Chapter 4: Force and Motion
Tuesday January 27th

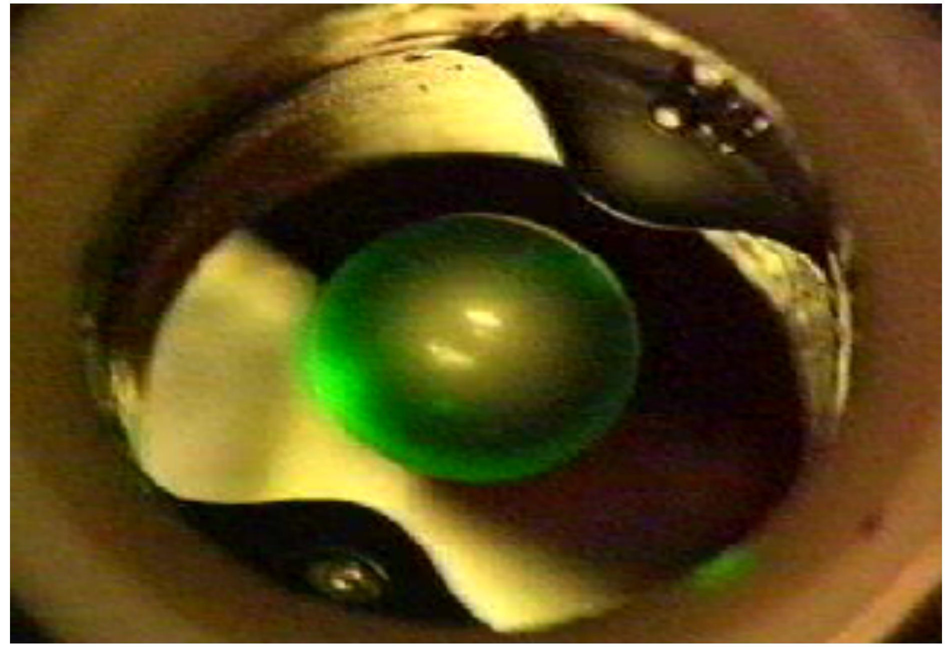
- Newton's laws:
  - Forces and acceleration; Newton's 1st law
  - Free-body diagrams
  - Newton's 2nd law
  - Normal/contact forces and weight
  - Apparent weight in non-inertial situations
  - Newton's 3rd law
  - Other forces relevant to 2048 (tension, spring, if time)
- Demonstrations, iClicker and example problems

Reading: up to page 62 in the text book (Ch. 4)

What causes acceleration?

Linguistic arguments:

- Some sort of interaction - loosely speaking, a push or a pull on an object.
- We call this a **force**, which can be said to act on a body.
- Examples of forces:
  - → Normal or "contact force"
  - → Gravitational force
  - Electromagnetic force
  - Weak and strong nuclear forces


Newton's first law

"A body in uniform motion (constant velocity) remains in uniform motion, and a body at rest remains at rest, unless acted upon by nonzero net force"

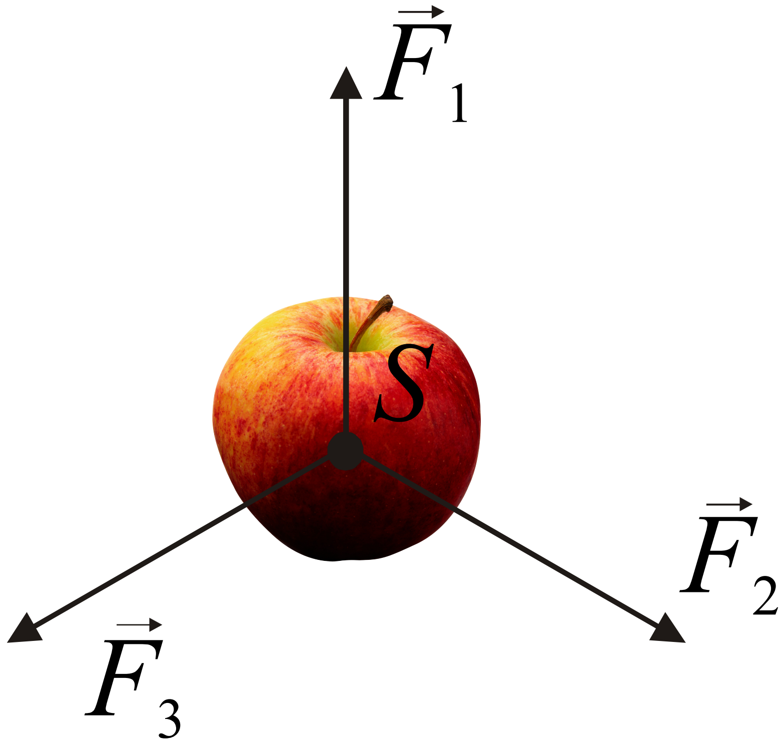
"If no net force acts on a body, then the body's velocity cannot change; that is, it cannot accelerate"

