PROJECT

FORCES

“THE LITTLE REED, BENDING TO THE FORCE OF THE WIND, SOON STOOD UPRIGHT AGAIN WHEN THE STORM HAD PASSED OVER.”

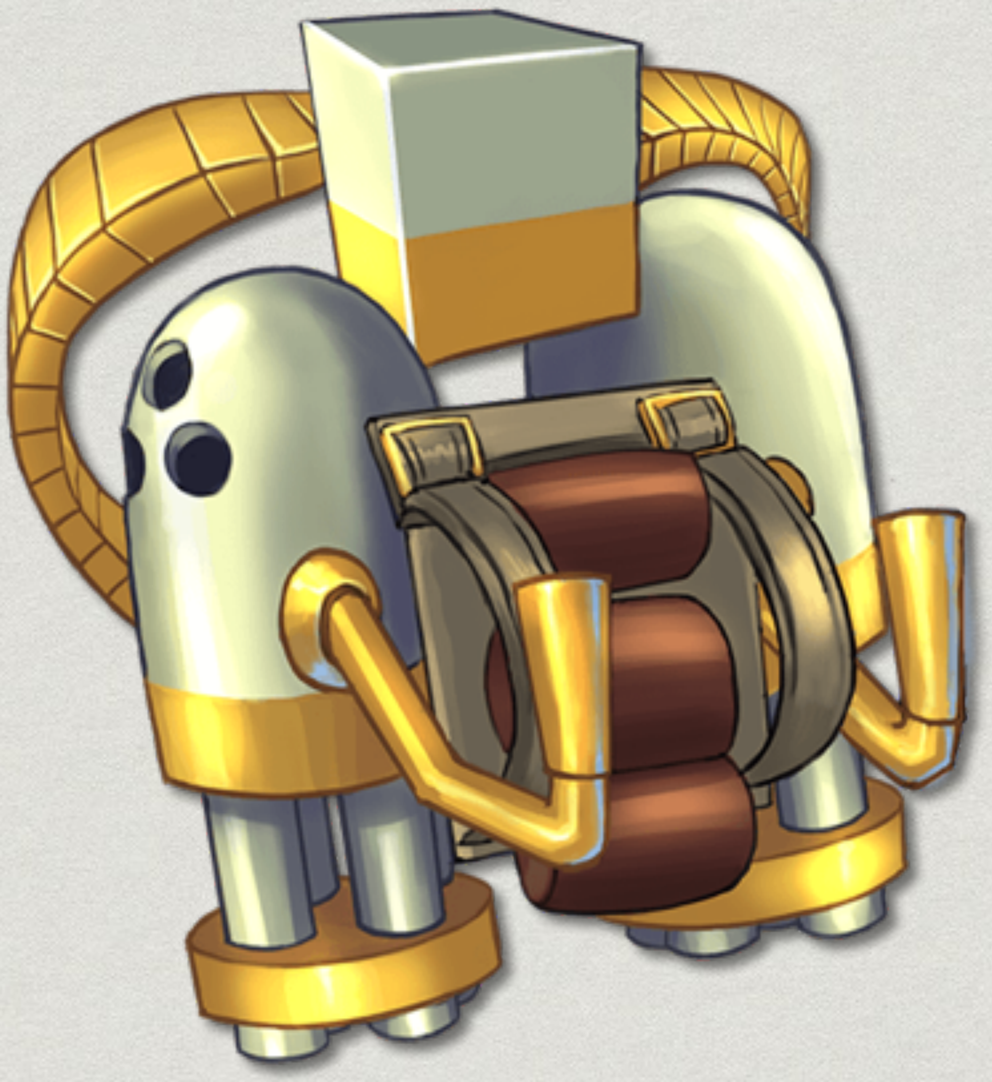
- AESOP

CLIENT

GENERAL PHYSICS

Machine-Gun Jetpack

- Is it possible to build a jetpack using downward-firing machine guns?

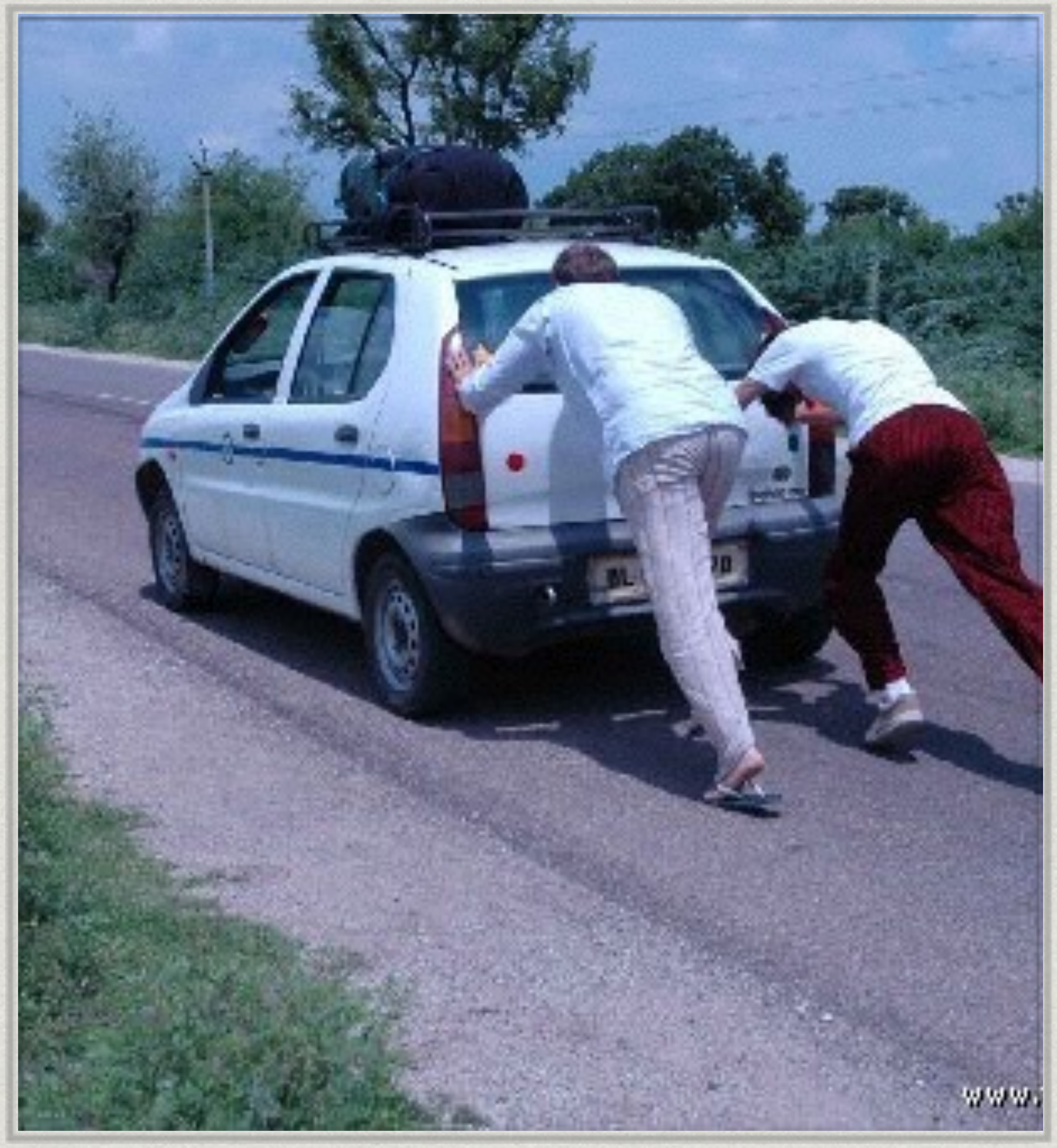


Dynamics

- The first two units we talked about kinematics
  - Branch of mechanics that describe *how* things move
- Now, we begin dynamics
  - Branch of mechanics that describes *why* things move

