Forces of Stage Design

The Normal Force, Frictional Force, and Force Body Diagrams

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Physics for Fine Arts

Learning Objectives

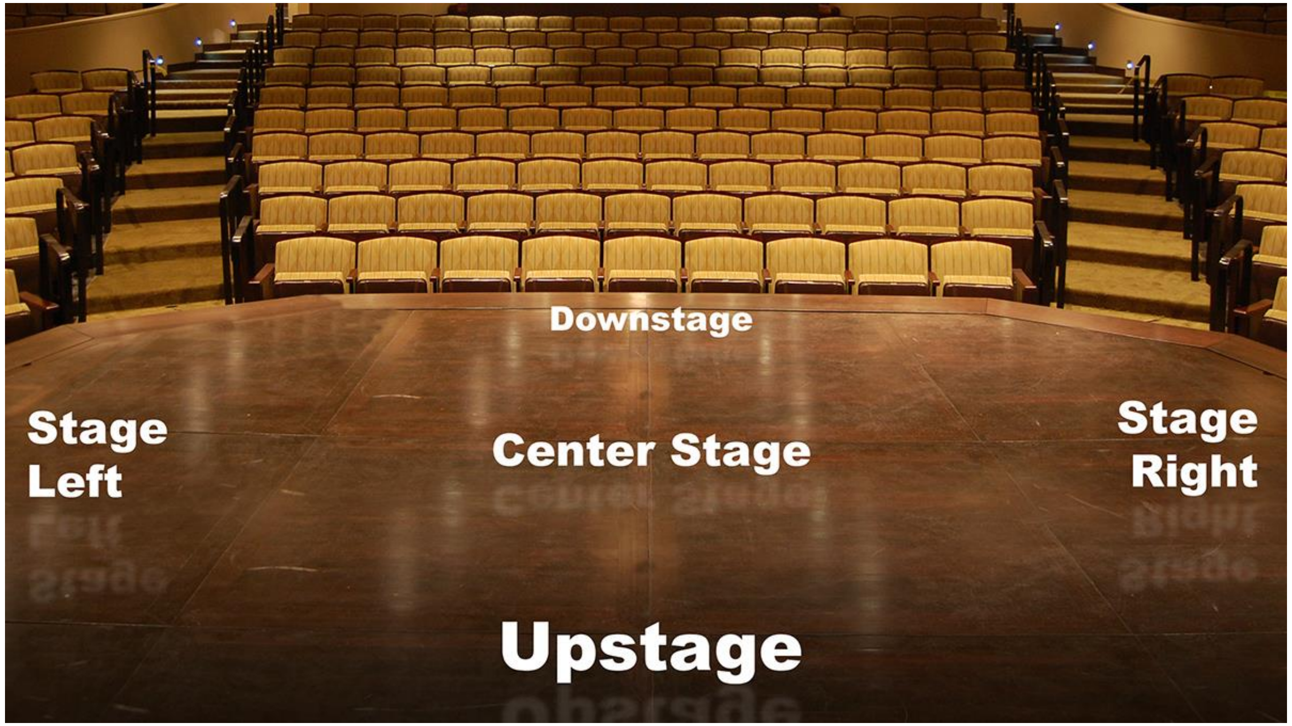
- Learn the origins of “downstage” and “upstage”
- Recognize what a normal force is
- Calculate frictional force based on the normal force
- Draw force body diagrams for a mass on an inclined plane
- Consider ethical implications of theater and stage design

Which part is “downstage” and which part is “upstage”?

- The front of the stage is “downstage”
- The back of the stage is “upstage”

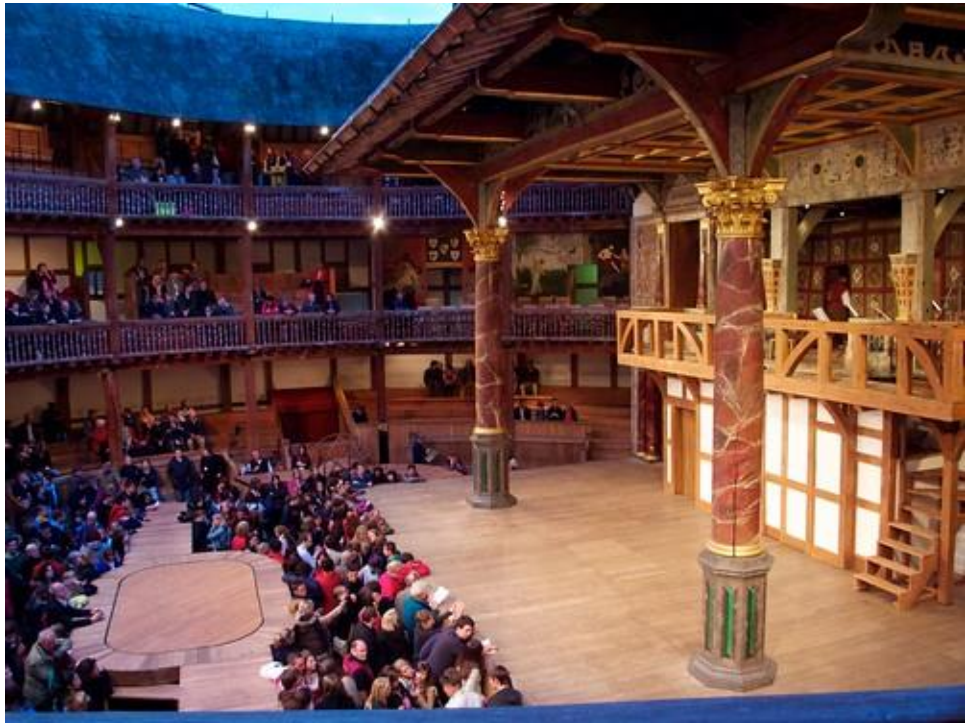
Why is this the typical naming convention?