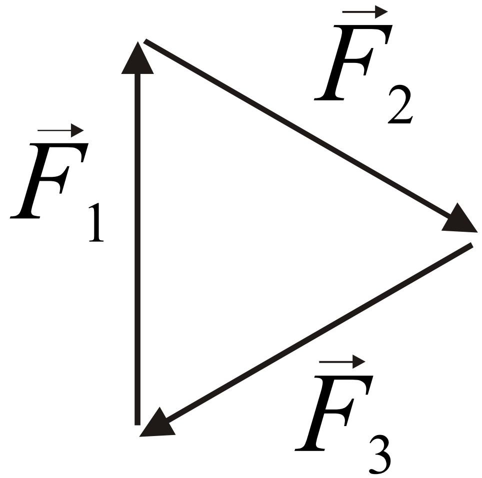
"Forces cause changes in motion (acceleration)"

WARNING LABEL

1. Friction and air resistance have a tendency to distort our comprehension of the nature of forces.
2. Acceleration applies to velocity, not speed: there are situations in which your speed remains constant, yet you are accelerating.
3. "Net Force" implies that the sum of all forces is non-zero.

Free-body diagrams





$$\sum \vec{F} = 0 = \vec{a}$$

The 'net' force equals zero

- The forces shown above are what we call "external forces."
- They act on the "system" *S*.
- *S* may represent a single object, or a system of rigidly connected objects. We do not include the internal forces which make the system rigid in our free body diagram.

Newton's second law

Newton's definition: *"The rate at which a body's momentum changes is equal to the net force acting on the body"*

The more familiar version: $$\vec{F}_{\text{net}} = m\vec{a}$$

Note that Newton's 2nd law includes the 1st law as a special case ($F = 0$).

- We may treat the components separately.

$$F_{\text{net},x} = ma_x, \qquad F_{\text{net},y} = ma_y, \qquad F_{\text{net},z} = ma_z$$

- The mass, m, is a scalar quantity.
- 1 N = (1 kg)(1 m.s^{-2}) = 1 kg.m.s^{-2}

Gravitational Force

During free fall $$\left|\vec{a}\right| = g$$

$$\Rightarrow \qquad F = ma = mg$$

Gravitational Force

During free fall $\vec{a} = -g\,\hat{j}$

y

If I define up as +ve

$$\Rightarrow \quad \vec{F} = m\vec{a} = -mg\,\hat{j}$$

- This is always true at the surface of the earth, and will usually be the case for problems worked in this class.
- Even when a mass is stationary, e.g., on the surface of a table, gravity still acts downwards with a magnitude equal to mg.
- This leads to the concept of a normal force.

What is mass (and weight)?

This is not a trivial question!

