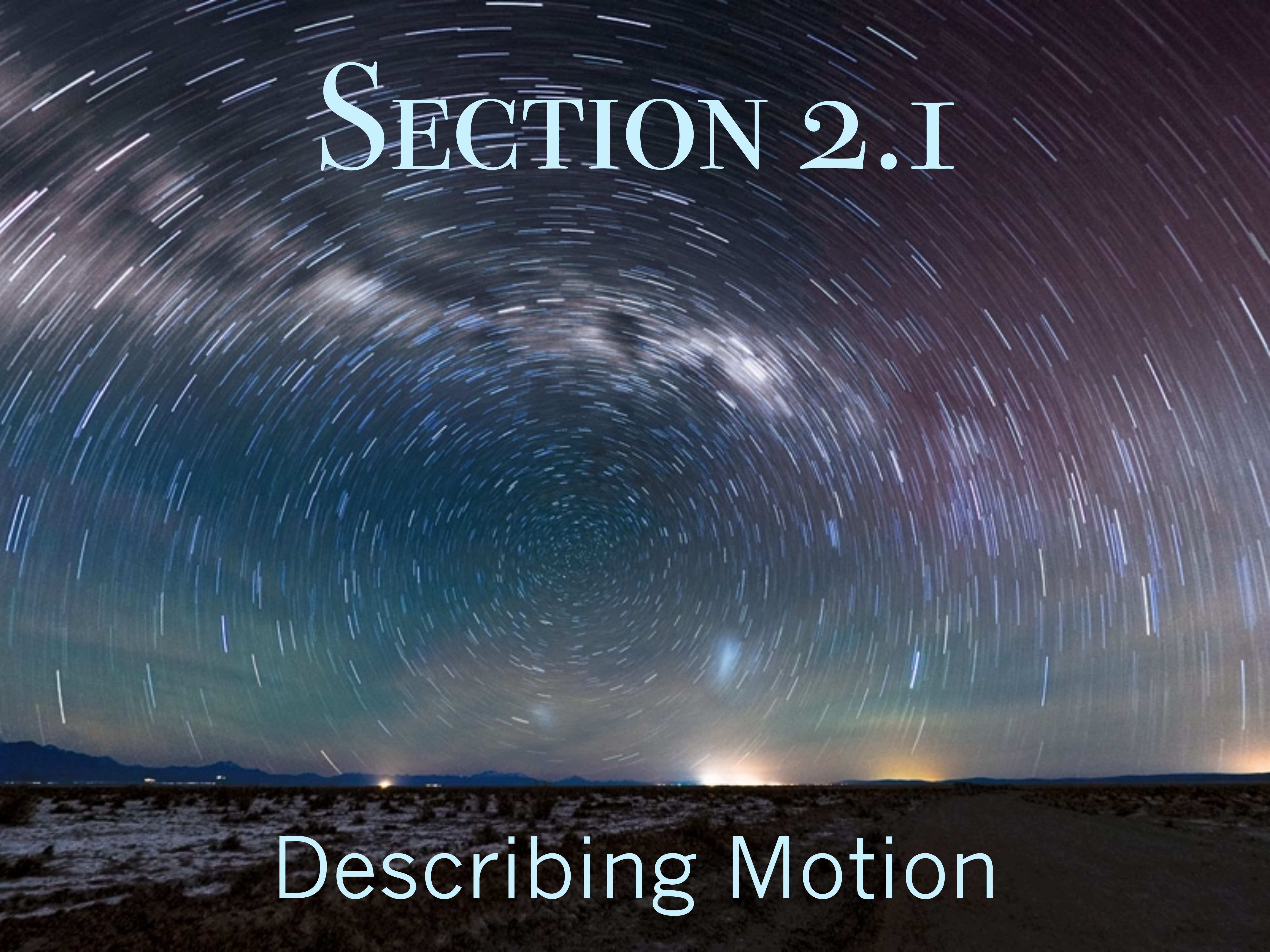
Chapter 02

Motion



Section 2.1

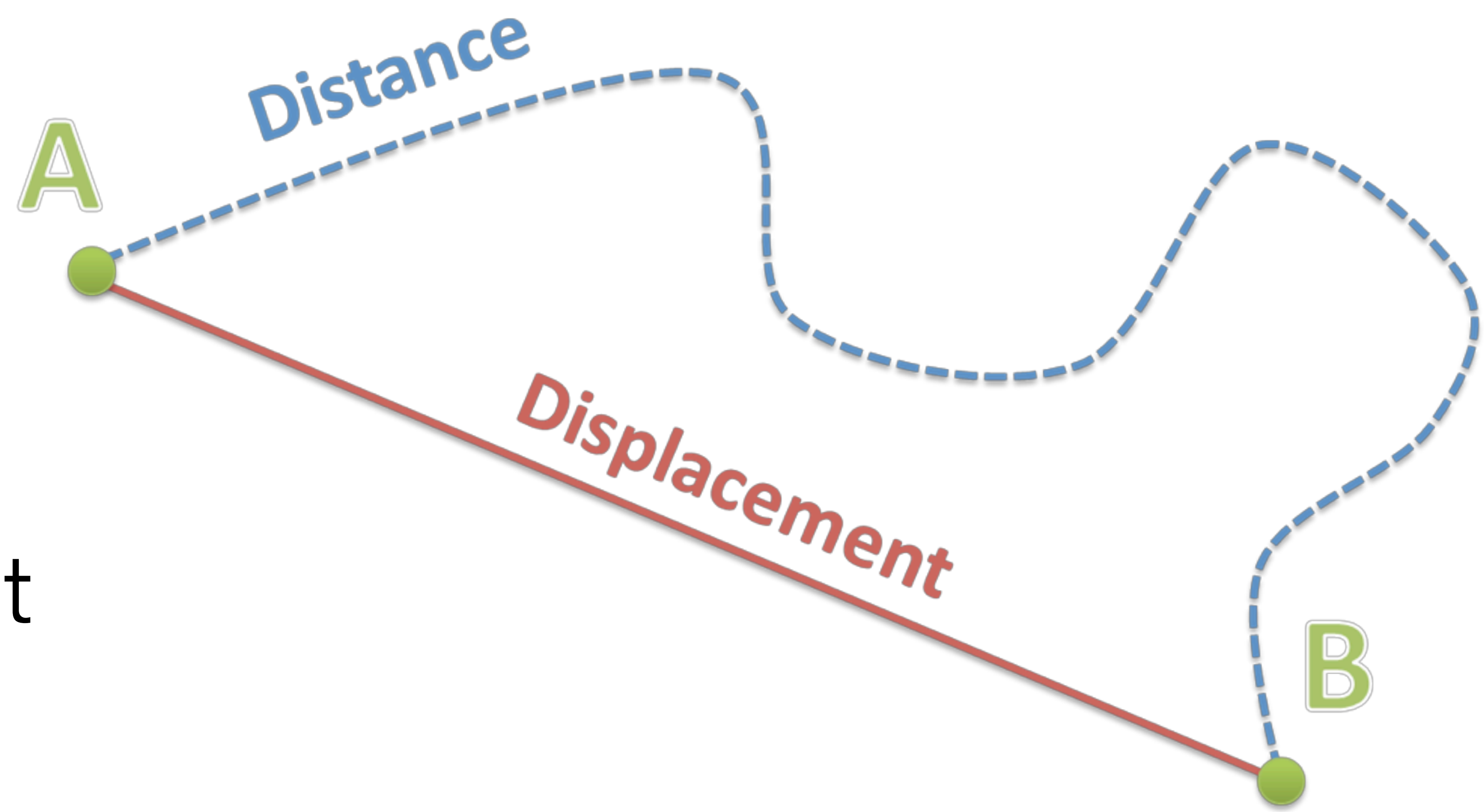
Describing Motion

Things Move…How Do You Know?

- It was right there yesterday…today, it's all the way over here
- What are the important parameters? Time and place
- How are they related? Change in place occurs during some interval of time

It's All Relative

- Relative means "with respect to"
- Displacement: change in location compared to something specific
- Point of reference might be at rest or also in motion



You set your car keys on the kitchen table. When you come back later, they are in a different location. What's the displacement?