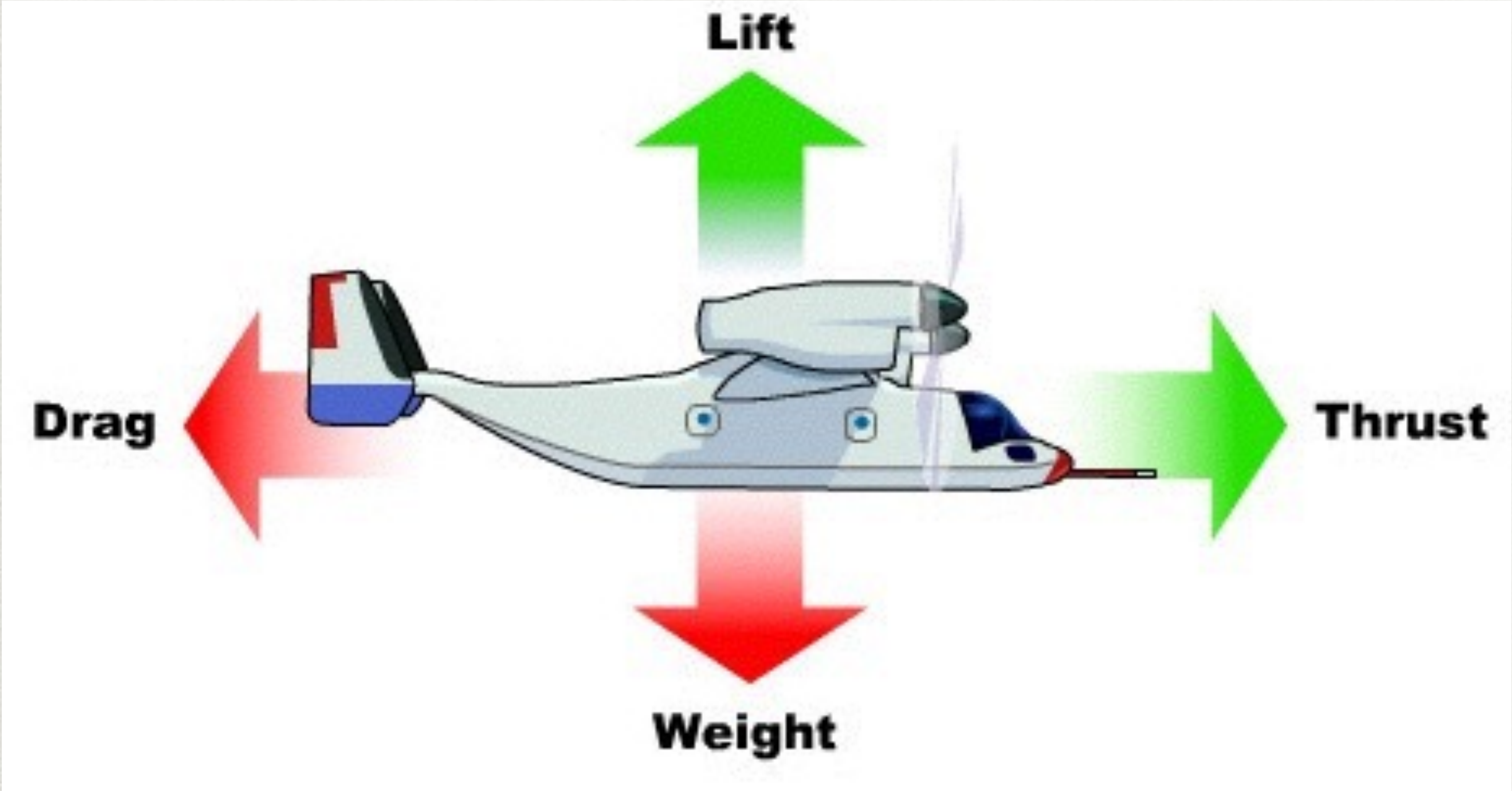
Force

- Force is the push or pull on an object
- The forces needed to
  - push your car up a hill
  - hold the planets in orbit
  - draw back a stiff spring
  - or hold a magnet on a refrigerator
- can all be described in much the same way



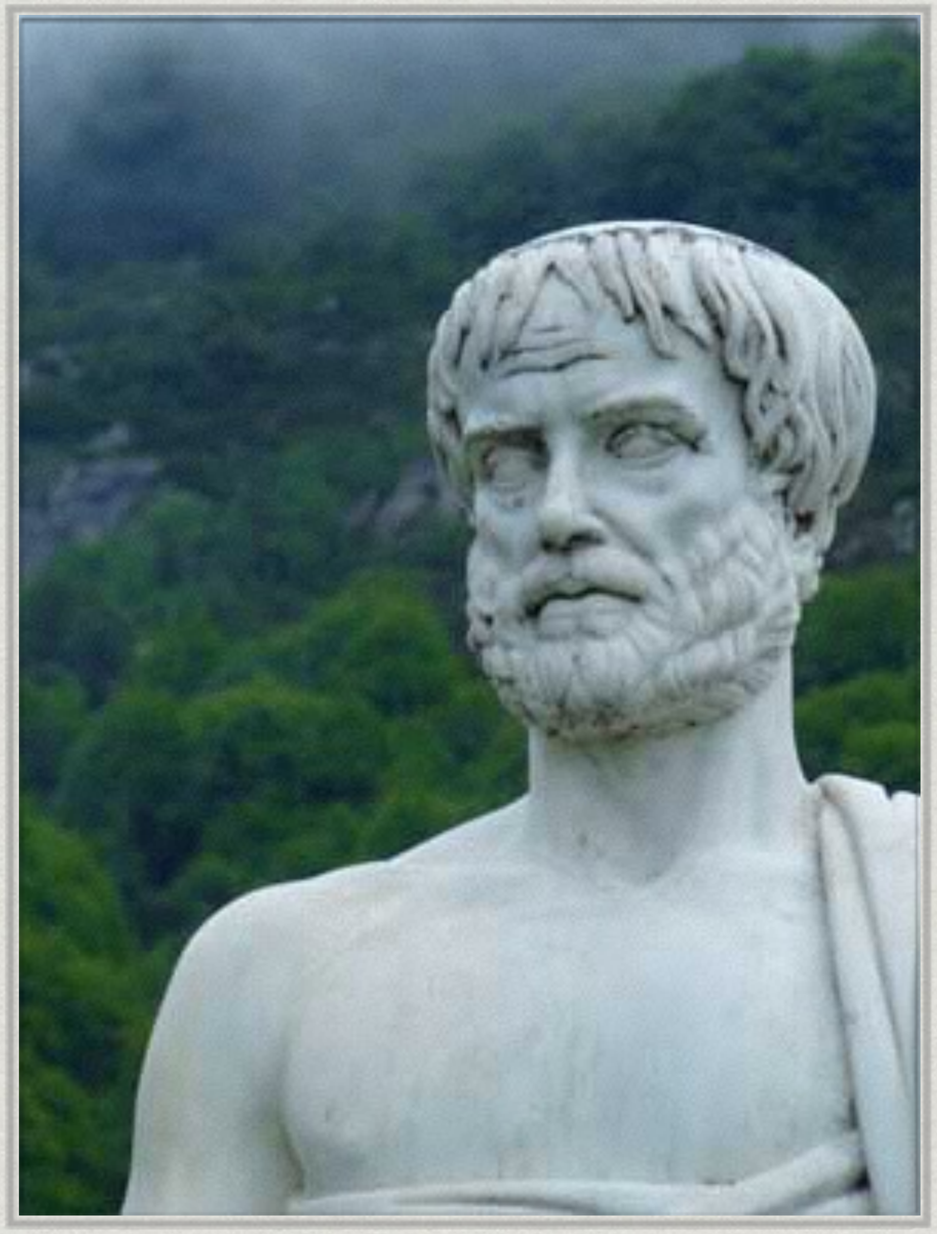
Force

- force is a vector
- measured in Newtons (N)



Force and Velocity

- Aristotle surmised that for objects to maintain motion, they must have a force continuously exerted upon them
- Also, the greater the force on the body, the greater the body's speed
- How is this view incorrect?