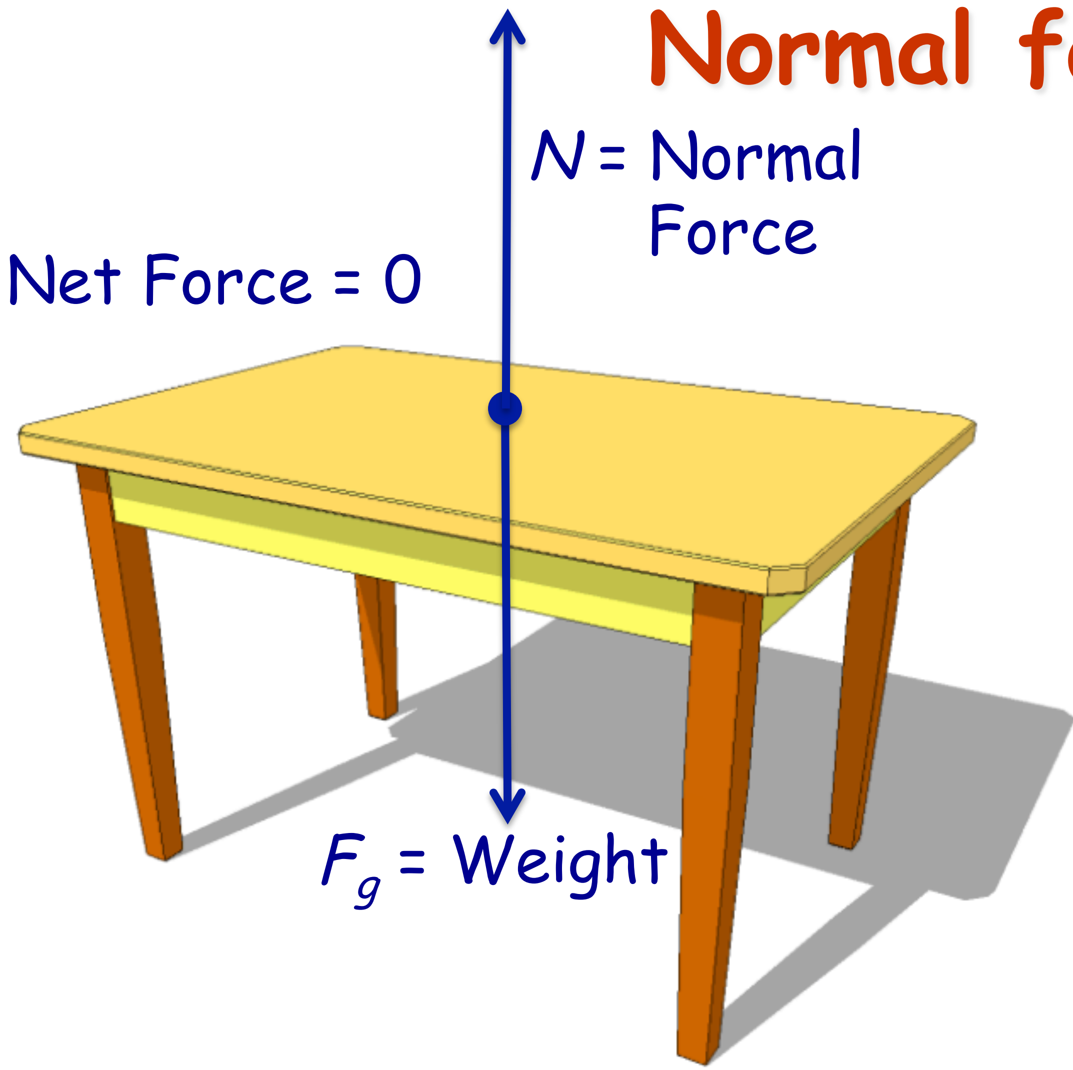
- On earth, we typically* use the fact that the acceleration due to gravity is constant for all objects, and characterize mass according to the force needed to balance the earth's gravitational pull.
- We call this "weight", measured in Newtons (v. important!)
- In outer space, everything is weightless, but not massless!!

Mass is simply the characteristic of a body that relates a force on the body to the resulting acceleration

- This is how one has to measure mass in outer space; no static method works, e.g., a balance or scale (answer depends on g).
- **YOUR MASS DOES NOT CHANGE IN OUTER SPACE!!!**

*Not always the case, particularly in laboratory experiments.