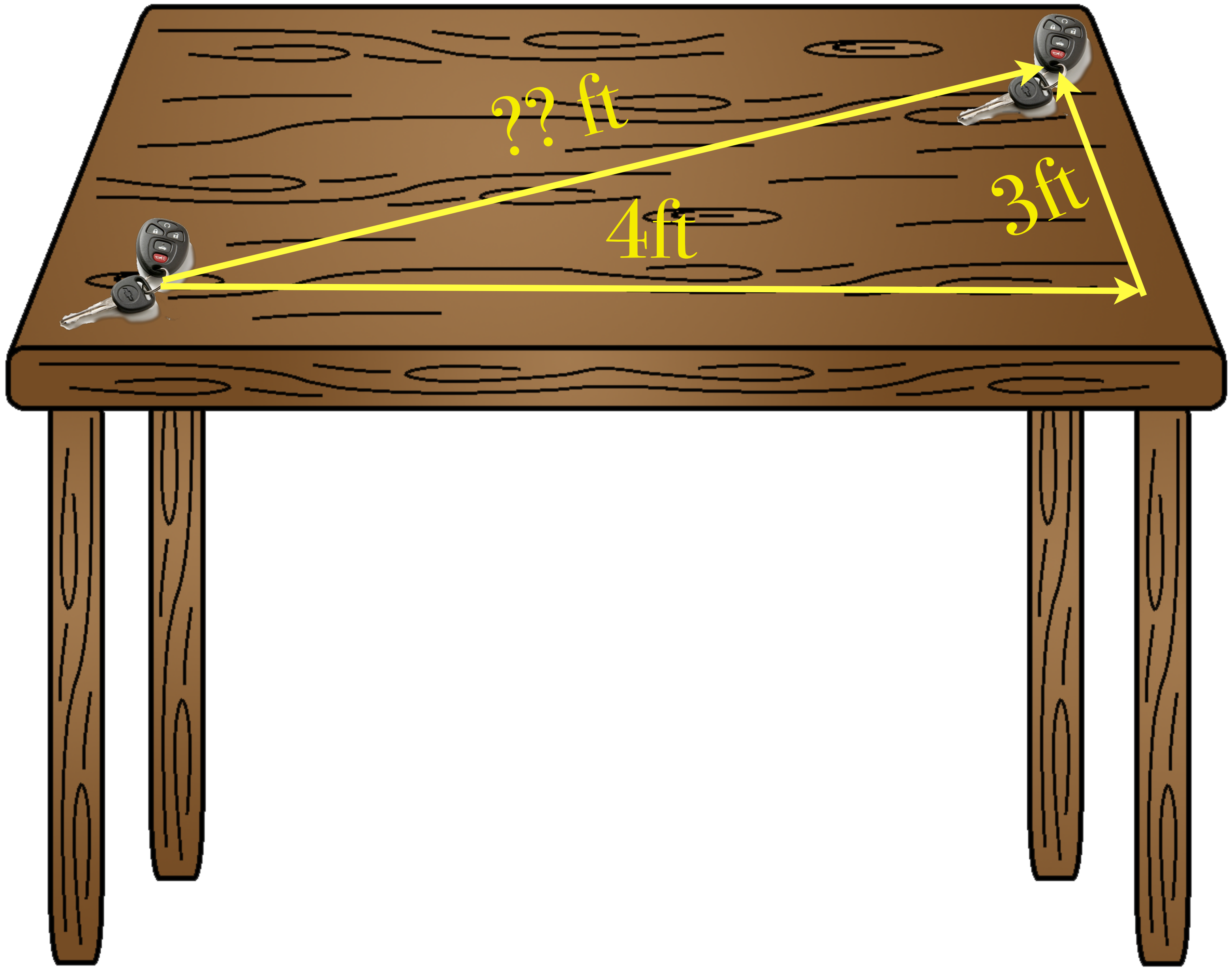
A) 0 ft

B) 3 ft

C) 4 ft

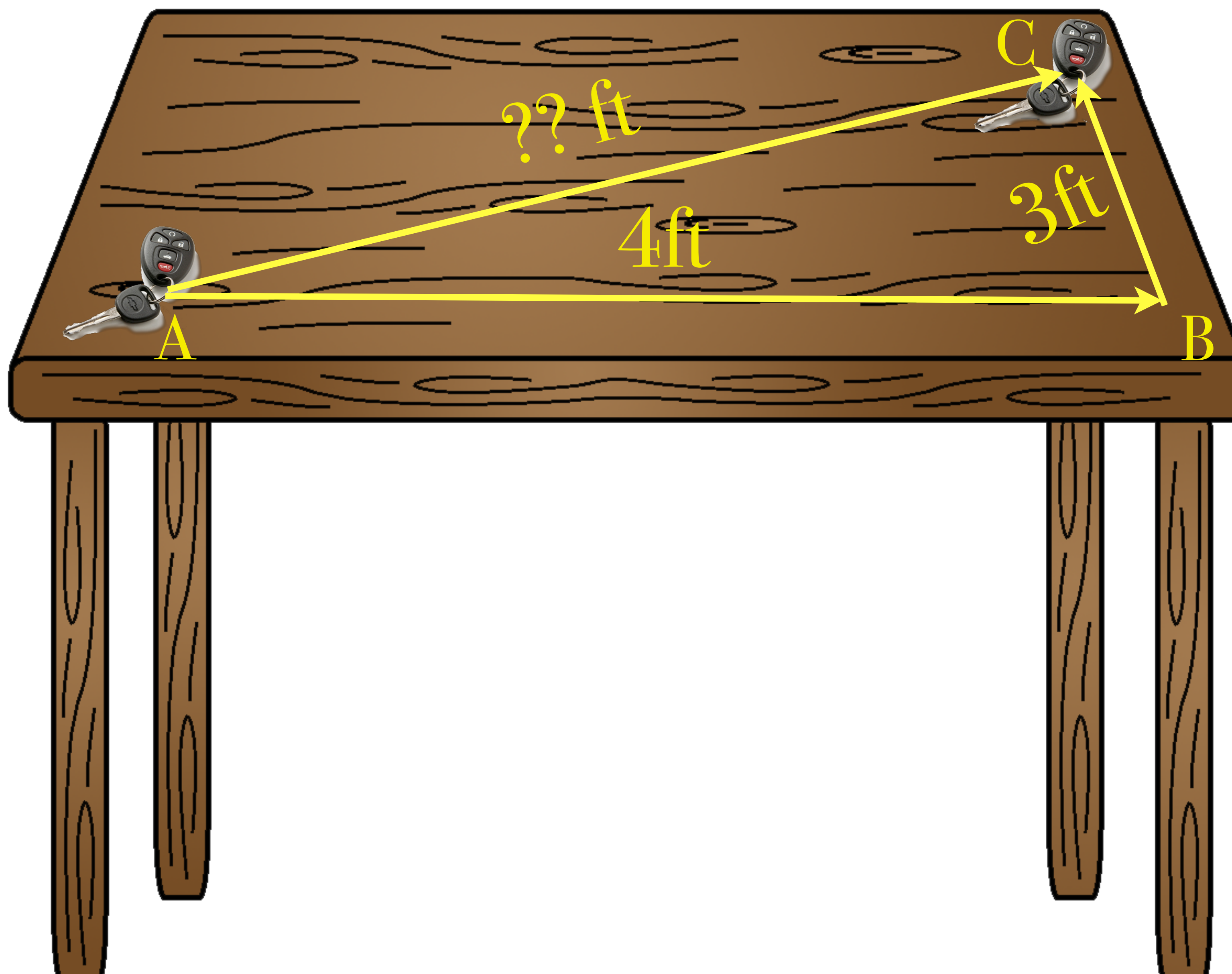
D) 5 ft

E) 7 ft



Let's say you slid the keys from point A to B to C:

- Displacement of keys still = 5ft
- They still end up 5 ft away from where they started
- Distance traveled by the keys = 7 ft
- Distance not necessarily equal to displacement!



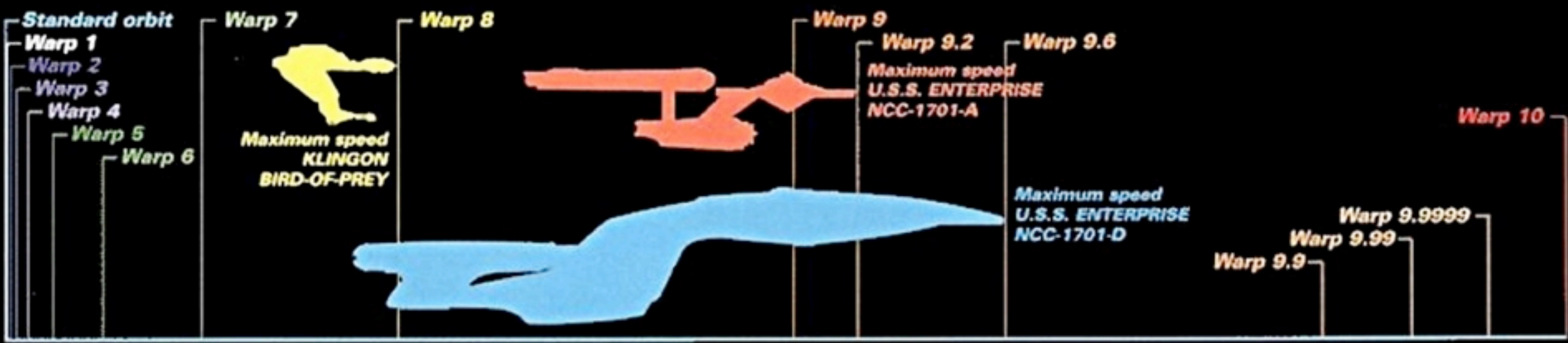
Section 2.2

Measuring Motion

Speed

- How fast = distance divided by time: v = d/t
- Ratio! d/t compares how far and how long
- Time in denominator means "rate of change"

WARP SPEED CHART



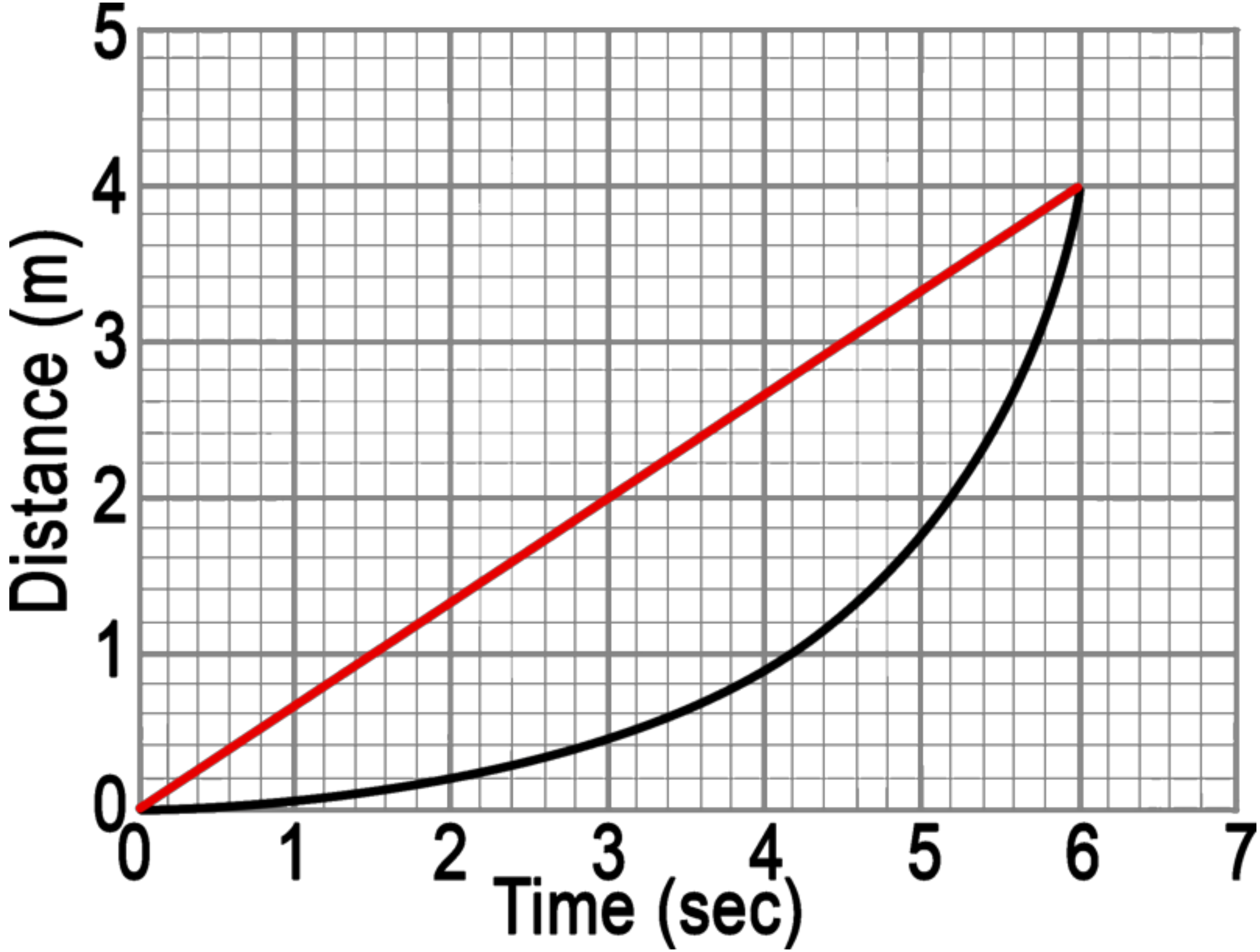
APPROXIMATE TIME TO TRAVEL

SPEED	Kilometers per hour	x lightspeed	Earth to Moon 400,000 kilometers	Across Sol system 12 million kilometers	To nearby star 5 light-years	Across one sector 20 light-years	Across FEDERATION 10,000 light-years	To nearby galaxy 2,000,000 light-years	NOTES
Standard orbit	9600	less than 0.00001	42 hours	142 years	558,335 years	2 million years	1.12 billion years	223.33 billion years	Synchronous orbit around Class-M planet
Full impulse*	270 million	0.25	5.38 seconds	44 hours	20 years	80 years	400,000 years	8,000,000 years	Normal maximum impulse speed
Warp factor 1	1078 million	1	1.34 seconds	11 hours	5 years	20 years	100,000 years	2,000,000 years	Warp one = speed of light
Warp factor 2	11 billion	10	0.13 seconds	1 hours	6 months	3 years	9,921 years	198,425 years	
Warp factor 3	42 billion	39	0.03 seconds	17 minutes	2 months	1 year	2,568 years	51,360 years	
Warp factor 4	109 billion	102	0.013237 seconds	7 minutes	18 days	2 months	984 years	19,686 years	
Warp factor 5	230 billion	214	0.006291 seconds	3 minutes	9 days	1 month	468 years	9,357 years	Old cruising speed
Warp factor 6	423 billion	392	0.003426 seconds	2 minutes	5 days	19 days	255 years	5,096 years	New normal cruising speed
Warp factor 7	707 billion	656	0.002049 seconds	1 minutes	3 days	11 days	152 years	3,048 years	
Warp factor 8	1103 trillion	1,024	0.001313 seconds	39 seconds	2 days	7 days	98 years	1,953 years	
Warp factor 9	1.63 trillion	1,516	0.000886 seconds	26 seconds	1 day	5 days	66 years	1,319 years	
Warp factor 9.2	1.78 trillion	1,649	0.000815 seconds	24 seconds	1 day	4 days	61 years	1,213 years	Old normal maximum speed
Warp factor 9.6	2.06 trillion	1,909	0.000704 seconds	21 seconds	23 hours	4 days	52 years	1,048 years	Maximum rated speed, can be maintained for 12 hours
Warp factor 9.9	3.29 trillion	3,053	0.000440 seconds	13 seconds	14 hours	2 days	33 years	655 years	Auto-shutdown of engines

True or false:

Speed and
velocity mean the same thing.