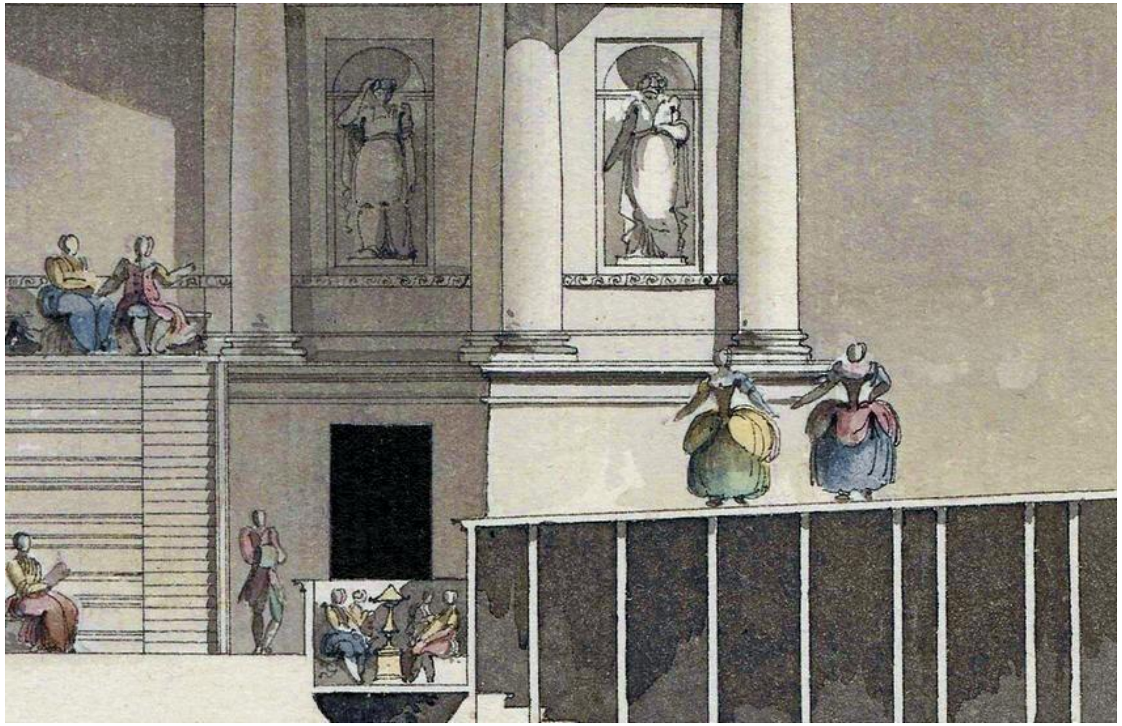
Current Stage Design



Modern stages are flat and seats are raised.

Historical Stage Design





The opposite! The audience was on flat ground and the stages were tilted. “Raked” stages were typically inclined less than 5 degrees.

Raked Stages for Audience Viewing

- From my high school’s production of *Baby*: a musical about three couples and their journey toward parenthood
- A bed on a raked stage helps the audience to see the cast members better

https://www.youtube.com/watch?v=wOt6aHeL5vA

Modern Raked Stages

- Some theaters in the US: Philadelphia Academy of Music and a few Broadway productions
- Most theaters in Europe

- Intentional raked stage: *Cat on a Hot Tin Roof* by the South Bend Civic Theater in Indiana

From Mark Abram-Copenhaver, SBCT Artistic Director:

"A raked stage allows for attractive visual composition of the actors and the scenery in addition to making it possible for the actors who are upstage to be easily seen. [...] But a rake can serve another purpose as well. You may already have thought about the fact that this stage space looks a little bit precarious to walk on. Making the stage a challenging space for the actors/characters to move in is a device used by the director and set designer to cause **the physical world of the production to reflect the inner struggles of the characters**. Big Daddy's house is not an easy place to live in for any of the characters in this play. By raking the stage the director and designer have made **the psychic and emotional challenges of the story a tangible part of the environment for the audience."**

Activity Time!