Forces: a Galilean View

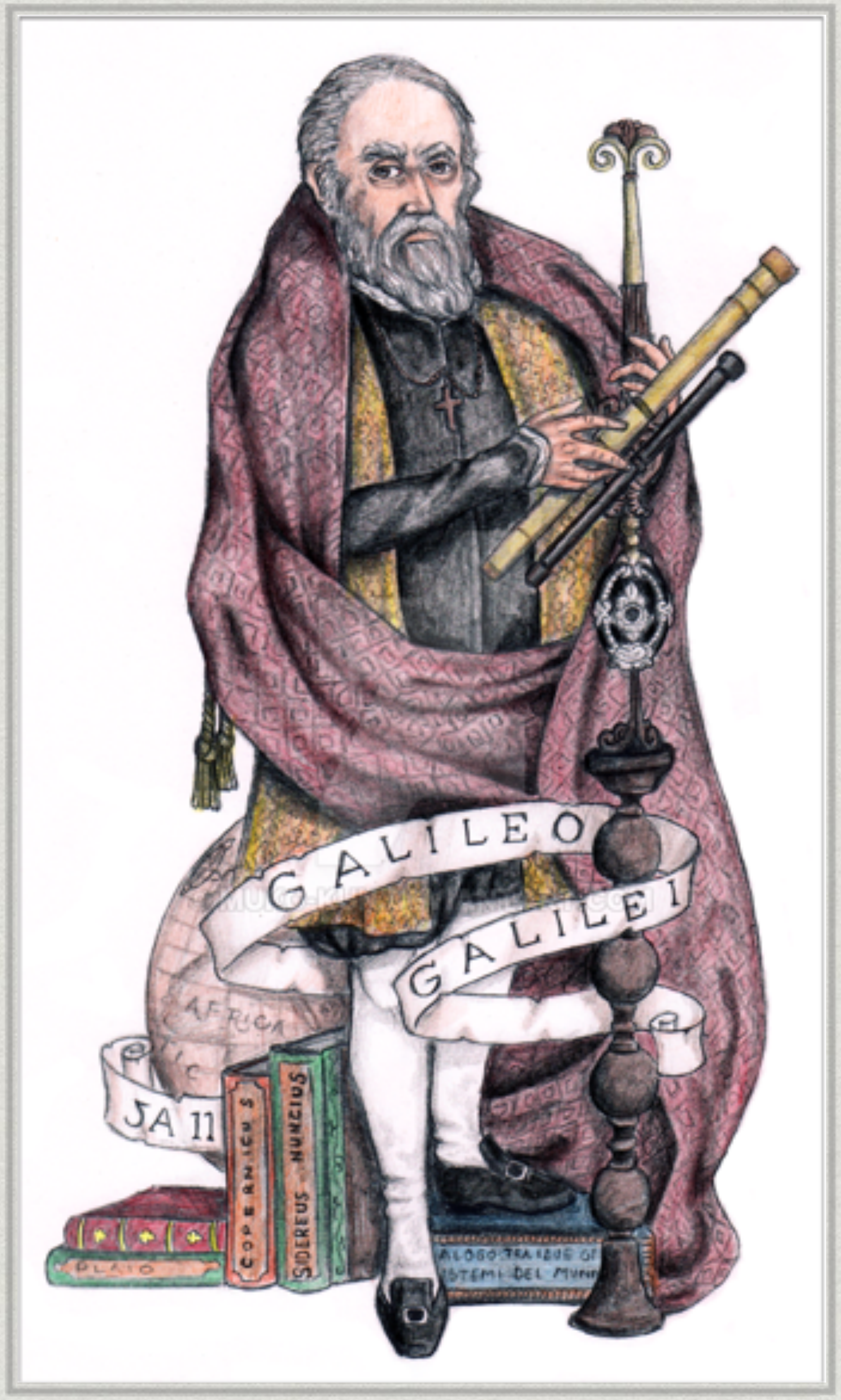
- In the absence of friction, an object will continue at a constant speed in a straight line
  - despite the fact no force is being applied!
- In fact, the object only slows down if a force is applied on it
- Thus, friction is a force just like ordinary pushes and pulls!

Forces: a Galilean View

- What's going on when you push a book across your desk at a constant speed?
- The force you apply forward is equal to the force friction applies backward
- The *net* force on the book is zero

An Important Lesson from Galileo

- Limiting Cases
  - What happens when you take a value to zero?
  - Or to infinity?
- One of the handiest methods for keeping your facts straight or adjusting your intuition



Isaac Newton

- Inspired by Galileo's work, Isaac Newton used Galileo's conclusions as the foundation of his own study of motion
- In his great work, the *Principia* (pub. 1687), Newton summarized his theory of motion

Newton’s First Law of Motion

I. An object continues in its state of rest or of uniform speed in a straight line unless acted on by an external, unbalanced force

The 1st Law

- Also called the *Law of Inertia*
- Inertia is a body's resistance to changes in it's motion
  - a measure of the object's "laziness"

Reference Frames

- The 1st Law is *not* true in all reference frames
  - E.g. You ramp up the car from 30 mph to 65 mph. The cup of hot coffee you left on your dashboard may accelerate toward you even though there is no force acting on it in that direction. Thusly, you spilling hot liquid all over your Newton-shaming lap.
- The 1st Law only holds up in non-accelerating reference frames
  - called inertial reference frames
- We will *always* assume an inertial reference frame

Mass

- Mass is the measure of the inertia of a body
- More mass = harder to change motion
  - Harder to get moving from rest, harder to stop moving when started

Mass vs. Weight

- NOT THE SAME THING
- Mass is a property of the object itself
- Weight is a force - the force due to gravity
- An astronaut who weighs 600 N here on Earth would only weigh 100 N on the Moon thanks to the weaker gravity
    - But her mass would still be the exact same (61 kg)

Net Force

* What if there is a net force?
* A force on an object at rest will cause the object to move
* A force against the motion of an already moving object will cause it to slow down
* A force perpendicular to an object's motion will cause the object to change direction
* *A net force gives rise to acceleration*

Newton's Second Law of Motion

II. The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the direction of the net force acting on the object.

- $\mathbf{a} = \sum \mathbf{F}/m$

(One of) The Most Important Relationship(s) in Physics

- $\sum \mathbf{F} = m\mathbf{a}$

- Newton's 2nd Law relates the description of motion to the cause of motion: force
- One of the most fundamental relationships in physics
- Force: a better definition
    - *an action capable of accelerating an object*

A couple notes on force

- Force is a vector, so think in components
  - $\sum F_x = ma_x$
  - $\sum F_y = ma_y$
  - $\sum F_z = ma_z$
  - $\mathbf{F_{net}} = \sqrt{F_x^2 + F_y^2 + F_z^2}$
- $1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$

Example 1

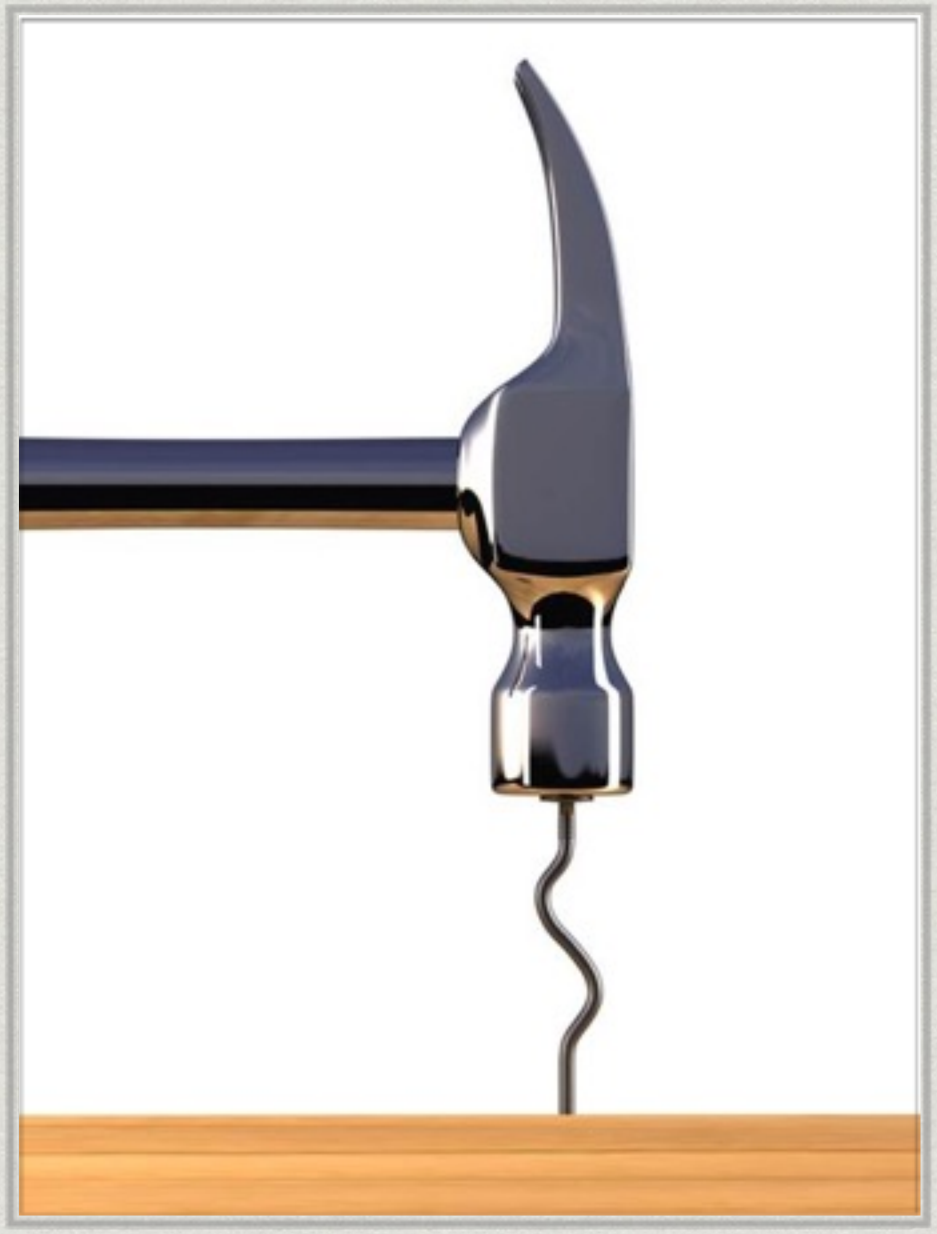
- Mad scientist Rick Sanchez and his grandson Morty need to accelerate their 1000 kg spaceship at ½*g* in order to escape the Gazorpazorps. What net force is needed?
  - *Answer*: F = 5000 N

Example 2

- Rick and Morty escaped the Gazorpazorps and pull into the garage. The 1000 kg spaceship is brought to rest in the garage from a speed of 100 km/h within a distance of 55 m.
- What's the net acceleration?
  - *Answer*: $a = -7.0\ \mathrm{m/s^2}$
- What's the net force required?
  - *Answer*: $F = -7.0\times10^3\ \mathrm{N}$

(Re)Actions

- A force applied *to* any object is always applied *by* another object
- A hammer applies a force on a nail
- But what happens to the hammer?
  - It's speed rapidly reduces to zero
  - Only a strong force could cause such a rapid change in velocity
  - The nail must be exerting a force back on the hammer!