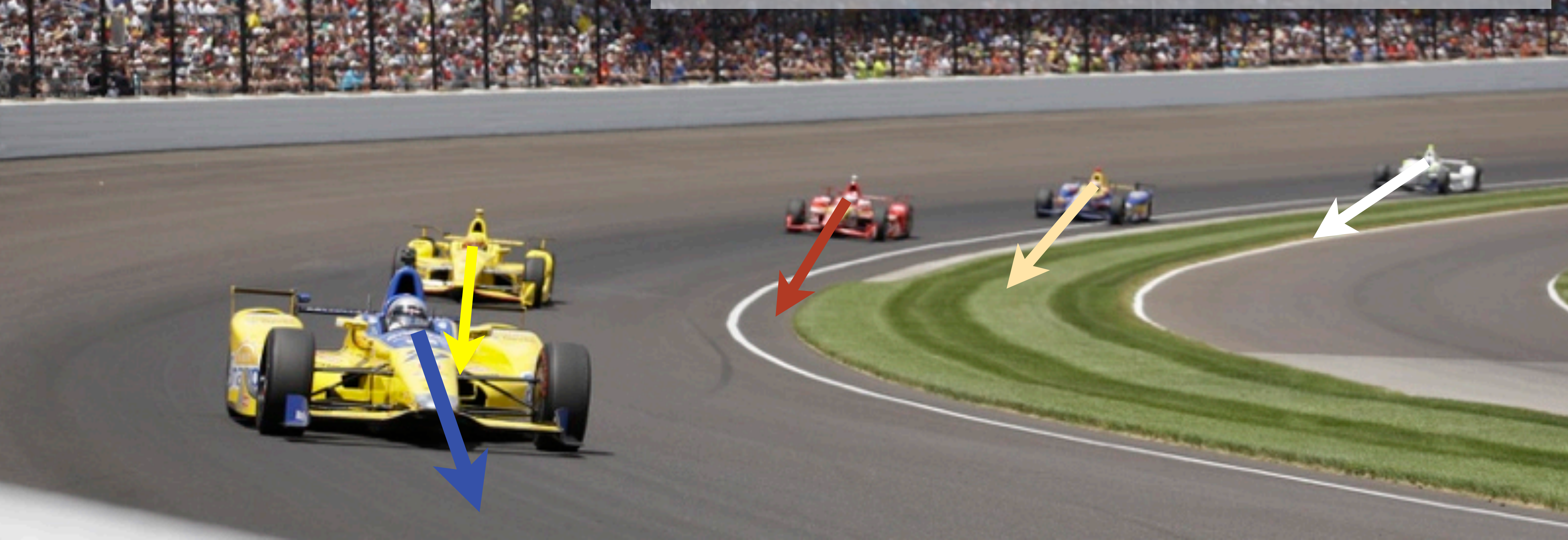
Average Speed



- An object might travel at a constant speed for the entire time
- v = d/t ignores any speeding up or slowing down (or even stopping)
- When you say "distance = rate × time," you are assuming either constant speed or average speed

Velocity

- This really is different than speed! $v = \Delta x / \Delta t$ (The equation tells you!)
- Vector velocity has two parts: magnitude and direction
- Speed is the magnitude (how fast)
- To be complete you also must specify the direction of the motion



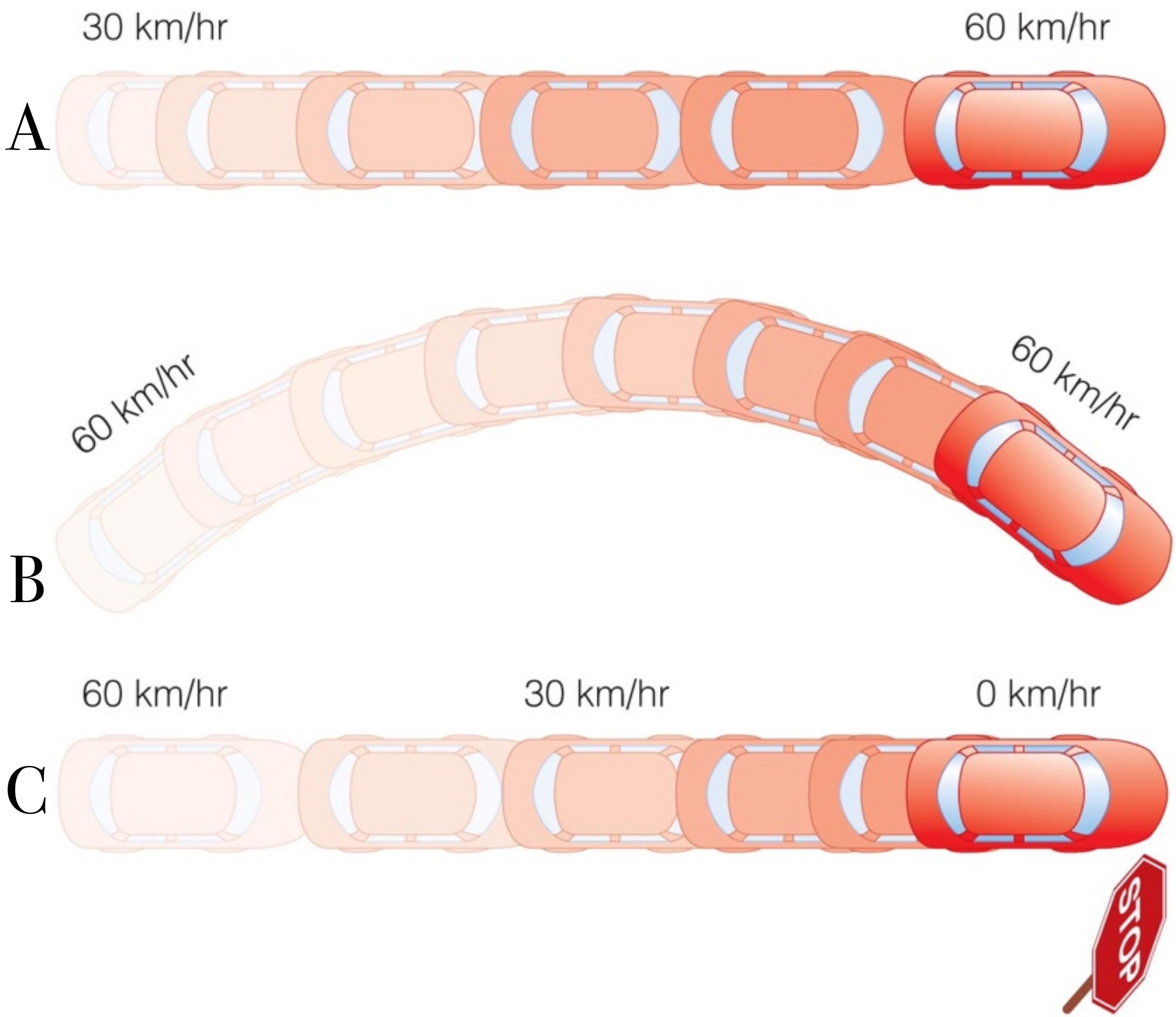
If your average velocity is zero, then your average speed

A) must also be zero.

B) cannot be zero.

C) might be zero. Or it might not. It's complicated.

Which car is accelerating?



A) Only A.

B) Only B.

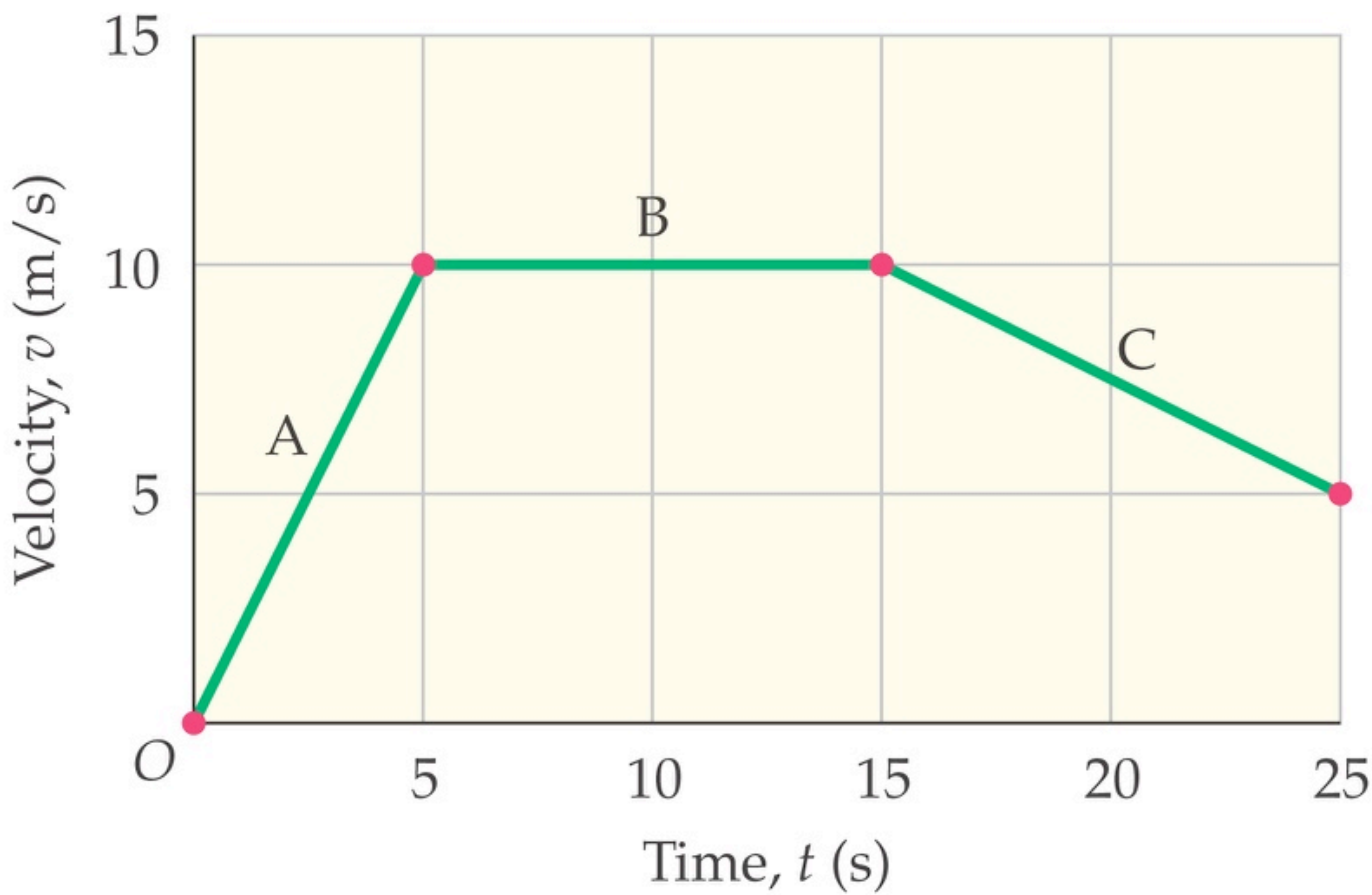
C) Only C.