Do part 1 of the activity, take a 5 minute break, then come back to lecture.
We’ll take another 5 minute break before the second part of the activity.

What were the main observations?

- As the angle increased, the measured mass decreased
- The difference in mass was larger for the heavier mass
- The trends were the same for both masses

Why did we observe these key trends?

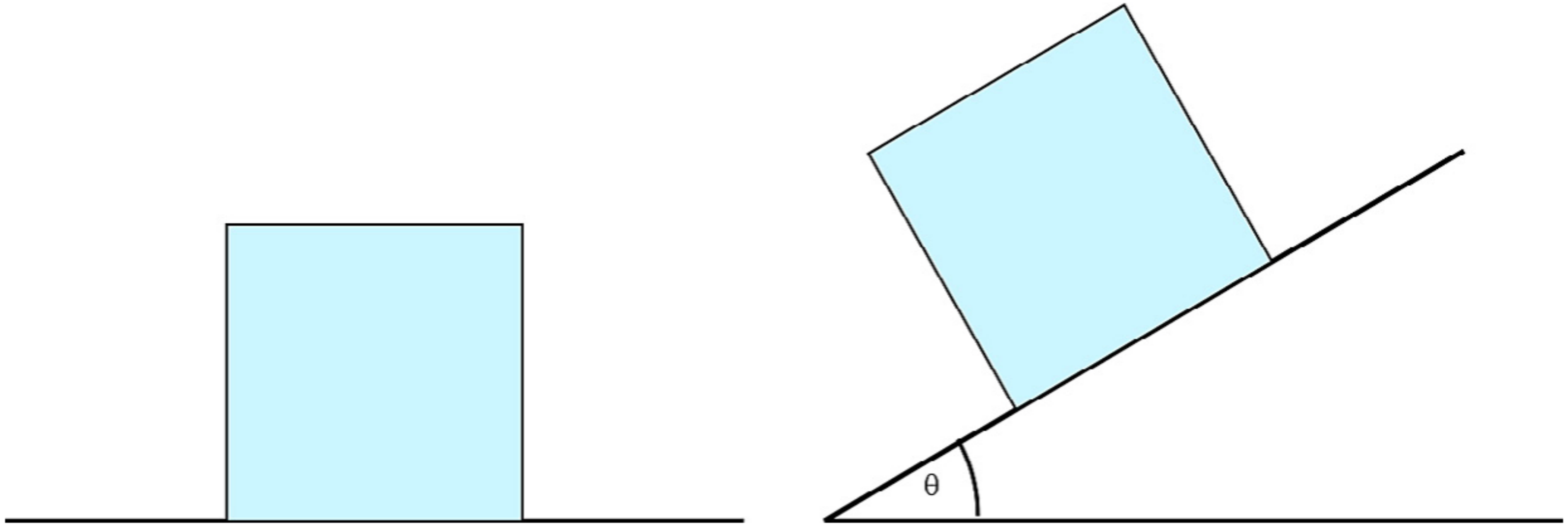
A More Common Example: Skiing

Cross country skiing: 7 – 10 mph

Downhill skiing: 20 - 40 mph

Assuming the snow is the same, why do these skiers have such different speeds?

Let's first look at our force balance:



What forces are acting on these two boxes?