Newton’s Third Law of Motion

III. Whenever one object exerts a force on a second object, the second exerts an equal and opposite force on the first

(Re)Action

- Identify the action-reaction pairs

    1. Baseball in freefall
    2. A baseball bat knocks a ball into left field
    3. Enclosed air particles push balloon wall outwards
    4. Rocket launches into the air
    5. Usain Bolt runs around the track

- Reactions:

    1. Baseball pulls Earth up
    2. the ball pushes the bat back and to the right
    3. balloon wall pushes air inward
    4. Rocket fuel pushes rocket up
    5. Ground pushes Usain forward

Sanity Check

- Svenrich wants to show off his brick collection to his friend Viktoriya. He loads up his sled with bricks before remembering that when he exerts a forward force on the sled, the sled will exert an equal and opposite force backward. He calls up Viktoriya to let her know he can’t make it and explains his situation. How does Viktoriya (who is better at physics than Sven) respond?

Newton's Law of Motion

I. An object continues in its state of rest or of uniform speed in a straight line unless acted on by an external, unbalanced force

II. $\sum F = ma$

III. For every action there is an equal and opposite reaction

Force of Gravity

- Use Newton's 2nd Law to derive the force of gravity on an object with mass *m*
  - $F_g = mg$
  - The magnitude of the force of gravity is called weight

Example 3

- Raphaldo (m = 71.0 kg) sits in his room minding his own business
- What is Raphaldo's weight?
  - *Answer*: $F_g = 697$ N
- A mysterious alien abducts Raphaldo and whisks him away to Mars. For some reason they have a bathroom scale on the Red Planet, and Raphaldo decides to weigh himself. He's finds his weight is only 263 N on Mars!
- What is the acceleration due to gravity on Mars?
  - *Answer*: $a_g = 3.71\ \text{m/s}^2$

Force of Gravity

- Gravity acts the same on both objects in free fall and objects resting on the ground
- If the same force of gravity is acting on the object on the table, then why doesn't it accelerate?
  - The table pushes up on the object!
- Normal force — contact force which acts perpendicular to a common surface of contact

Note

- Since the object on the table remains at rest, F_g and F_N must be of equal magnitude in opposite directions
- However, these are *not* an action-reaction pair from Newton's 3rd Law
- Why not?
- What *are* the action-reaction pairs of the gravitational and normal forces?

Example 4

a) An unassuming 10.0 kg box rests on the ground.

- What is the weight of the box and the normal force acting on it?
- *Answer*: F_g = -98.1 N; F_N = +98.1 N

b) The box catches the eye of a young girl, Pandora. She pushes down on the box with 40.0 N of force.

- Now what is the weight of the box and the normal force acting on it?
- *Answer*: F_g = -98.1 N; F_N = +138 N

c) Pandora instead pulls up on the box with 40.0 N of force.

- Now what is the weight of the box and the normal force acting on it?
- *Answer*: F_g = -98.1 N; F_N = +58.1 N

Here's a Thought

- When you weigh yourself on the bathroom scale, what is the scale actually measuring?
  - *Answer: Normal force*

Example 5

- What happens if Pandora pulls upward on the 10.0 kg box with a force equal to or greater than the box's weight, say F_A = 100.0 N instead of 40 N?
  - *Answer*: $\sum F_y$ = 1.90 N; a_y = 0.190 m/s^2

Equilibrium

- We say a system is in ***equilibrium*** if the *net* force on it is zero
- A fun example is ***terminal velocity***
  - Terminal velocity is reached when $F_{drag} = F_g$
  - $v_{term} \approx 50$ m/s (110 mph)

Example 6

- A parachutist (m = 100 kg) is falling under the influence of Earth's gravity

a. Neglecting air resistance, what will be his acceleration?

   a. *Answer*: $a = 9.81\ \text{m/s}^2$

b. What is the net force acting on the parachutist?

   b. *Answer*: $F_{\text{net}} = 981\ \text{N}$

c. He then opens his parachute, which provides an additional drag force of 400 N. What is the new net force?

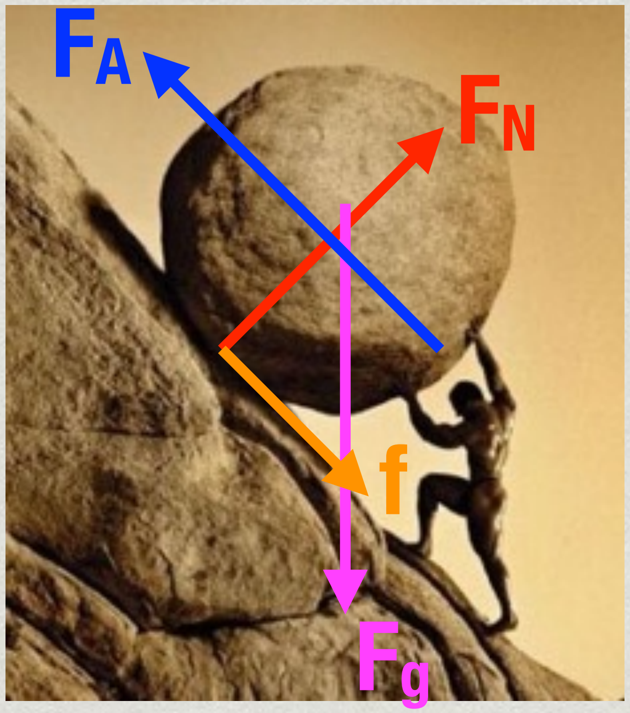
   c. *Answer*: $F_{\text{net}} = 581\ \text{N}$

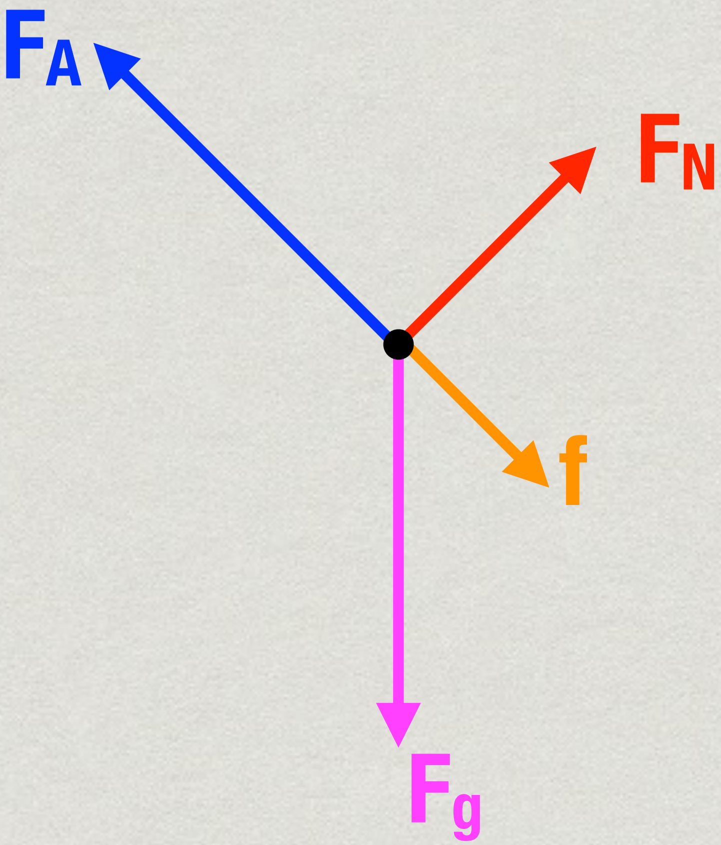
d. With the parachute open, what will be the parachutist's acceleration?