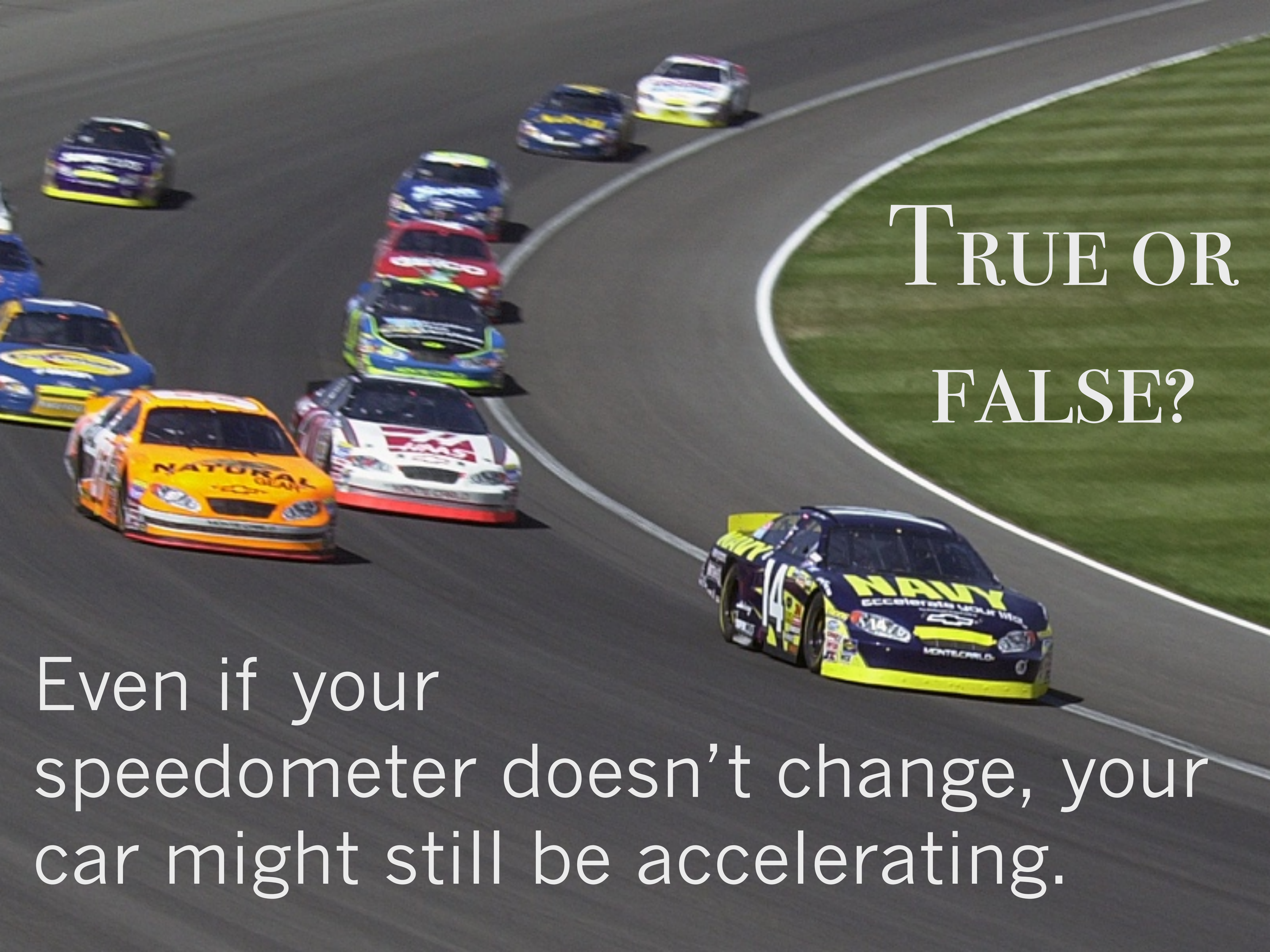
D) Both A and C.

E) ALL of these!

ACCELERATION

- Also a vector, also a rate of change: a = Δv/Δt
- Positive acceleration: speeding up
- Negative acceleration: slowing down




True or
false?
Even if your speedometer doesn't change, your car might still be accelerating.

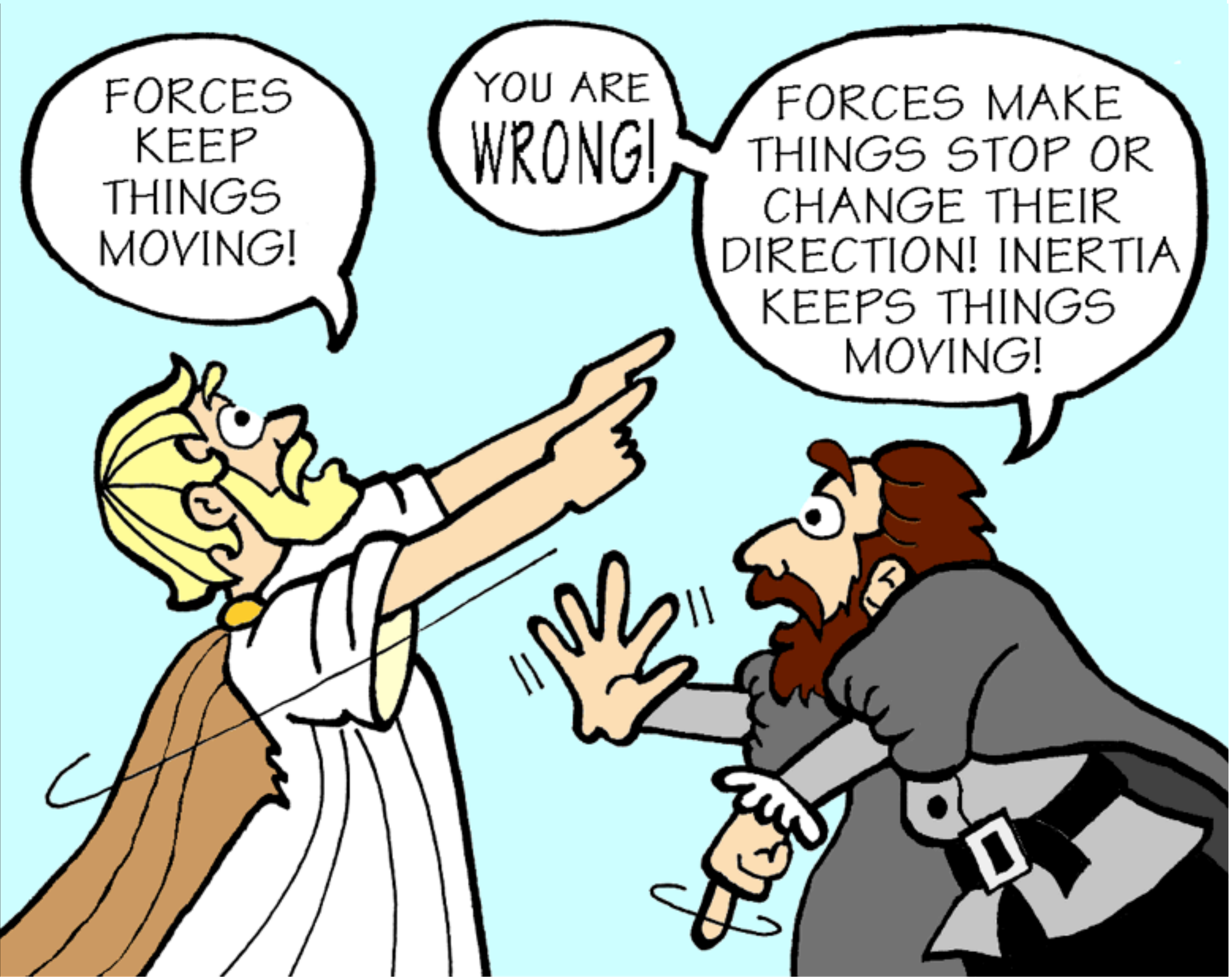
Change In Direction Is Acceleration!

- Object with a constant speed can still be accelerating!
- Constant velocity means both speed and direction remain constant
- Change direction means new velocity vector–which means acceleration

Section 2.3

Horizontal Motion on Land

Aristotle: So Wrong About So Much



- Frequently called the Father of the Scientific Method because of his insistence on explanations supported by observations
- Unfortunately, living 2300 or so years ago limited his ability to observe many things
- Incorrectly concluded that an object will only remain in motion if constantly subjective to some motive force

Galileo: Not Just All About the Telescopes

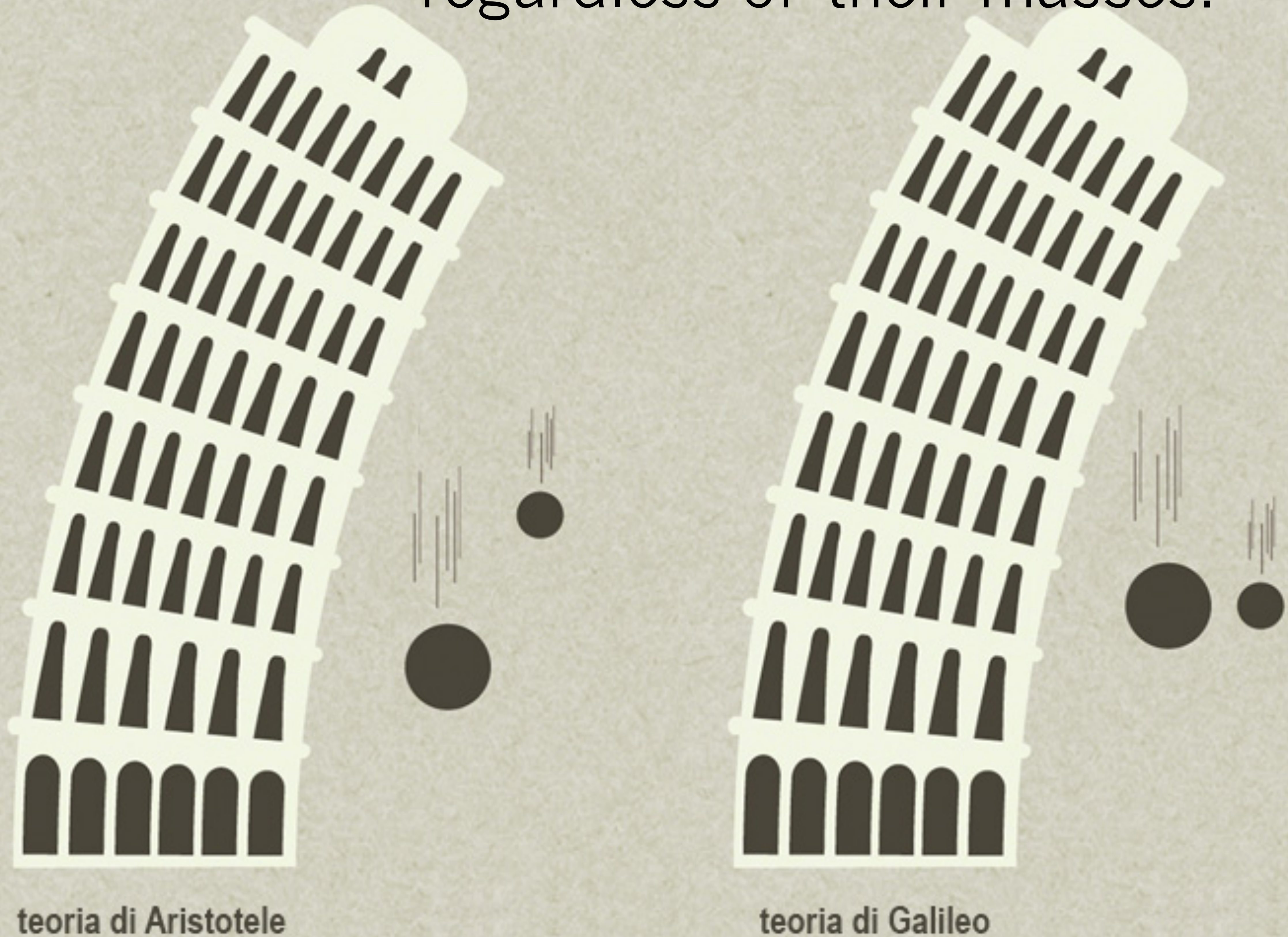
- Actually made some very important contributions to kinematics
- Used experimentation to get this→←close to Newton's laws of motion
- Correctly concluded that force was necessary to change motion (a subtle, but super–important distinction)