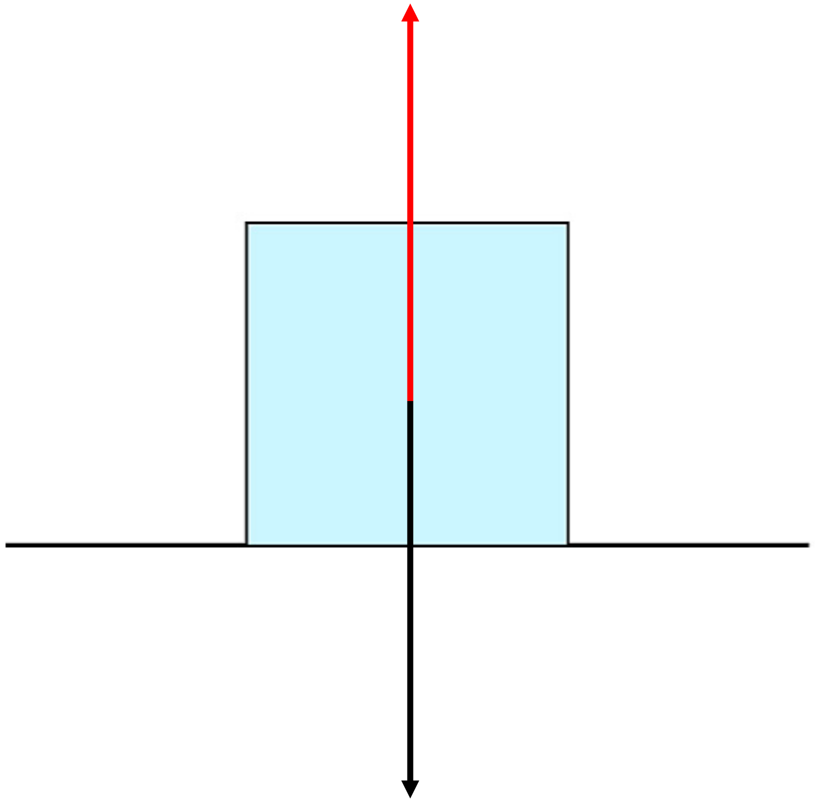
Take 5 minutes to draw this out in your group. Use arrows to indicate the direction of forces.

https://raeng.org.uk/media/vuxfappb/friction-and-sliding.pdf

For the Flat Box:

- Since the box isn't moving, all forces must sum to 0
- Force of gravity is negative: acting downwards
- **Normal force**: force acting normal (perpendicular) to the surface, contact force that prevents objects from passing through each other

Normal Force: F_N = mg (N)

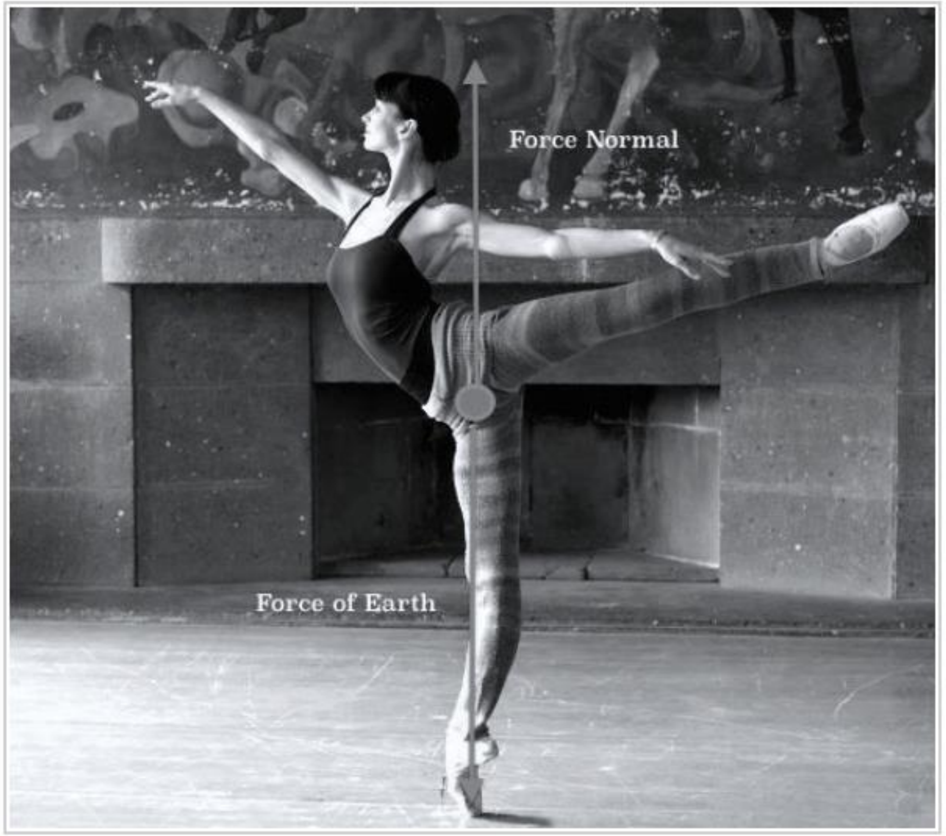


Gravitational Force: -(mass in kg * 9.8 m/s^2)