   d. *Answer*: $a = 5.81\ \text{m/s}^2$

Free-Body Diagrams

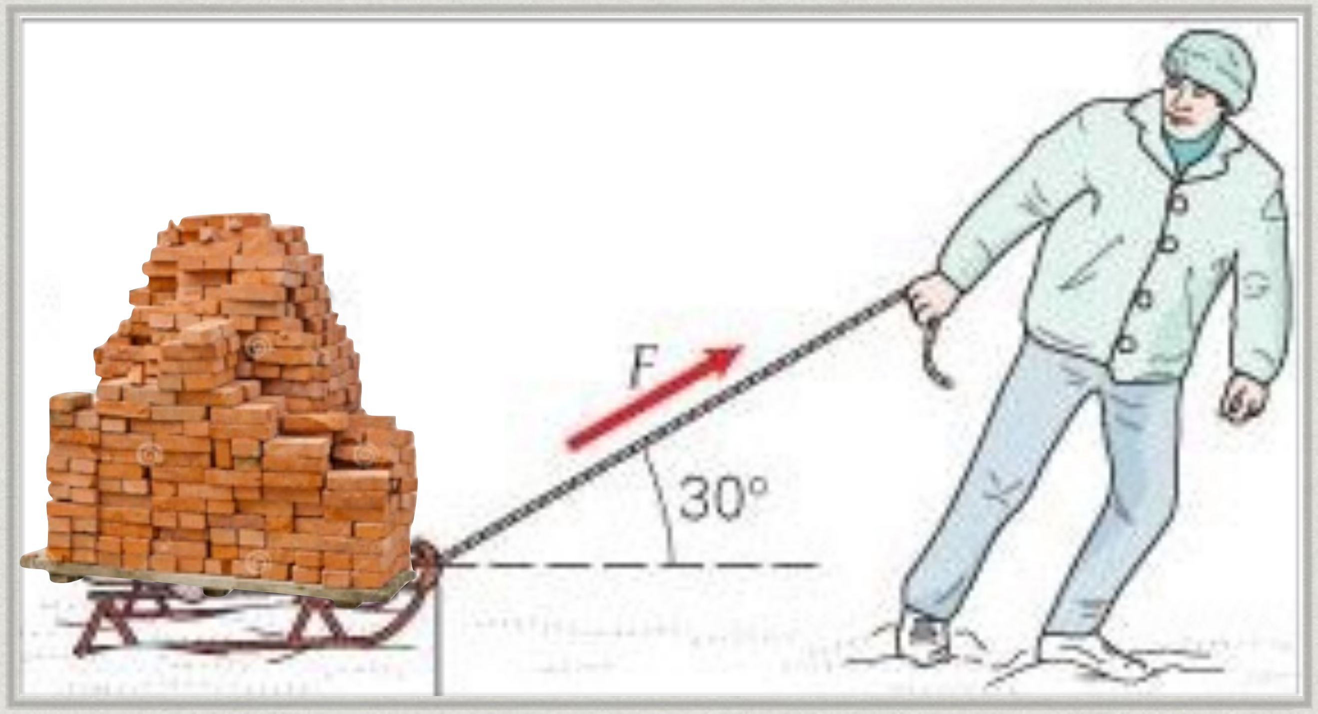
- Diagram showing all forces acting *on* the object involved
- Treat the object as a point
- Draw arrows to represent each force acting on the given body
  - Draw the arrows coming *from* the point
  - Be sure to include *every* force acting on the system





Example 7

- With renewed confidence after his conversation with Viktoriya, Svenrich loads up his bricks to bring to his friend's house. He pulls the 130.0 kg load with 400.0 N of force at an angle of 30º as shown.



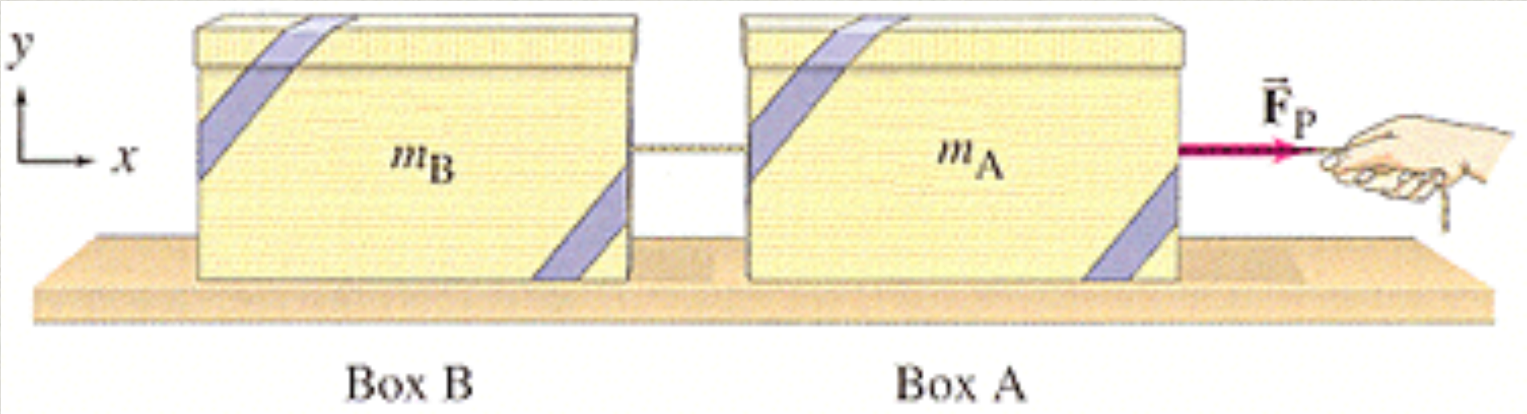
- Calculate the acceleration of the sled. (neglect friction)

- *Answer*: a = 2.66 m/s^2

Tension

* When a flexible cord pulls on an object, the cord is said to be under tension
* If the cord has negligible mass, the force of tension will be equal along its the entire length
* Ropes and cords can only pull
* The force of tension always acts along (parallel to) the rope or cord

Example 8



- Two boxes are connected by a lightweight cord and are resting on a frictionless table. The boxes have masses of 12.0 kg and 10.0 kg. A horizontal force F_P of 40.0 N is applied by a person to the 10.0 kg box, as shown above.

a. Find the acceleration of each box.

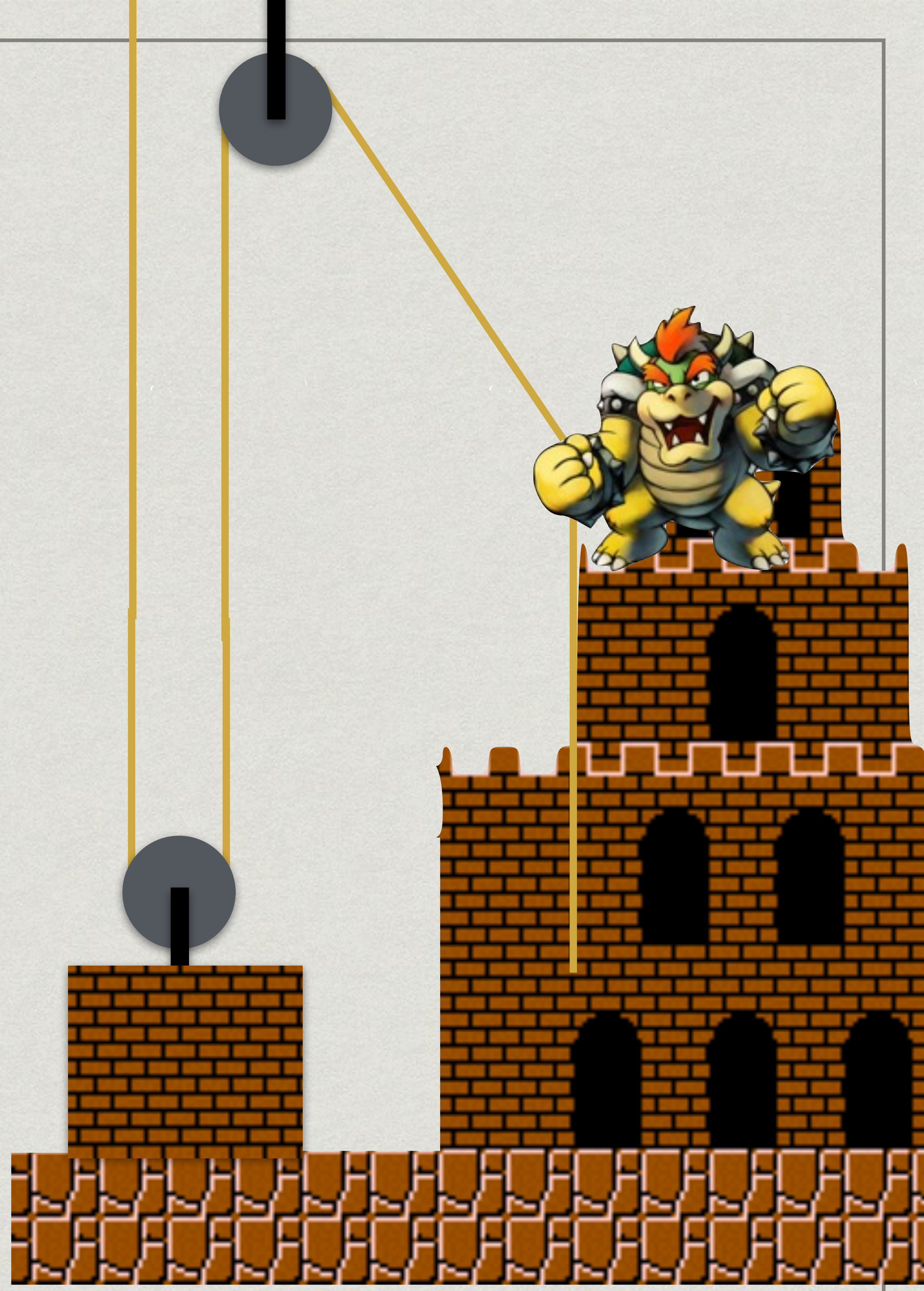
   a. *Answer*: a = 1.82 m/s^2

b. What's the force of tension is the cord?