SECTION 2.4

Falling Objects

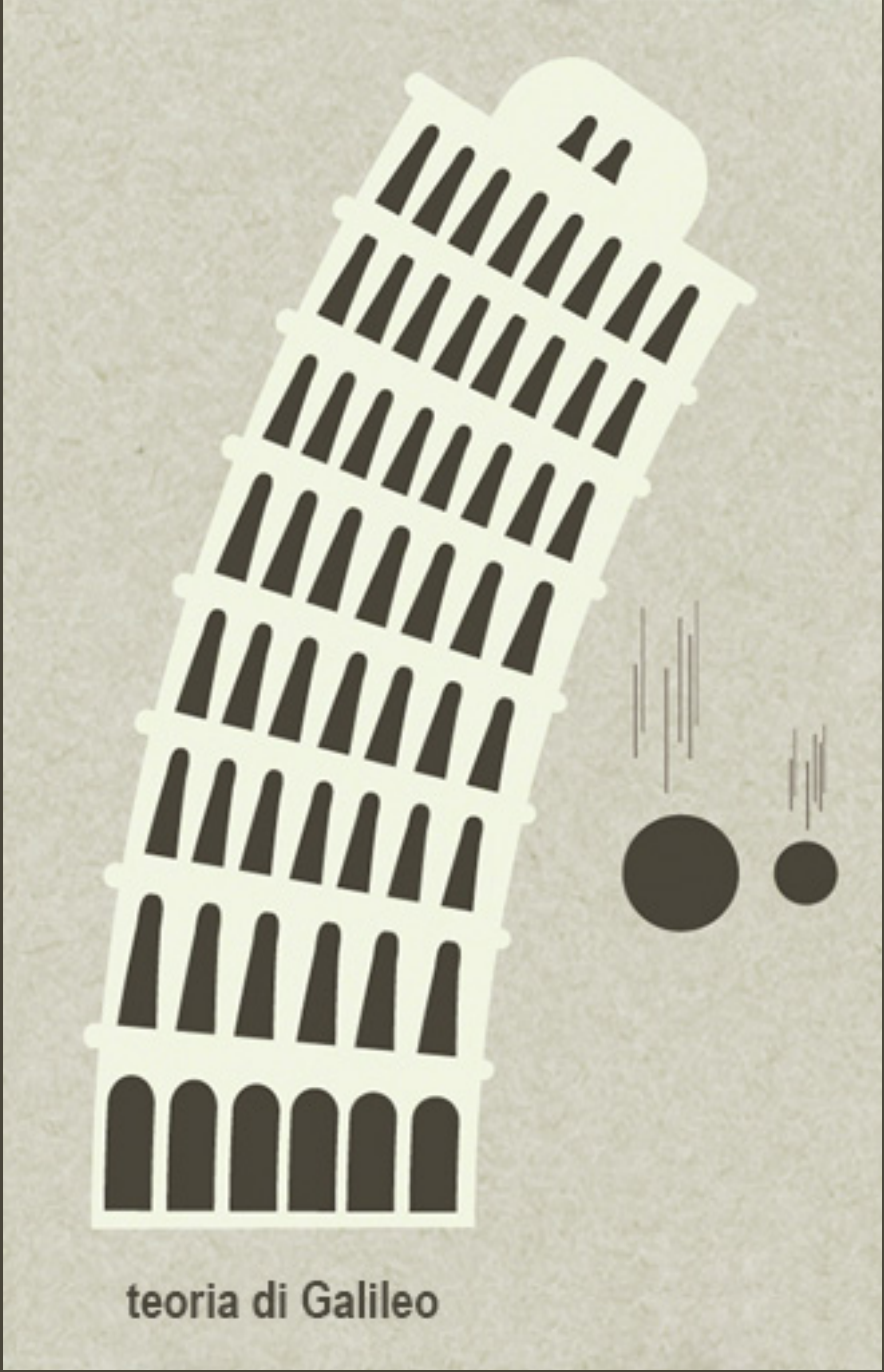
True or False:

Two objects dropped from the same height will fall at the same rate, regardless of their masses.



There Goes Galileo, Dropping Things Off Towers Again…

- Demonstrated that the speed of a falling object doesn't depend on its weight
- Yes, but…yes, there's a lot more to it, but start with round balls of the same size/different weight
- If you measure your distances and times carefully, you can actually develop a working definition of acceleration
- He was able to measure the acceleration due to the earth's gravity (note that metric system did not exist yet, so no, he did not come up with 9.8 m/s^2)



Forces

- Another vector! Yay for vectors!
- Magnitude: How hard are you pushing (or pulling)?
- Direction: Which way are you pushing (or pulling)?

ADD THESE FORCES!

A) $F_1+F_2=20N$ (+x)

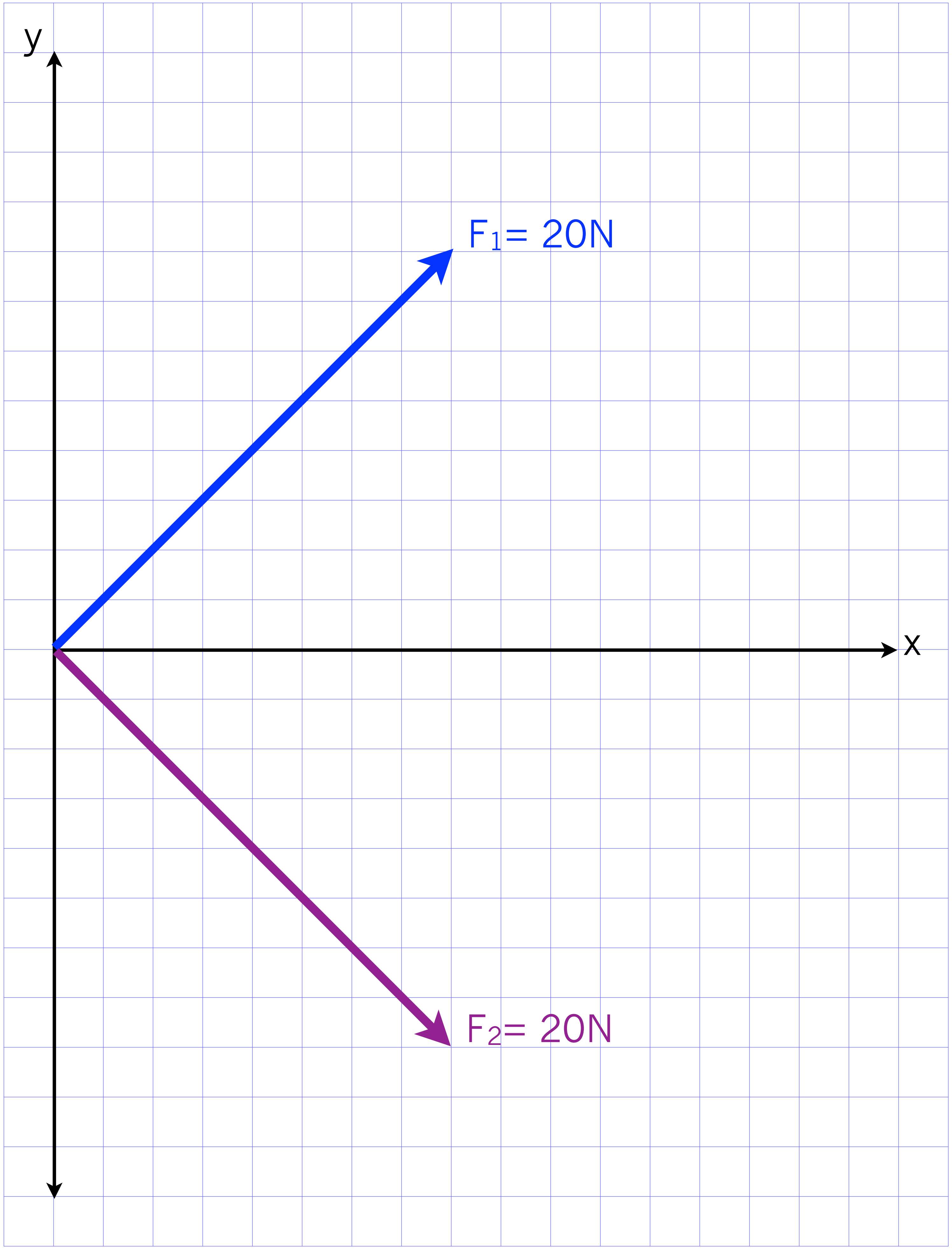
B) $F_1+F_2=20N$ (+y)

C) $F_1+F_2=28N$ (+x)

D) $F_1+F_2=28N$ (+y)

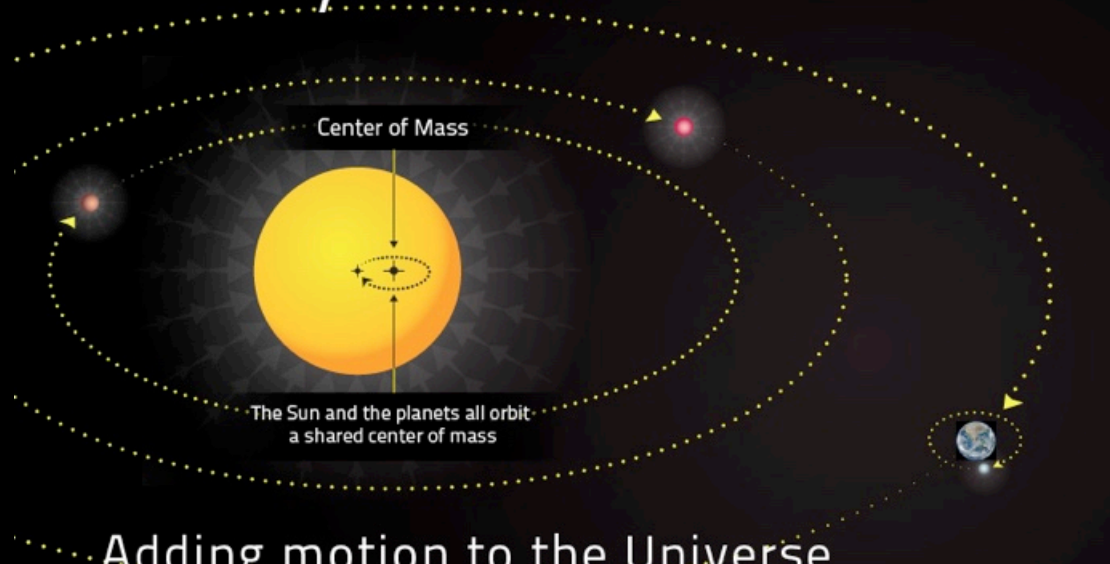
E) $F_1+F_2=40N$ (+x)

F) $F_1+F_2=40N$ (+y)



Fundamental Forces

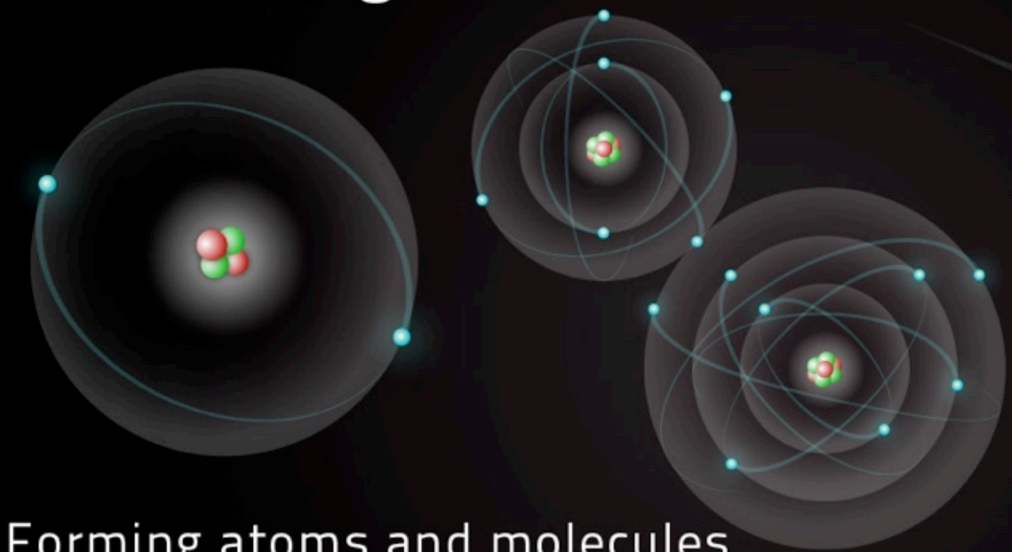
Gravity



Adding motion to the Universe

Gravity forms stars, planets, and moons, and forces these objects to spin on an axis and move along an orbital path. The planets appear to be orbiting the center of the Sun, but the Sun and planets all orbit a shared center of mass. Planets with enough mass can develop orbiting moons or rings of debris.