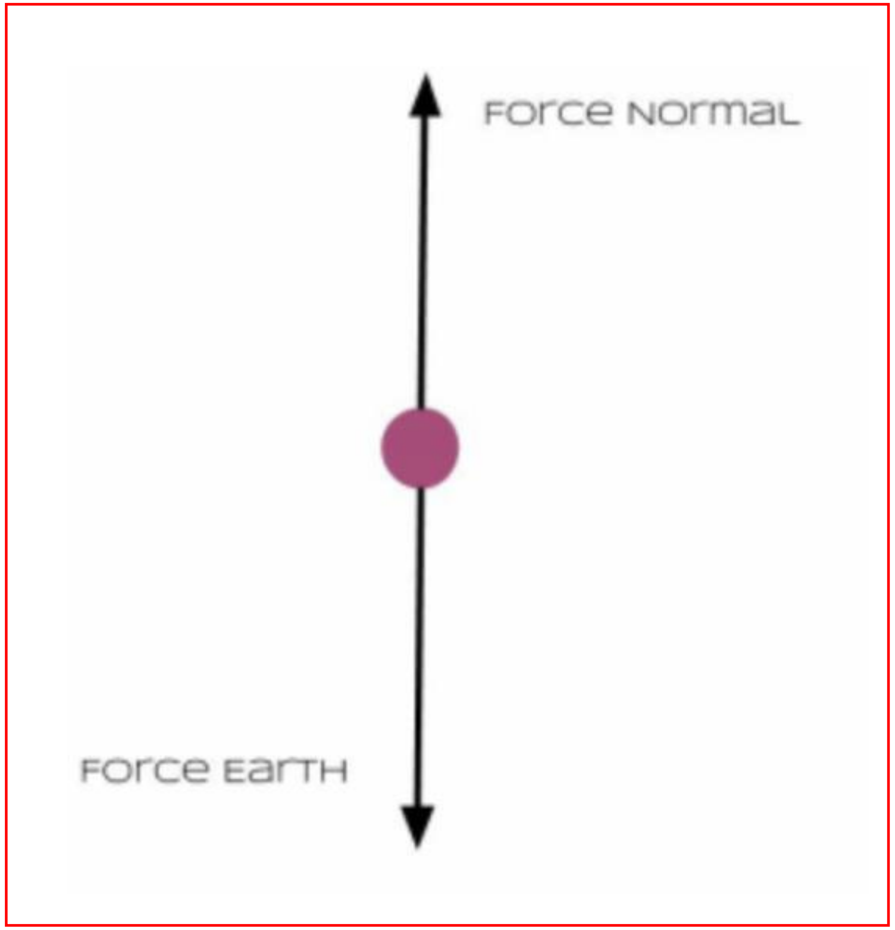
F_g = -mg (N)

Newton's Second Law! F_{net} = ma

Normal Force in Dance



Force Body Diagram



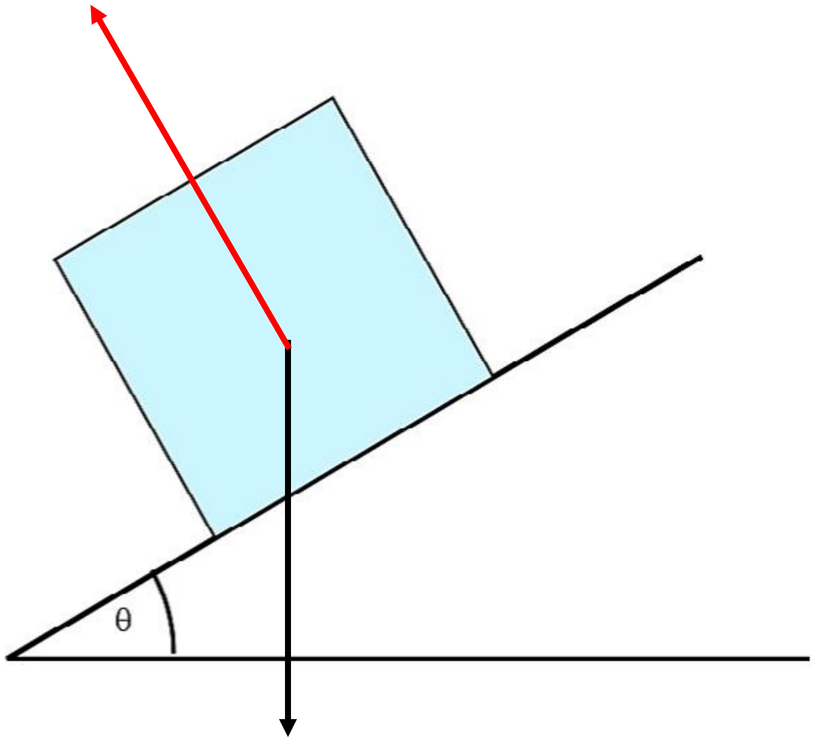
Newton's Third Law: for every action (force) in nature there is an equal and opposite reaction

https://lsanataliep.weebly.com/free-body-diagrams.html

For the Inclined Box:

- Since the box isn't moving, all forces must sum to 0
- Force of gravity is negative: acting downwards
- Normal force**:** force acting normal **(perpendicular) to the surface**, contact force that prevents objects from passing through each other