   b. *Answer*: T = 21.8 N

Example 9

- How does Bowser build so many castles so quickly? Why, using pulleys of course!
- The Koopa King is trying to lift a block (slowly) up to the top of his castle. He is using a rope looped over two pulleys. How much of the block's 2000 N weight does he have to pull on the rope?
  - *Answer*: T = 1000 N

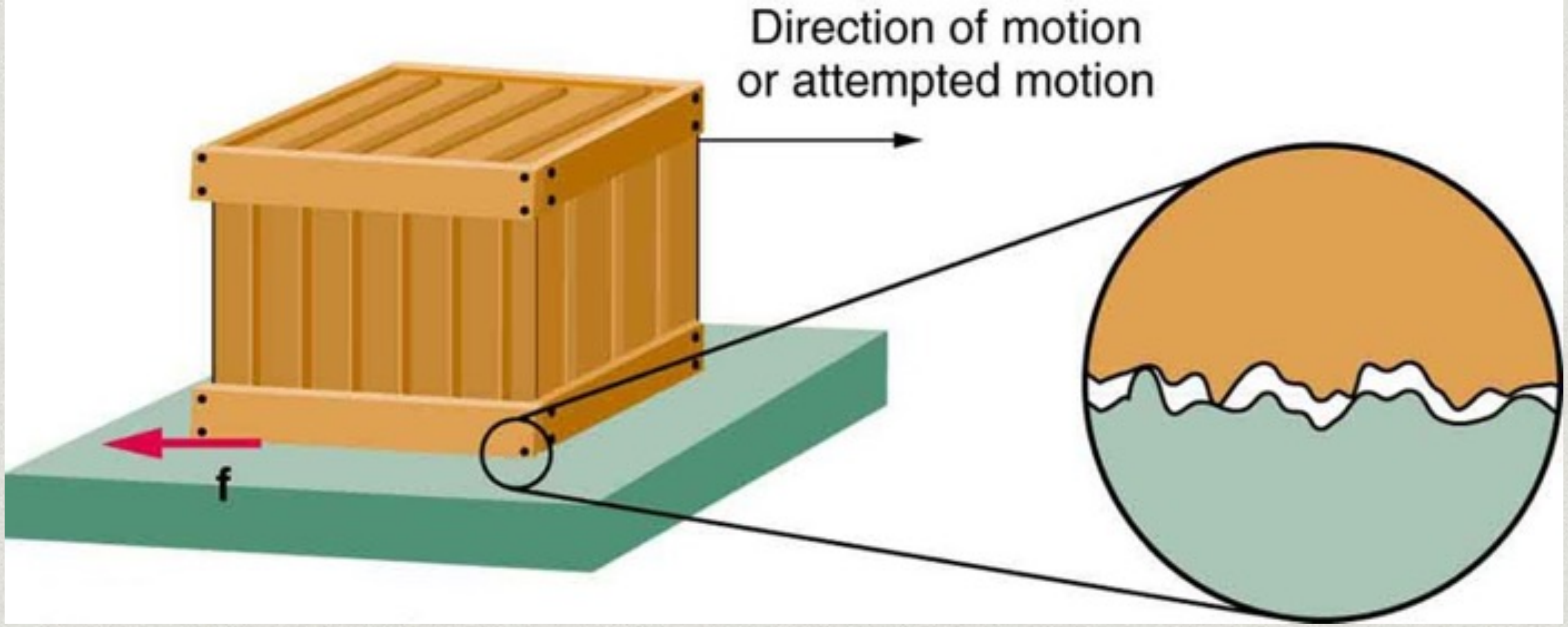


Friction

- Friction is a contact force
- Occurs when one surface attempts to move along another
    1. kinetic
    2. rolling
    3. fluid
    4. static
- Always opposes motion

Why Friction?

- What is it about the surfaces that causes friction to occur?
  - Tiny corrugations bump into each other and impede motion
  - Electrostatic forces can cause chemical bonding on the atomic level



World's Smoothest Object

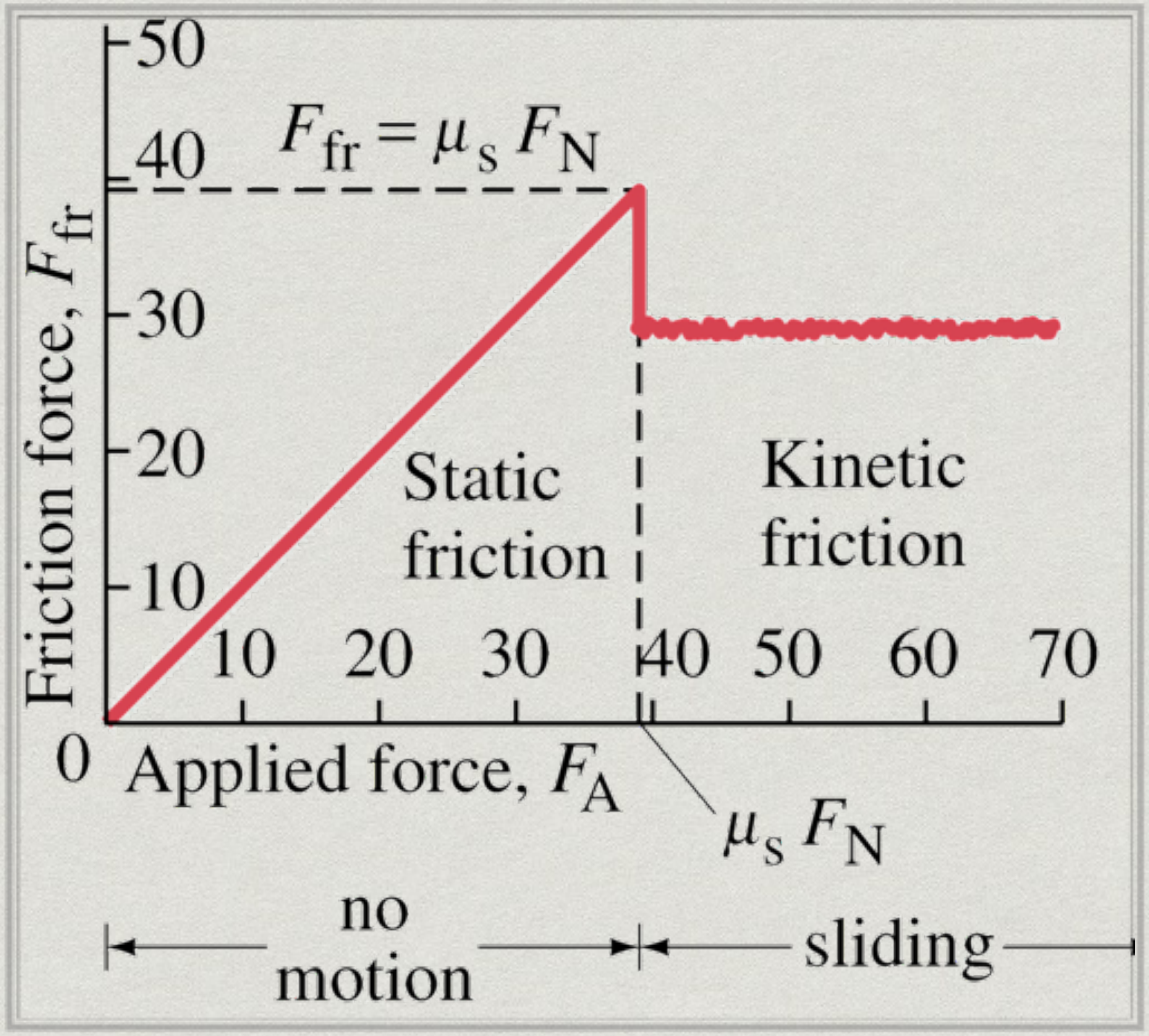
https://www.youtube.com/watch?v=ZMByI4s-D-Y

Friction

- Apart from the relative roughness of the surfaces, what other factors affect force of friction?
- $F_f = \mu F_N$
  - μ is the called the coefficient of friction
  - depends on the nature of the two surfaces
  - *independent* of the surface area of contact
  - *independent* of sliding speed