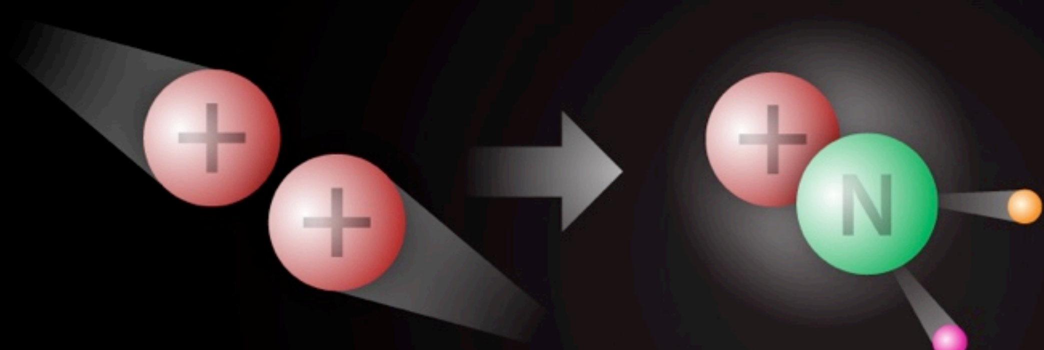
Electromagnetic Force



Forming atoms and molecules

The electromagnetic force pulls negatively charged electrons into bound orbits around positively charged nuclei to form atoms and molecules. As a gas cools, electrons will find their way into the presence of atomic nuclei. Larger nuclei with a greater positve charge pull in more electrons until atoms and molecules have a balance of charges.

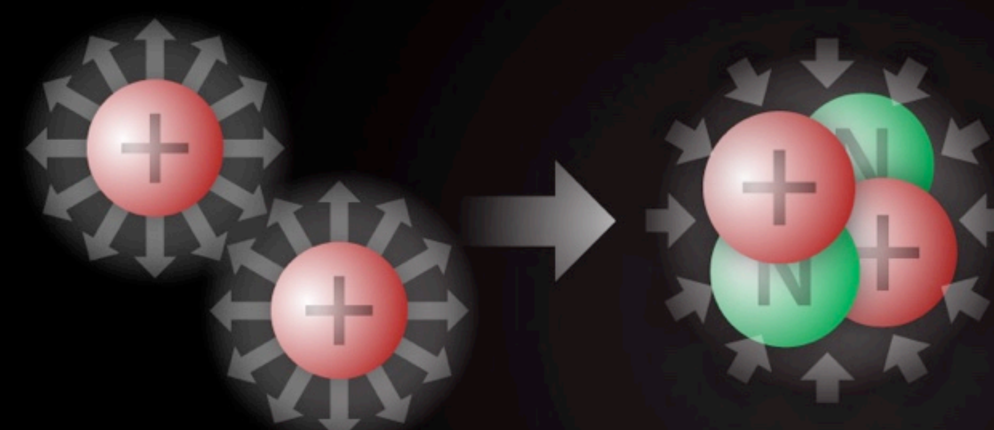
Weak Nuclear Force



Converting protons into neutrons

When two protons collide and fuse, a disruption in the weak nuclear force emits a positron and neutrino, which converts one of the positively charged proton to a neutrally charged Nuetron. Without the weak nuclear force converting protons into nuetrons, certain complex nuclei cannot form.

Strong Nuclear Force

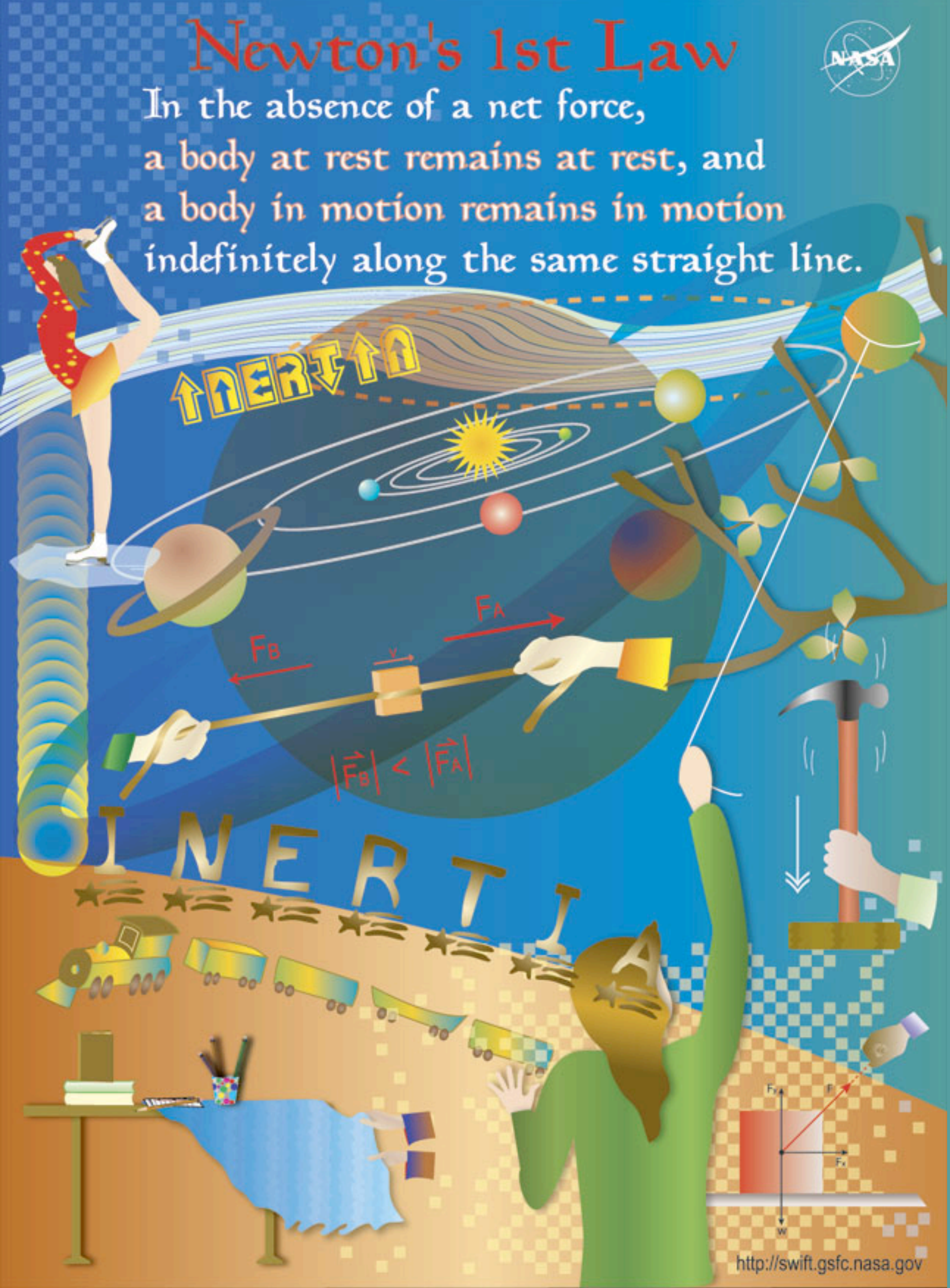


Binding protons in atomic nuclei

Positively charged particles naturally repel each other, it takes an extreme amount of force to hold protons together. The strong nuclear force overcomes the repulsion between protons to hold together atomic nuclei. Without the strong nuclear force, complex nuclei cannot form.

Section 2.6

Three Laws of Motion



NEWTON'S FIRST LAW

- "Every object retains its state of rest or its state of uniform straight-line motion unless acted upon by an unbalanced force."
- **Inertia Law:** Inertia is an object's tendency to keep doing whatever it's doing
- An object's mass is a measure of its inertia: more mass = more resistance to change

Newton's Second Law

- F = ma: If you push it, it goes. (push = F, it = m, goes = a)
- Or: the harder you push an object, the more you change the motion (speeding up or slowing down)
- Or: the more massive an object, the more force needed to move it