Normal force

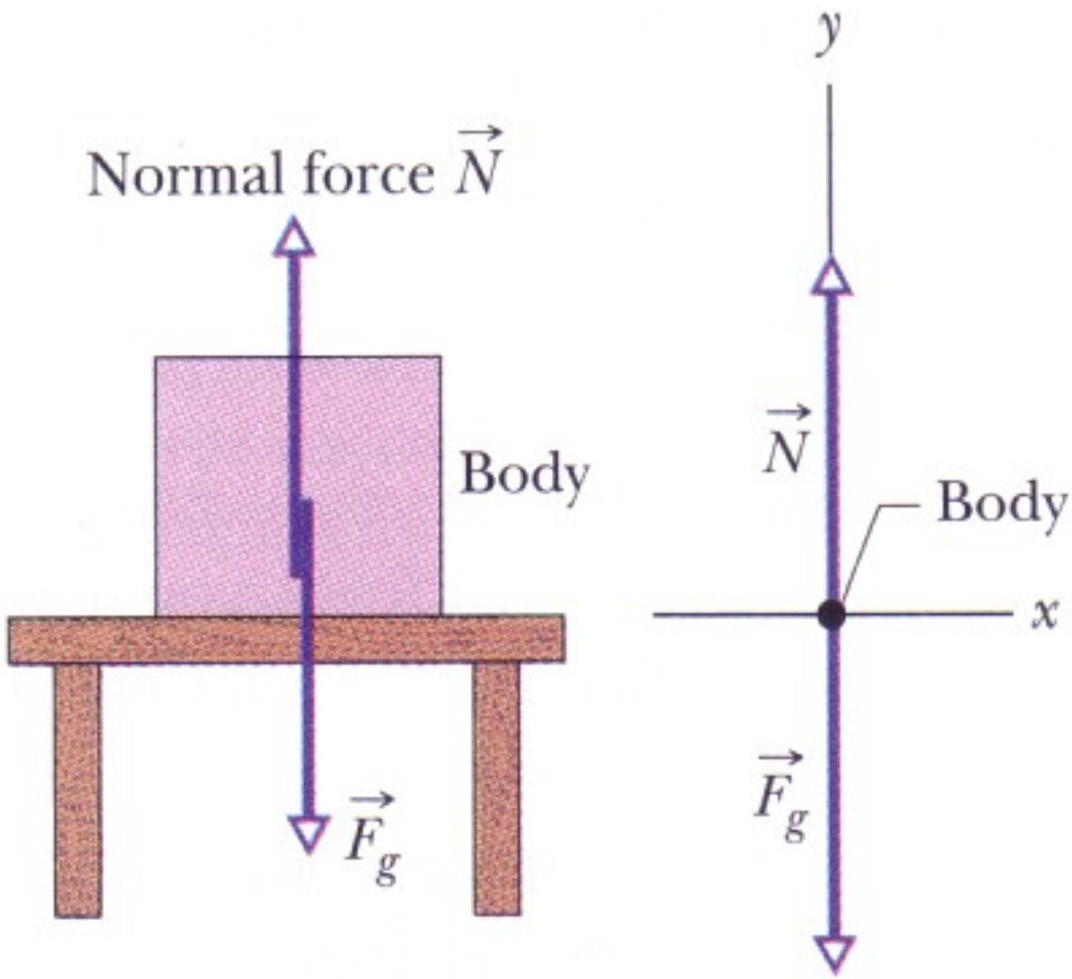


- The internal forces within the table supply a **normal force**, which is directed normal to the surface of the table, i.e., up.
- If the body remains stationary, then the normal force must be equal in magnitude (opposite in direction) to the weight.