Normal Force: $F_N = mg$ (N)



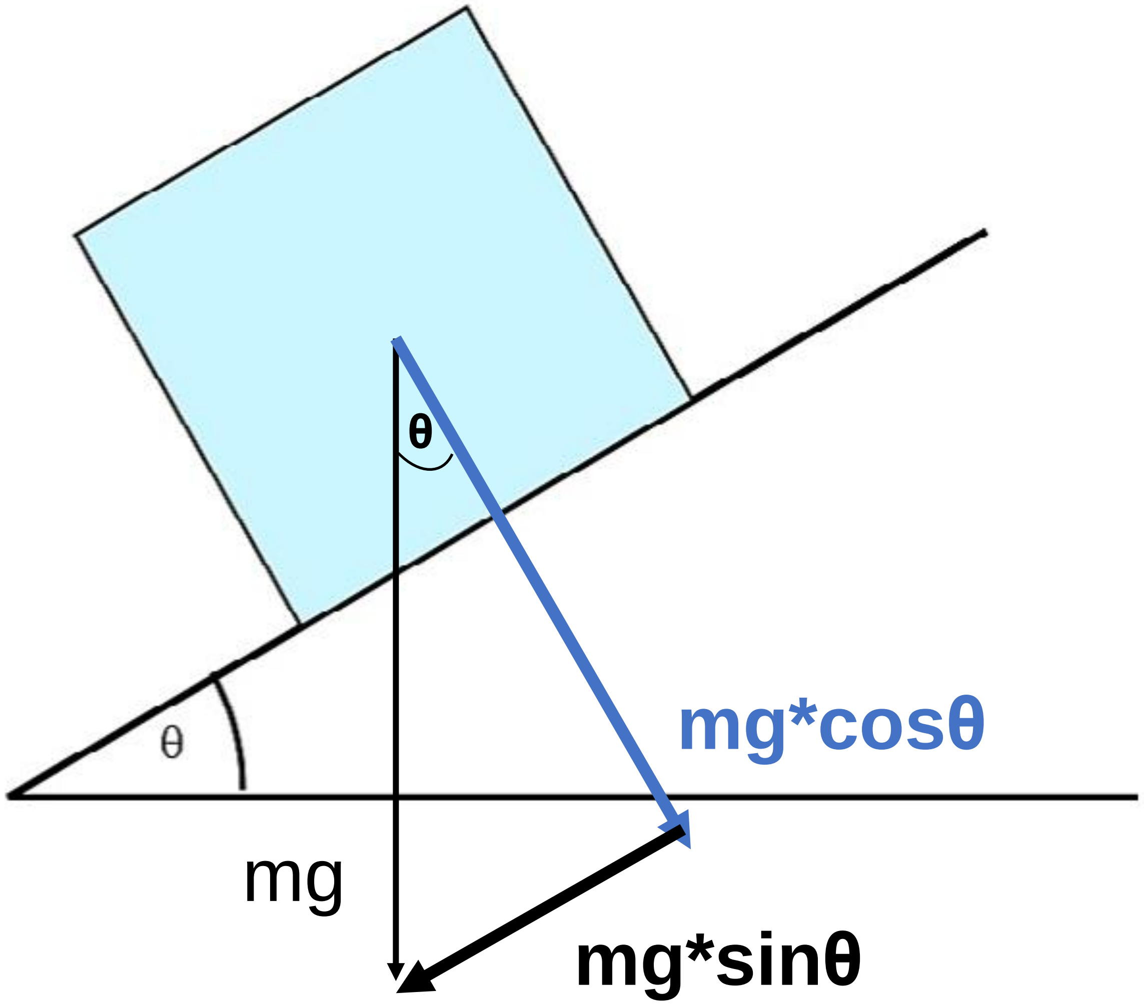
Gravitational Force: -(mass in kg * 9.8 m/s^2)

$F_g = -mg$ (N)

Let's take a closer look at the gravitational force:

- θ "theta": angle
- We can deconstruct gravitational force:
  - **Component perpendicular to the surface**
  - **Component parallel to the surface**

SOHCAHTOA!