You apply a 10N force to a 5kg object. Its acceleration is

A) $0\ m/s^2$

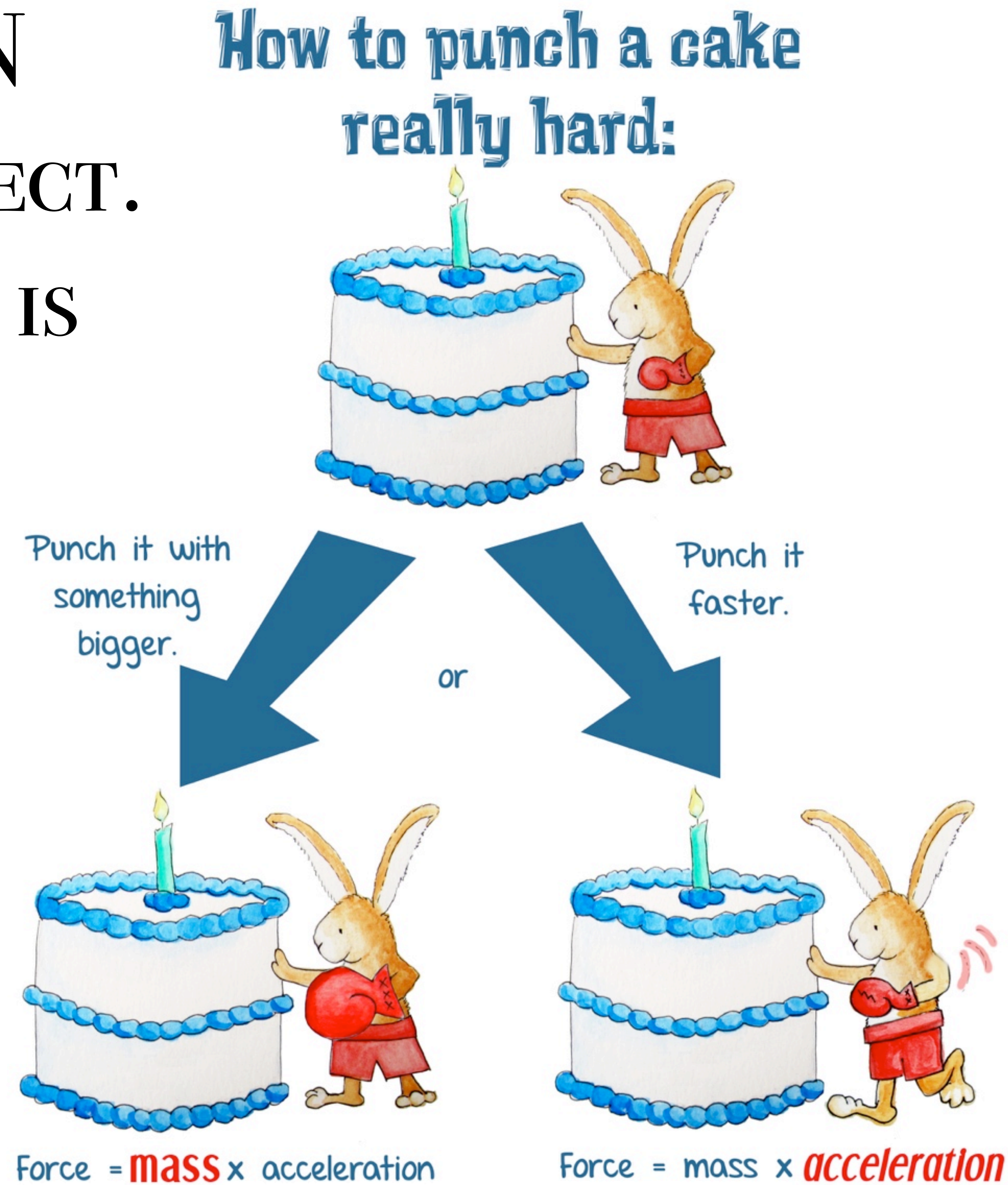
B) $1\ m/s^2$

C) $2\ m/s^2$

D) $5\ m/s^2$

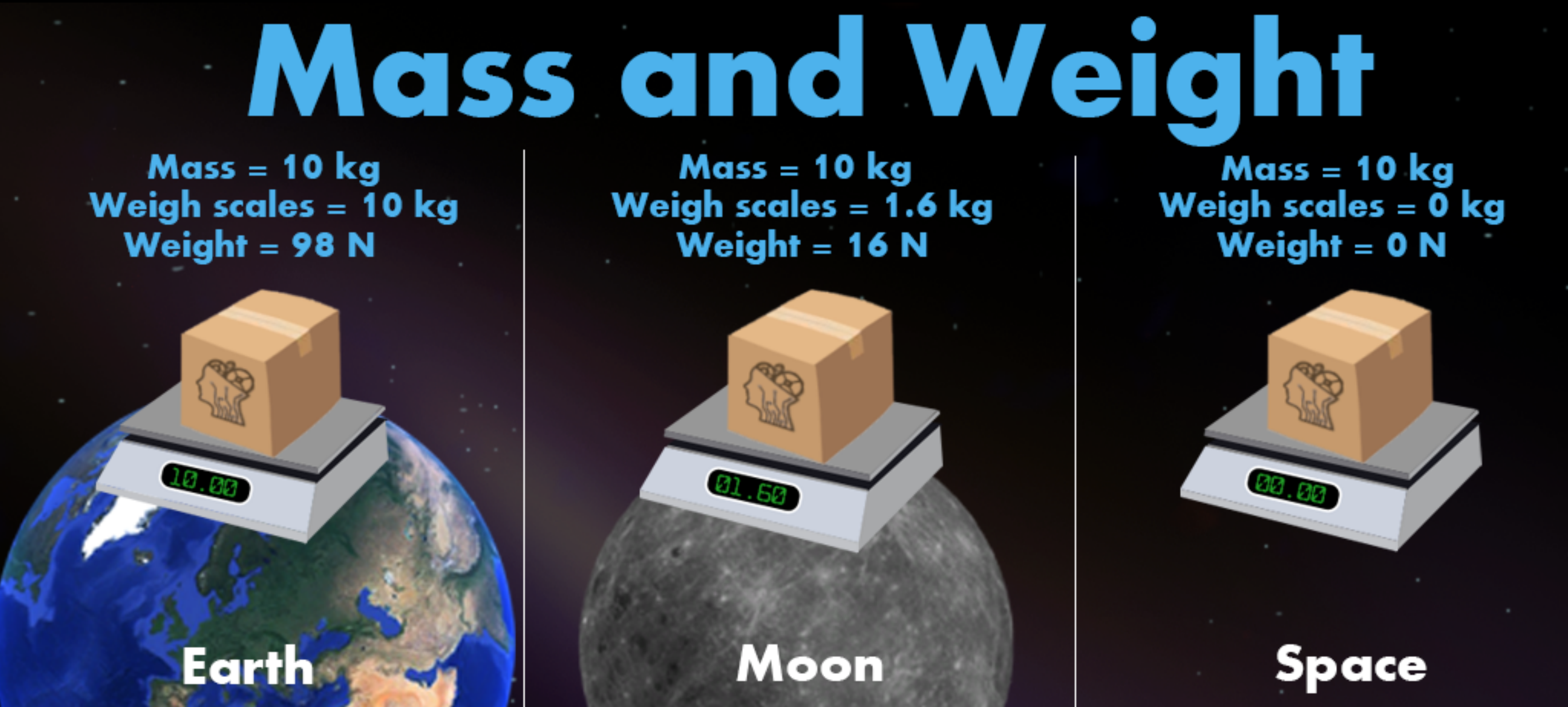
E) $10\ m/s^2$

F) $50\ m/s^2$



Weight and Mass

- Not the same thing! $w = mg$
- Mass m = amount of matter, measured in kg
- Weight w = force on object due to gravity, measured in Newtons
- Constant $g = 9.8 \text{m/s}^2$ (Earth's gravity, or the acceleration due to Earth's mass)



Newton's Third Law

- "Whenever two objects interact, the force exerted on one object is equal in size and opposite in direction to the force exerted on the other object."
- Forces must always exist in pairs! This is a very profound idea.
- For every action, equal/ opposite reaction

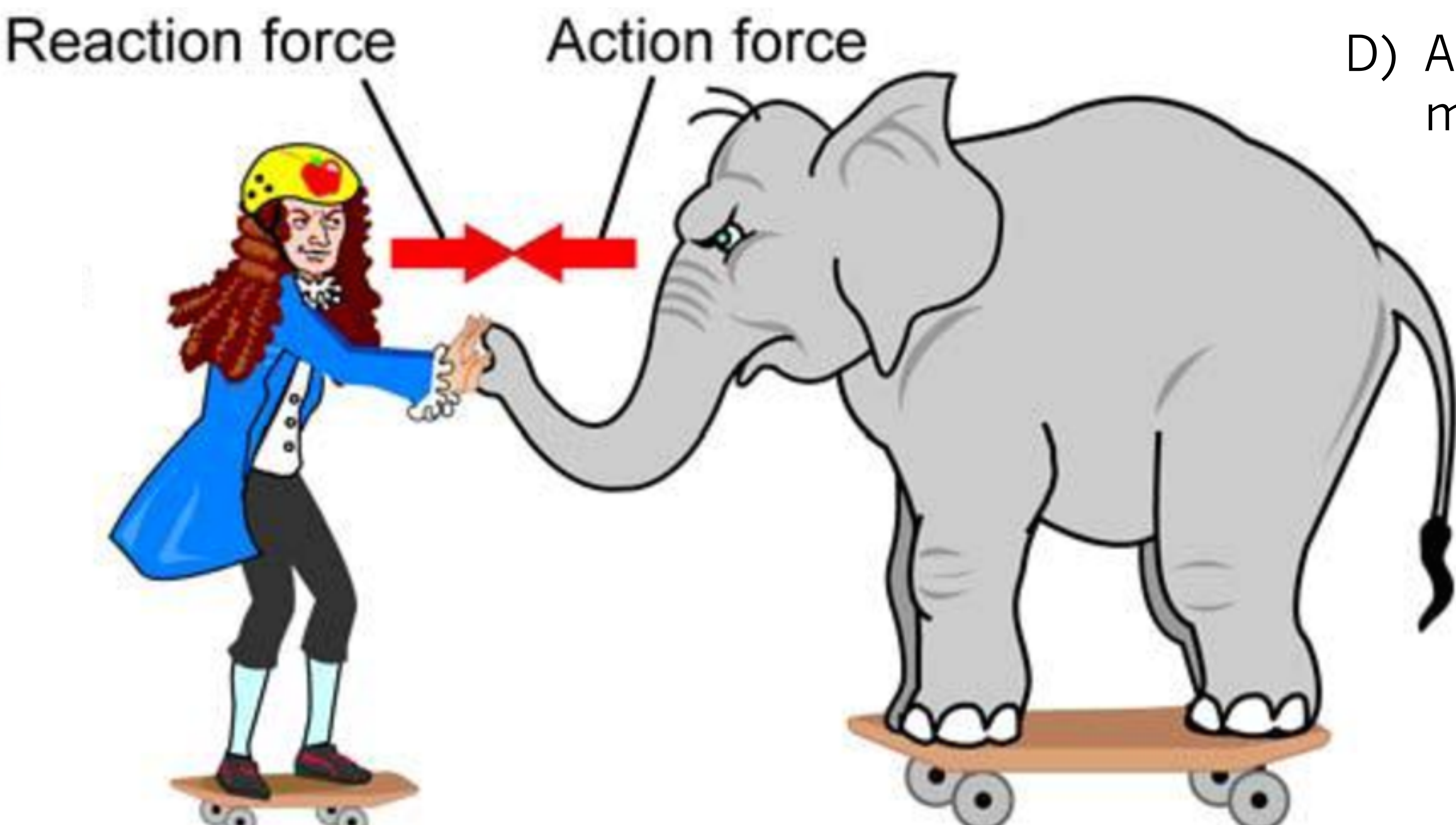
Tiny (the elephant) applies 100N of force to Ike (the dude in the wig). How much force does Ike apply to Tiny?

A) Absolutely 0N

B) Maybe 50 N

C) Exactly 100 N

D) At least a million N!



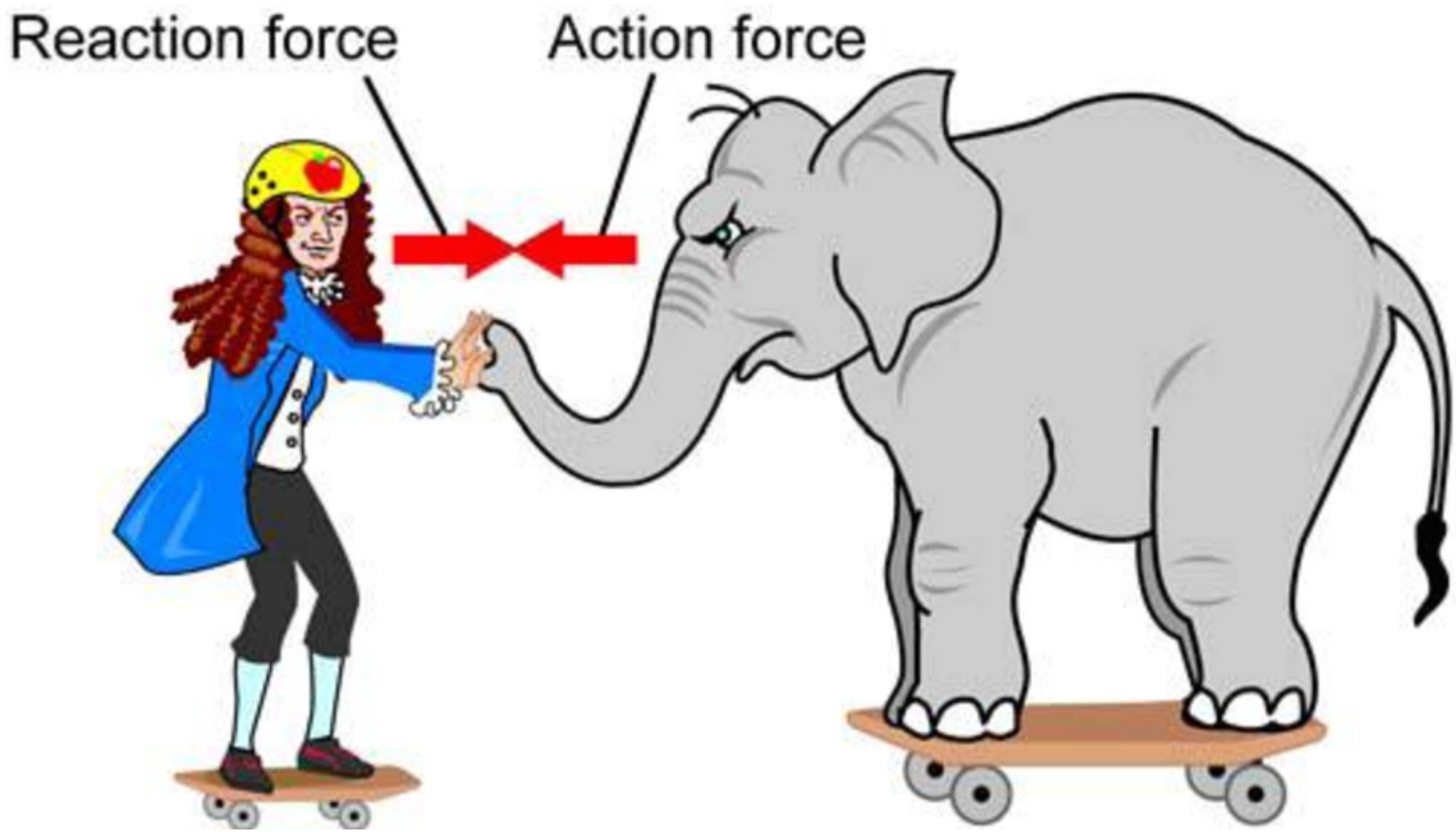
Who accelerates more as a result?