Weight (a force!):

$$N = W = F_g = mg \text{ Newtons (N)}$$

Normal force



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Normal force

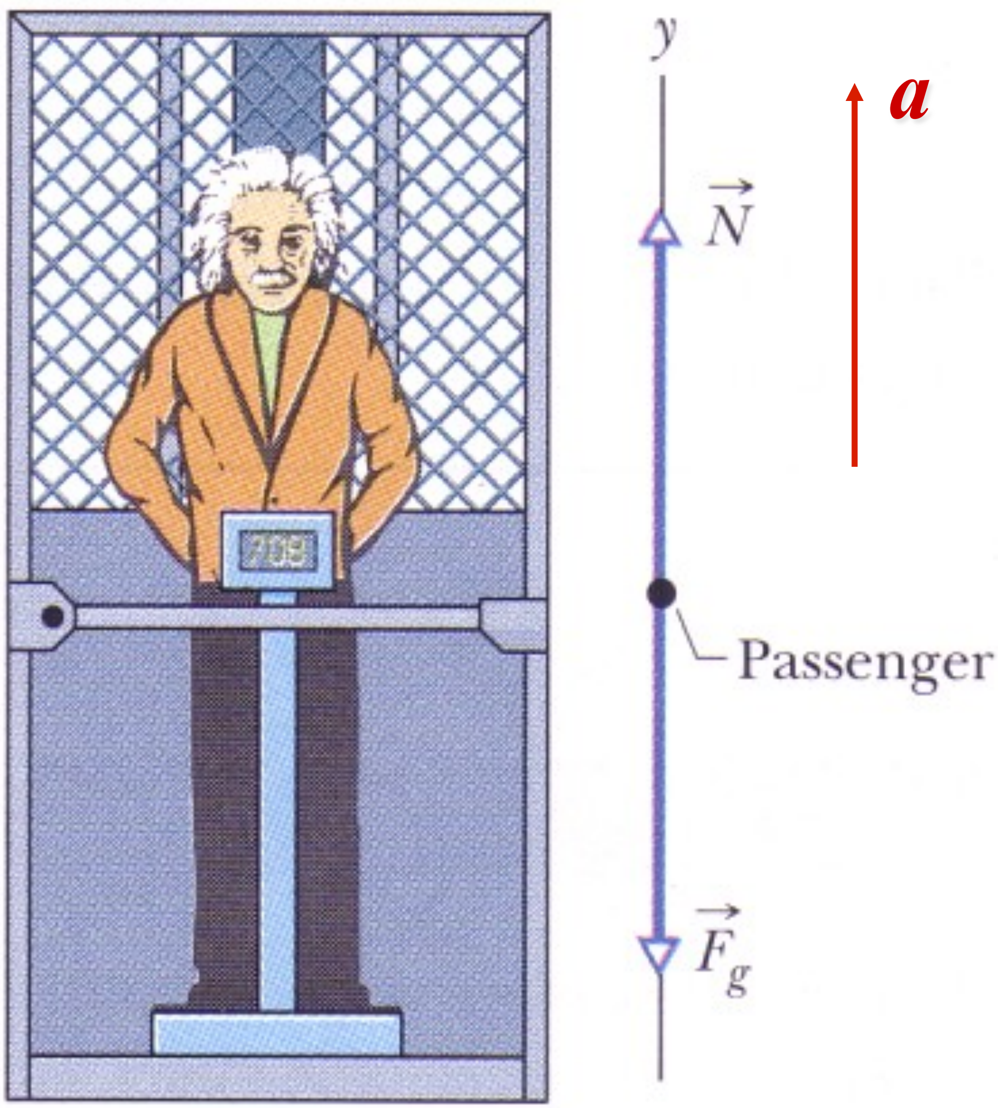
- If you are the one holding the mass in a stationary state, you must supply the necessary upward force.
- This is the sensation of weight.
- You would not feel this sensation in outer space.

Weight (a force!):

$$N = W = F_g = mg \text{ Newtons (N)}$$

Apparent weight in non-inertial frames

Newton's laws apply only in 'inertial reference frames'



- The scale reading is equal to the normal force on the passenger from the scale.
- If we are to use Newton's laws (specifically 2nd law), we must analyze this problem from an inertial frame, i.e., from the stationary frame corresponding to the ground.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Newton's 3rd law

If object **A** exerts a force on object **B**, then object **B** exerts an oppositely directed force of equal magnitude on object **A**.

For every **"action"** force, there is always an equal and opposite **"reaction"** force; we call these a **"third-law force pair."**

Newton's 3rd law

Newton's 3rd law

What happens next?