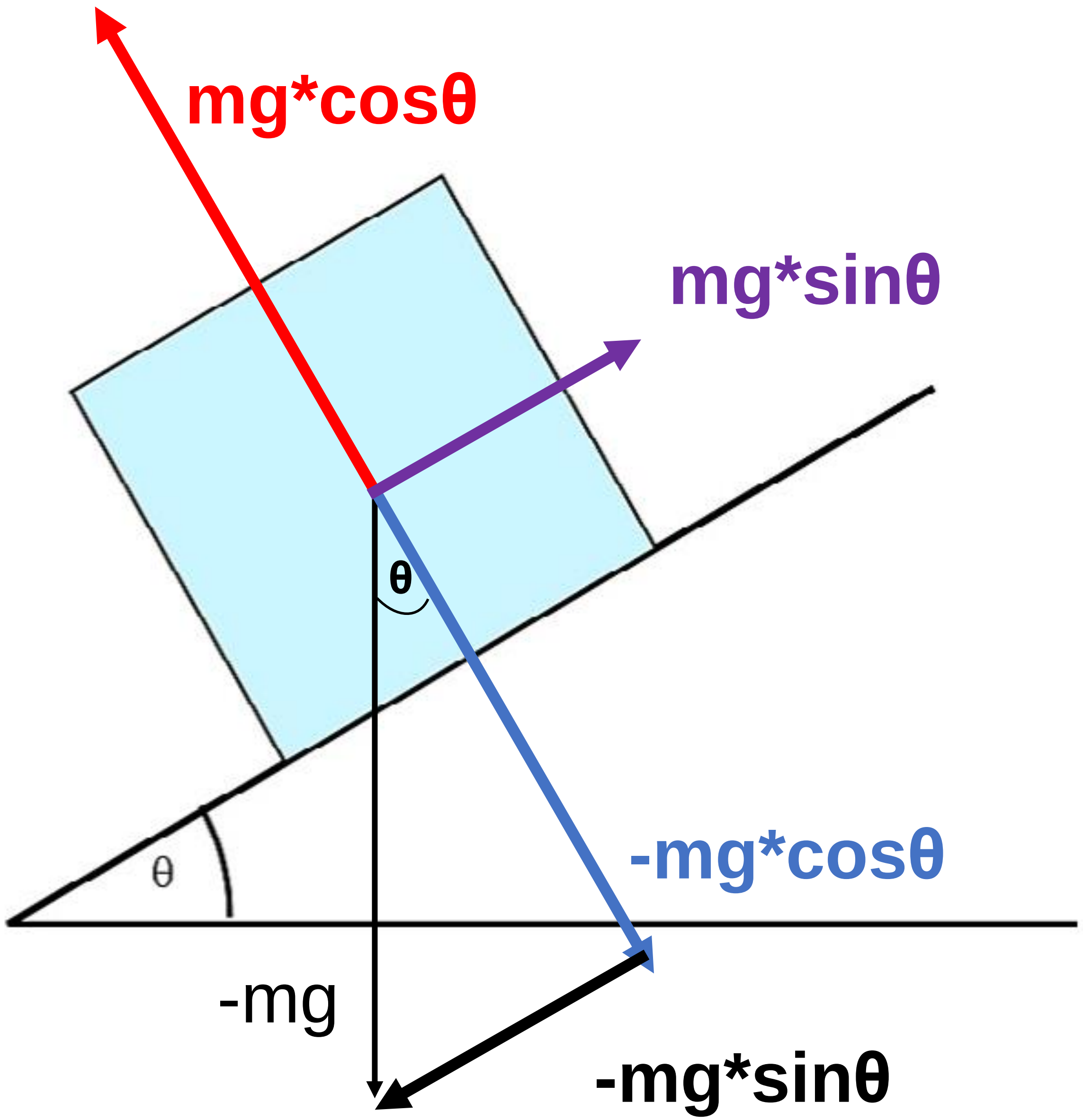


How do we balance the forces?

- **Normal force (F_N)**: cancels out **perpendicular gravitational force**
- **Frictional force (F_f)**: cancels out parallel gravitational force
- Cool physics relationship:

$F_f \leq \mu F_N$

μ (“mu”): coefficient of friction



What does this have to do with skiing?

- We learned from our activity that with an increase in the tilt angle, the measured mass decreases….
- What we were measuring was the normal force! In your activity sheet, the “calculated mass” was actually the normal force

- If the normal force decreases, the frictional force decreases based on $F_f = \mu F_N$
- Less friction → more speed!

How do raked stages affect dancers?

- Dancers on raked stages often experience more injuries
- Landing on tilted surfaces increased ground reaction force and impacted knee and hip angles

Clin Biomech (Bristol, Avon). 2007 Nov;22(9):1030-6. doi: 10.1016/j.clinbiomech.2007.07.012. Epub 2007 Sep 10.

The effect of an inclined landing surface on biomechanical variables during a jumping task

Marshall Hagins [1], Evangelos Pappas, Ian Kremenic, Karl F Orishimo, Andrew Rundle

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PMID: 17826875 PMCID: PMC2699559 DOI: 10.1016/j.clinbiomech.2007.07.012

Free PMC article

We also see this in high heels:

- This 2020 study showed that women wearing high heels had more force experienced on their knees when walking

- They recommend not wearing heels above 5 cm tall (around 2”)
- Imagine having to wear high heels on a raked stage!