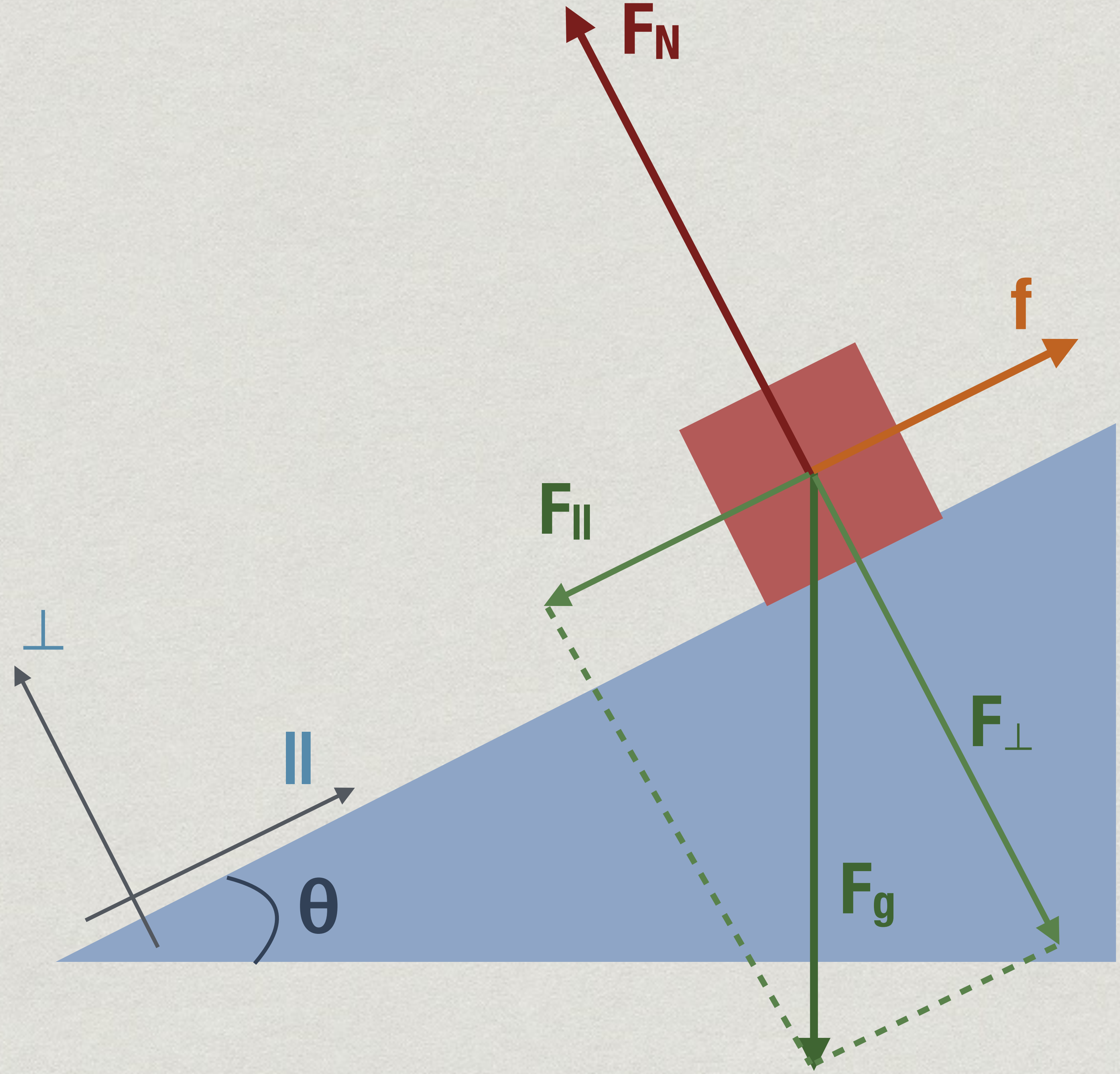
Kinetic vs Static Friction

- Static friction increases to match the force applied
  - Until the breakaway point where static friction reaches its maximum
  - $F_{f,s} \leq \mu_s F_N$
- $\mu_s > \mu_k$



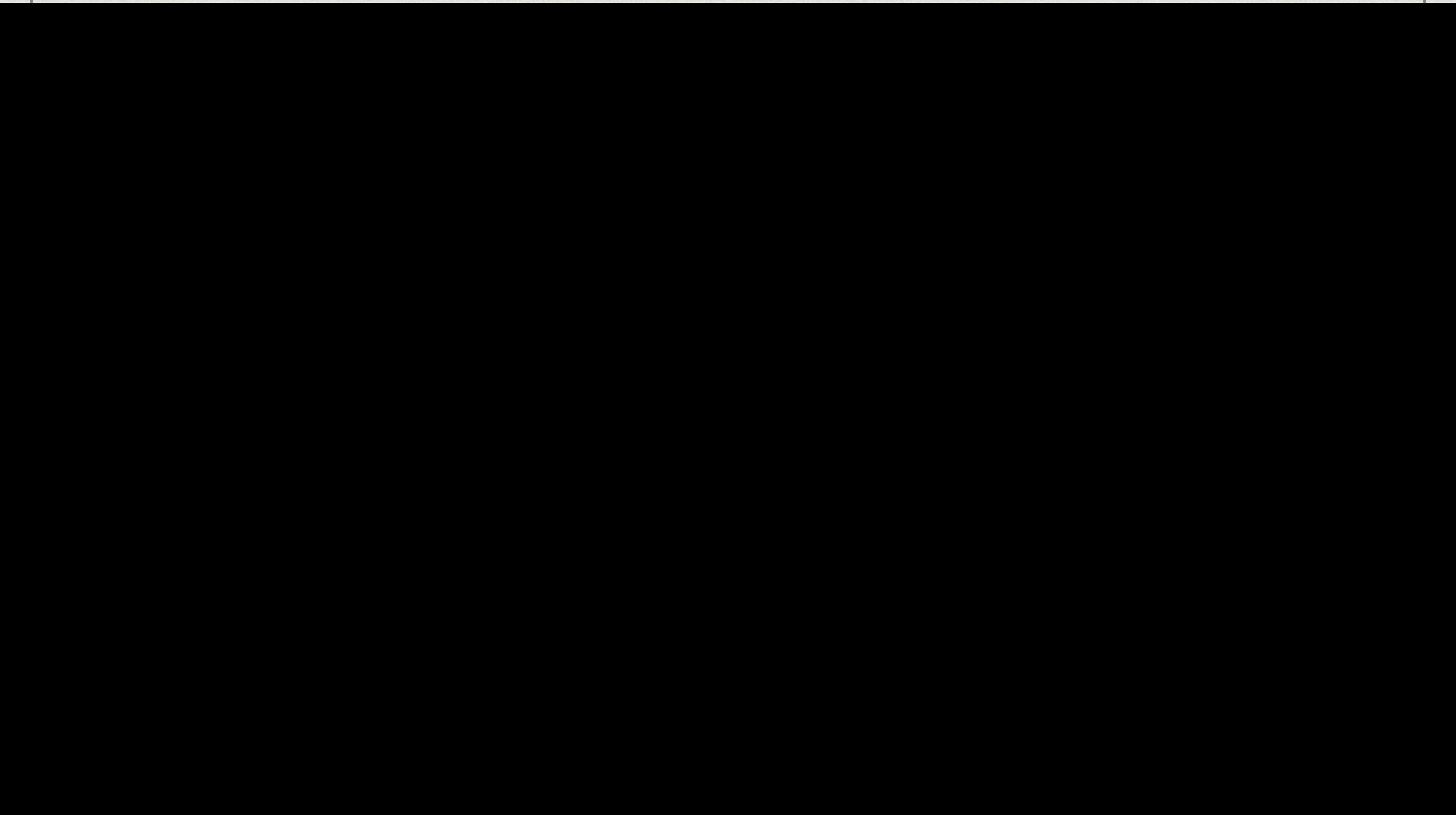
Objects on an Incline

- Typically more convenient to think about vectors acting *parallel* and *perpendicular* to the incline
- $F_{\|} = F_g \sin\theta$
- $F_{\perp} = F_g \cos\theta$