Newton's 3rd law

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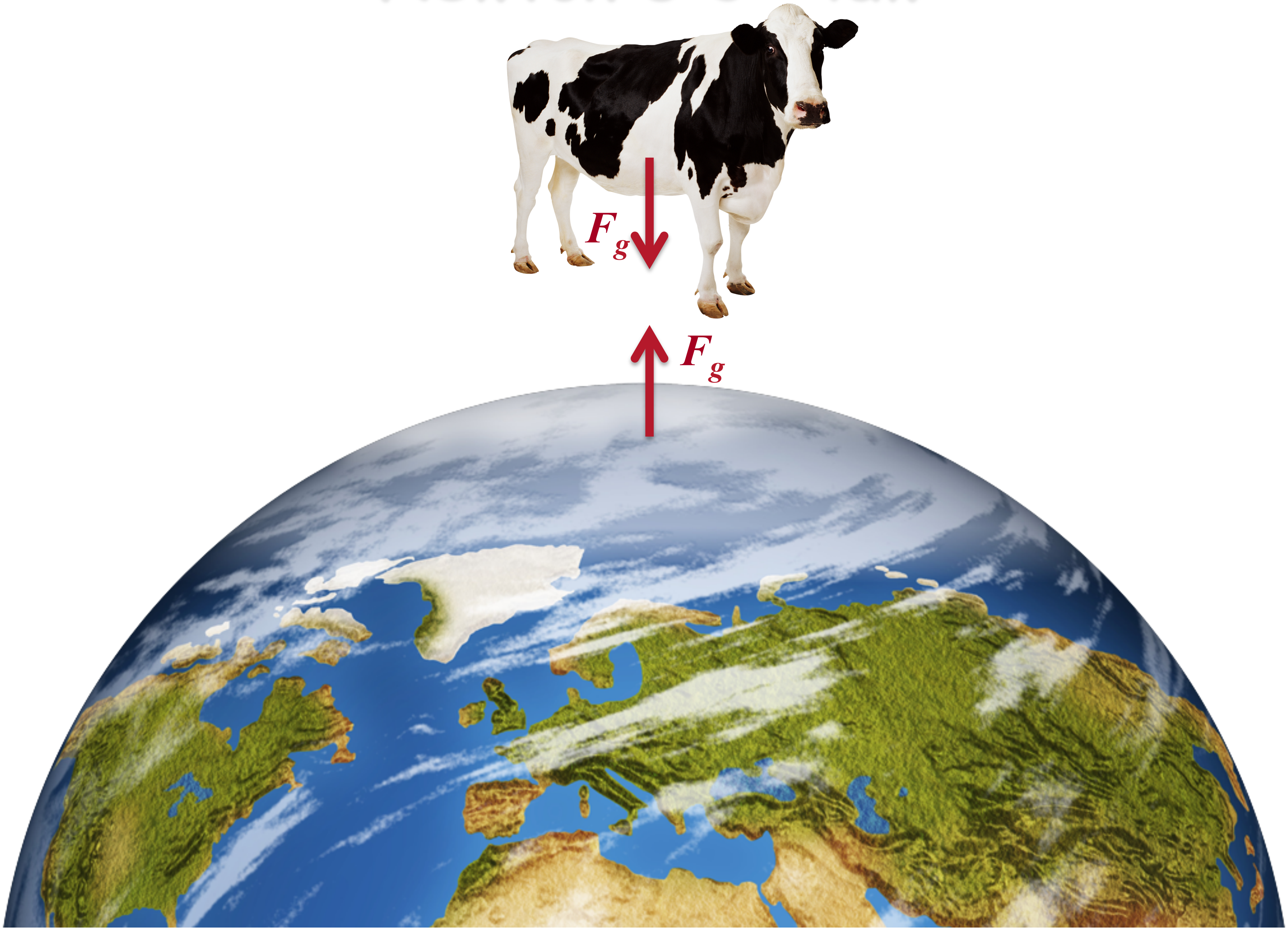
Newton's 3rd law



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Why doesn't the earth fall?