PAPER • OPEN ACCESS

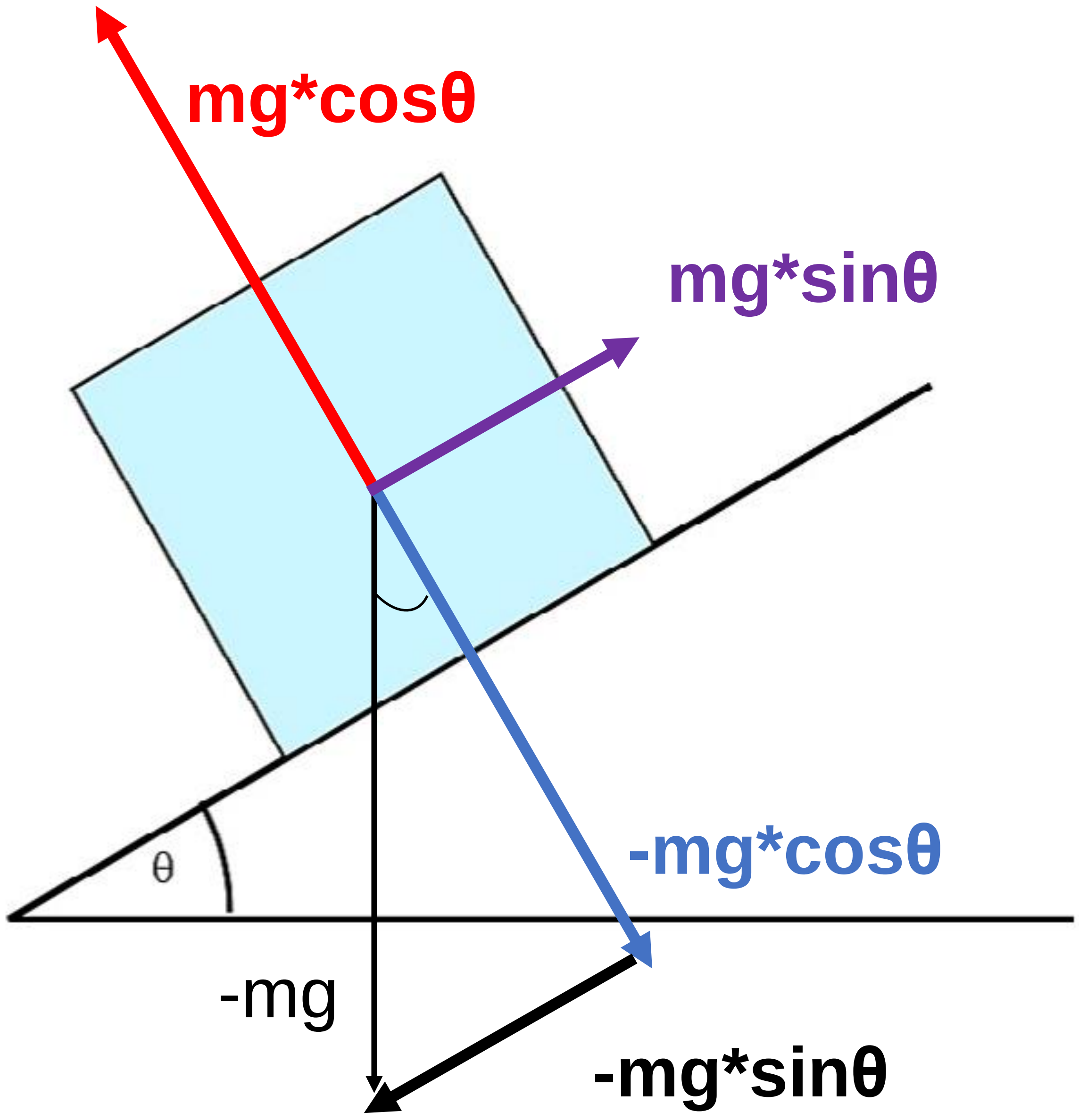
Biomechanical study with kinematic and kinetic descriptions of the effect of high-heeled shoes in healthy adult females based on gait analysis

To cite this article: Sadiq J. Hamandi and Duaa M. Ruken 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **671** 012063

Accomplished Learning Objectives

- Learn the origins of “downstage” and “upstage”
  - ✓Stages used to be tilted
- Recognize what a normal force is
  - ✓Force that counters gravity
- Calculate frictional force based on the normal force
  - ✓Frictional force = friction coefficient * normal force
- Draw force body diagrams for a mass on an inclined plane
  - ✓FBD considers all balanced forces
- Consider ethical implications of theater and stage design
  - ✓Impact on dancer’s health vs. theater effects

Activity Time!



Let’s take another 5 minute break before the second part of the activity.