Slope and Slide Lab

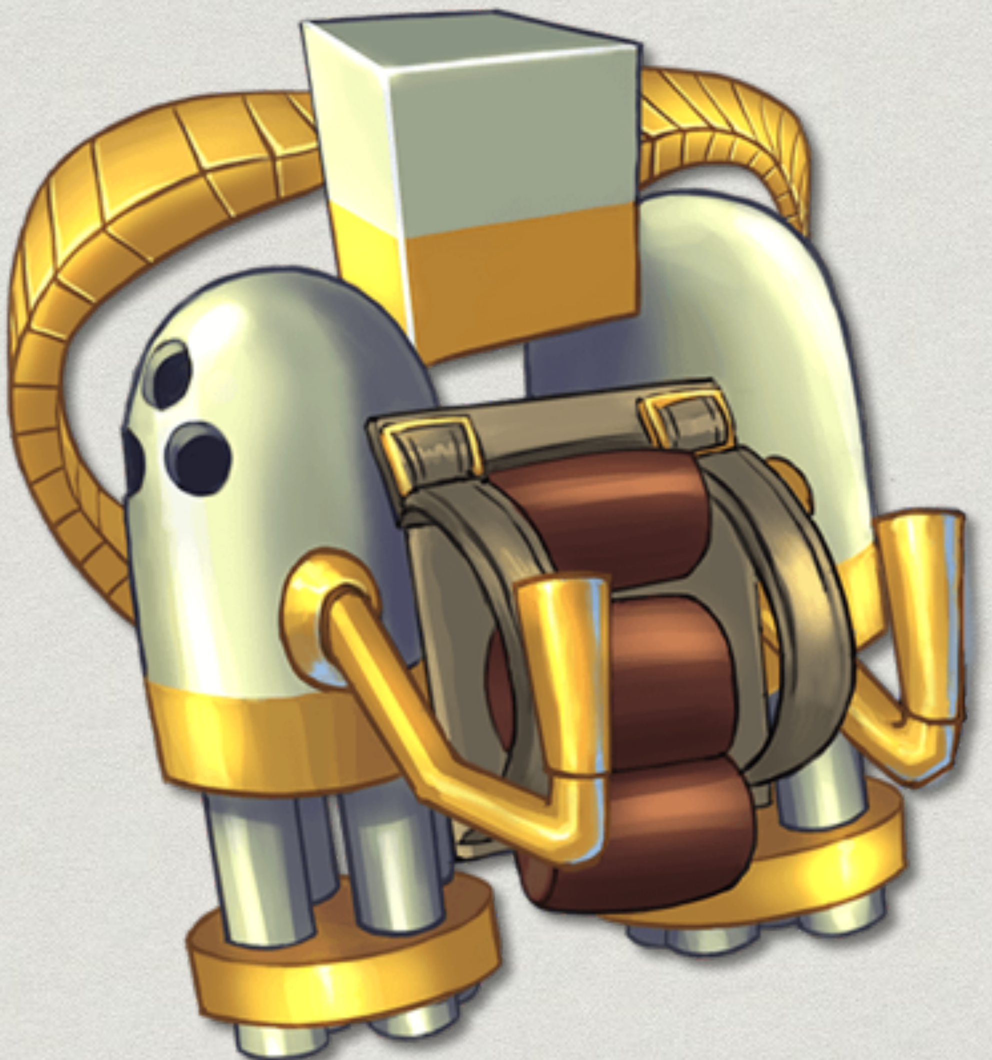
- *Research Question*: How does the angle of incline affect the force of friction?
- *Claim*: (state your conclusion)
- *Evidence*: Measure and plot $f_{s,max}$ and f_k on three different inclines using three different surfaces each
- *Justification*: In physics terms, why do friction and the angle of incline have the relationship you observed?



https://www.youtube.com/watch?v=QD3hbVG1yxM

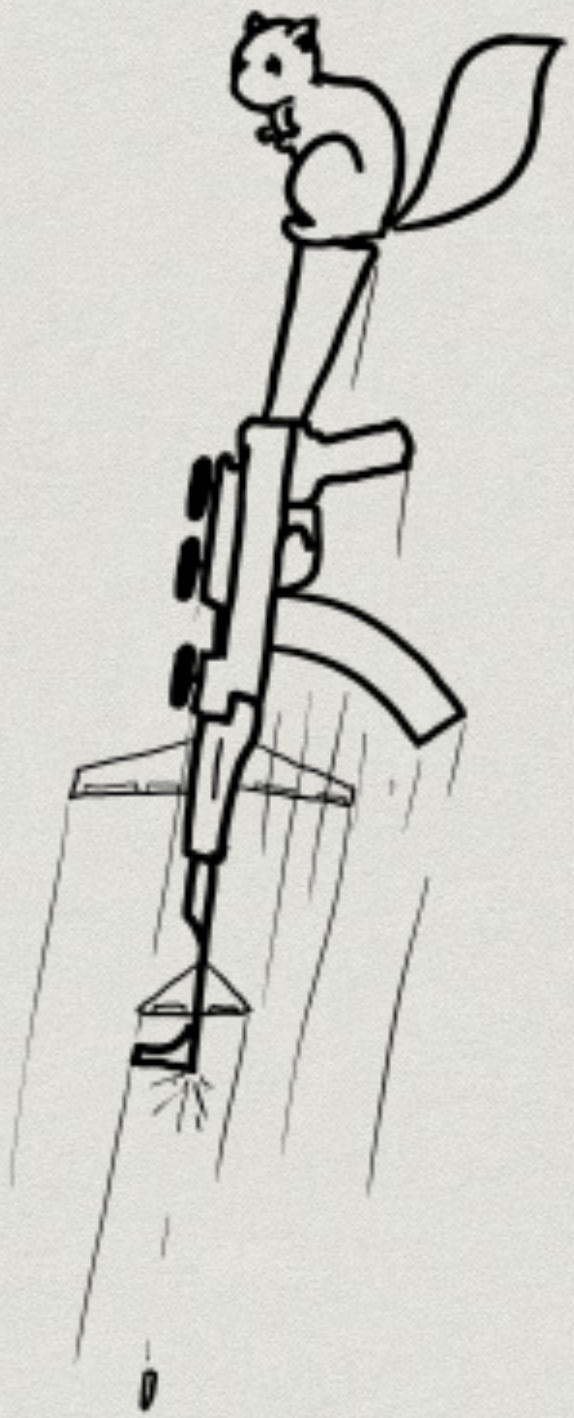
Machine-Gun Jetpack

* Is it possible to build a jetpack using downward-firing machine guns?



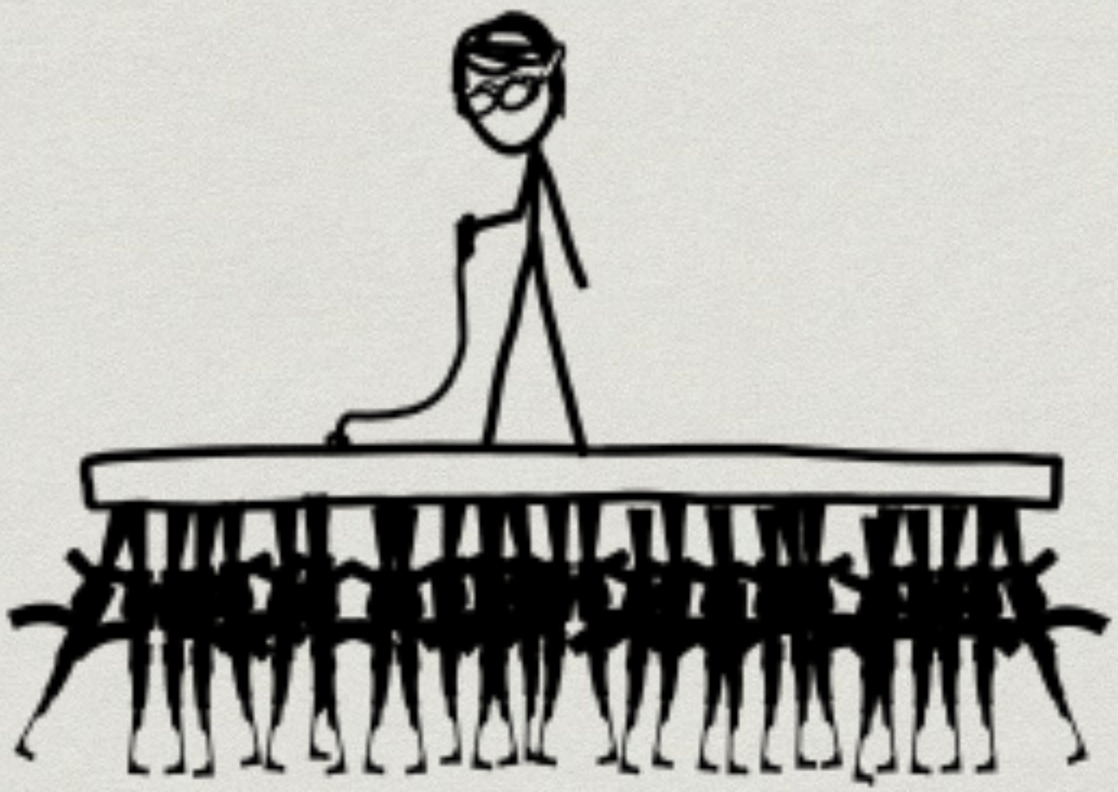
Machine-Gun Jetpack

- The amount of thrust created by a rocket (or firing machine gun) depends on (1) how much mass it's throwing out behind it, and (2) how fast it's throwing it
- If an AK-47 fires ten 8-gram bullets per second at 715 m/s, what is the force of thrust is generates?
  - *Answer*: $F_{\text{thrust}} = 57.2$ N
- A fully loaded AK-47 weighs about 47 N, so it could take off, but it doesn't have enough spare thrust to lift anything heavier than a squirrel



Machine-Gun Jetpack

- If an AK-47 produces 57.2 N of thrust and each gun weighs 47 N, how many would you need to lift a 70 kg person?
  - *Answer*: at least 68



Machine-Gun Jetpack

- **One major problem with this jetpack (one of many) is that an AK-47 magazine only hold 30 rounds**
- **At 10 rounds per second, this would provide a measly three seconds of acceleration**
- **We can improve this with a larger magazine, but only up to a point?**
    - **Why?**