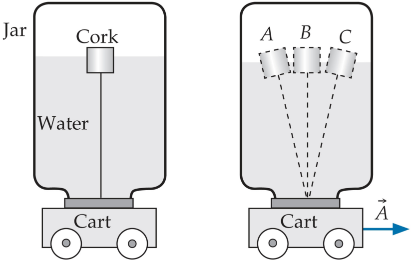

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The water will slosh to the back of the cart and pile up, which pushes the cork forward.

Think of a jar mostly full of water, but with an air bubble at the top. Which way does the air bubble go when the jar is on a cart which accelerates forward?

The water goes *backward* and the air bubble goes *forward*.

Or: we can pretend Newton's laws work in this accelerated frame as long as we add an "effective gravitational force" vector that points *opposite* to the direction of the frame's acceleration relative to the ground. This vector points to the left, which adds to the real downward gravitational force, for a summed force that points back and down. The cork will float opposite to this: forward and up.

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Similarly a balloon in an accelerating car will move *forward* (video).

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$$
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Therefore an object in a freely-falling frame behaves as if Newton's second law is valid, if we ignore the gravitational field in which the frame falls. **So we can treat freely falling frames as inertial!**

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Likewise, a frame accelerating at 9.8 m/s^2 in deep space is indistinguishable from a frame at rest on the Earth's surface.

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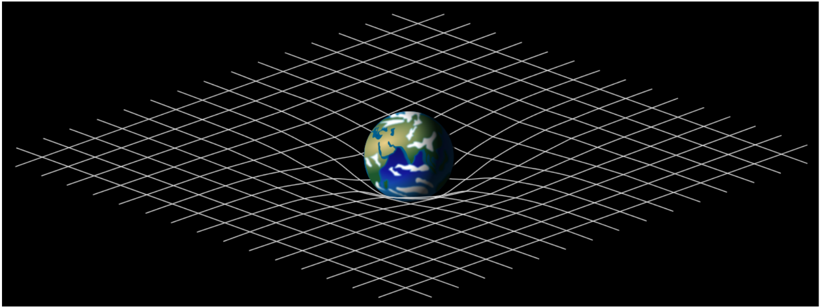
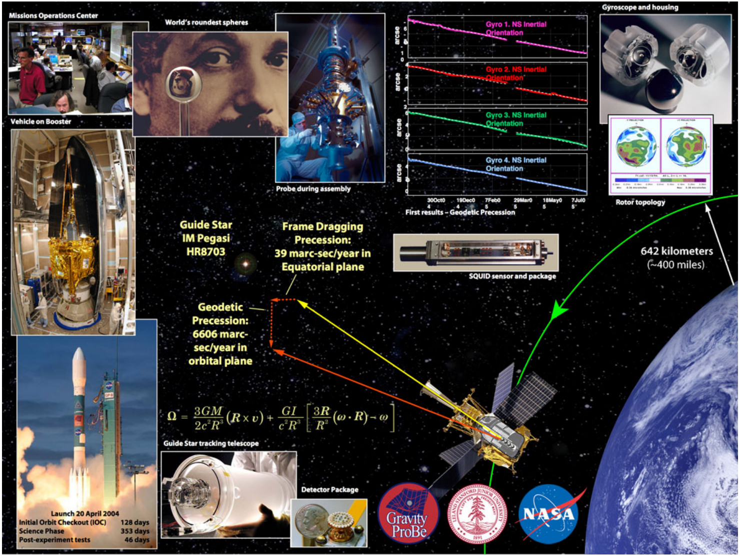
The equivalence principle is the foundation of Einstein's theory of general relativity.

The Equivalence Principle



Lattice analogy of the deformation of spacetime caused by a planetary mass.

Gravity Probe B



Gravity Probe B

The 645-gallon GP-B flight dewar (liquid helium)

Example Problem: N8R.1

You are kidnapped and put blindfolded in an elevator at the ground floor of a buiding. As the elevator starts, you notice that your weight seems to increase by 10% for 3 s, remain normal for 24 s, then decrease by 10% for 3 s. You are then taken out and put into a locked room. What is the approximate floor number your room is on?