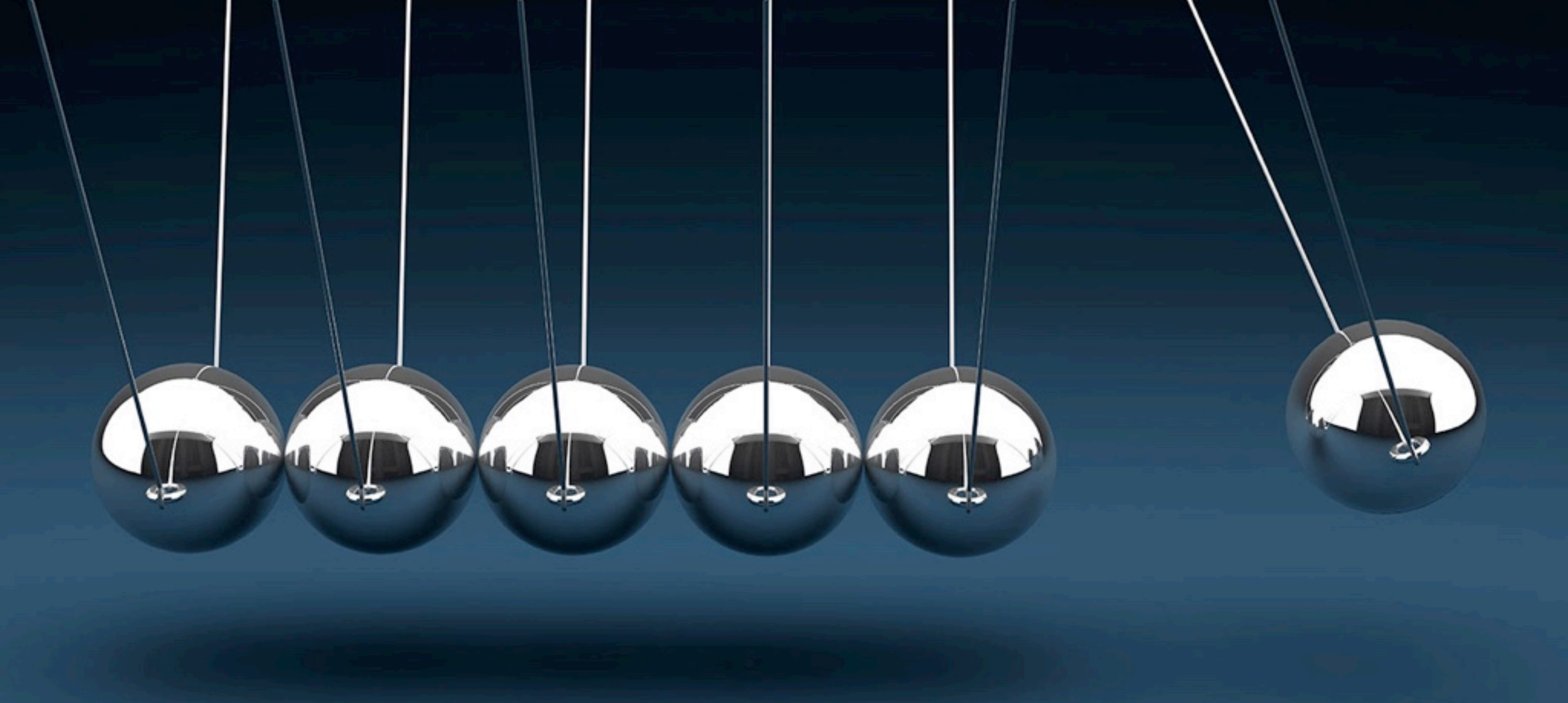
A) Same force, same acceleration!

B) Tiny clearly weighs more, so more acceleration!

C) Ike is less massive, so he will experience greater acceleration.

D) Seriously, why are they even on skateboards?!?



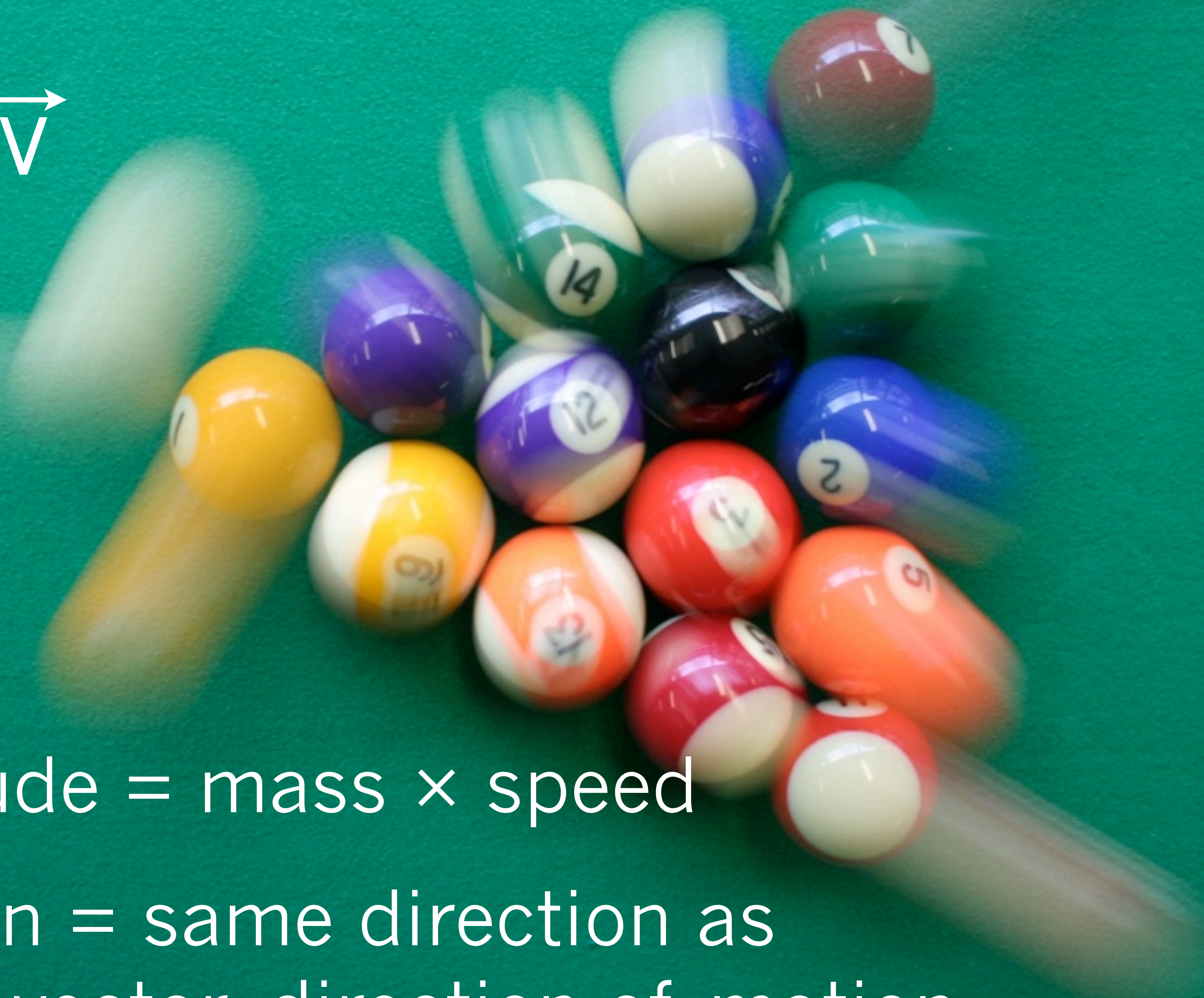


Section 2.7

Momentum

Momentum Is A Vector

$$\vec{p} = m\vec{v}$$

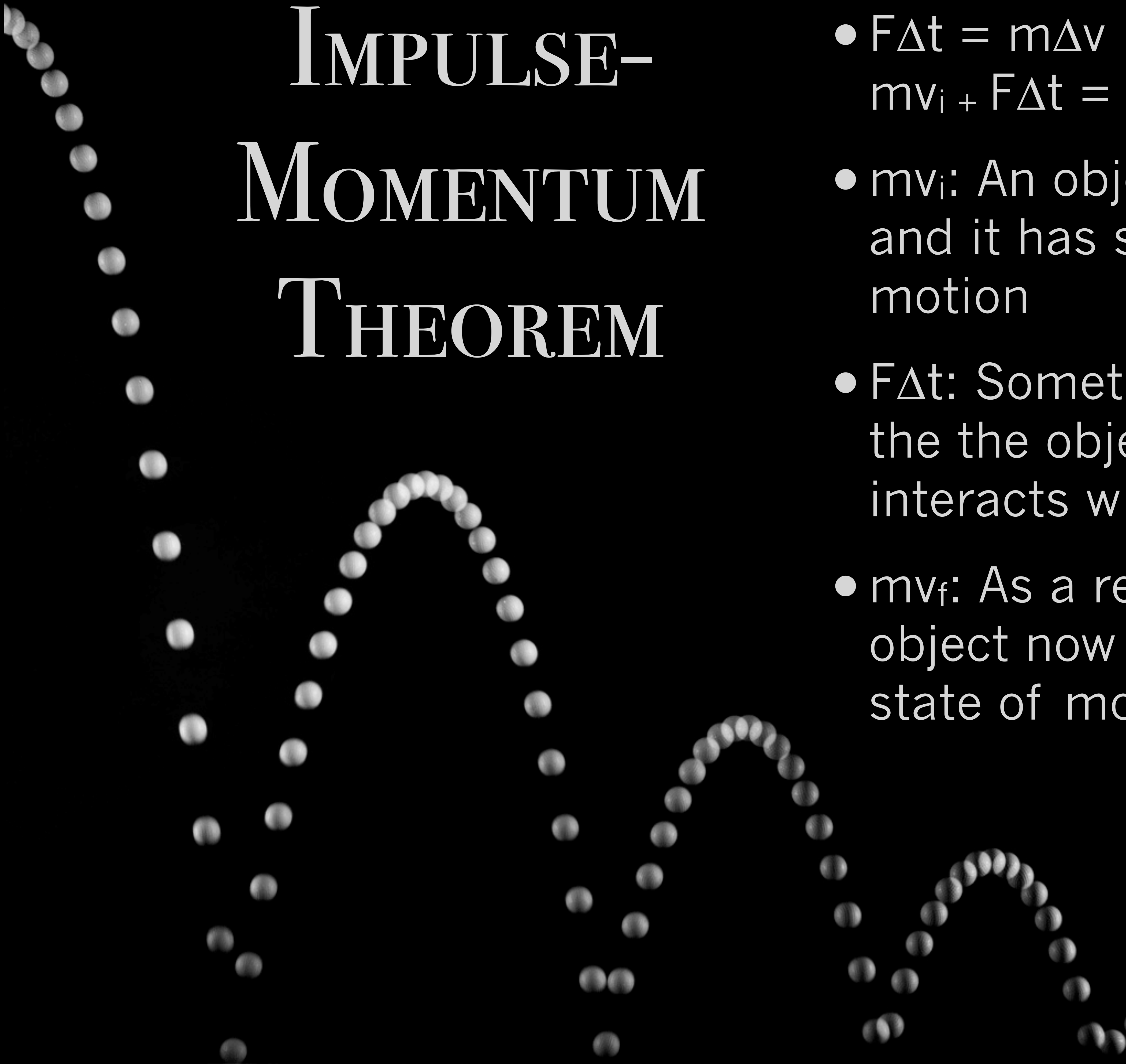


- Magnitude = mass × speed
- Direction = same direction as velocity vector, direction of motion

A CAR TRAVELING NORTH HAS 27,000 KG·M/S OF MOMENTUM.

True or false: The same car traveling at the same speed, but headed south, will have –27,000 kg·m/s of momentum.

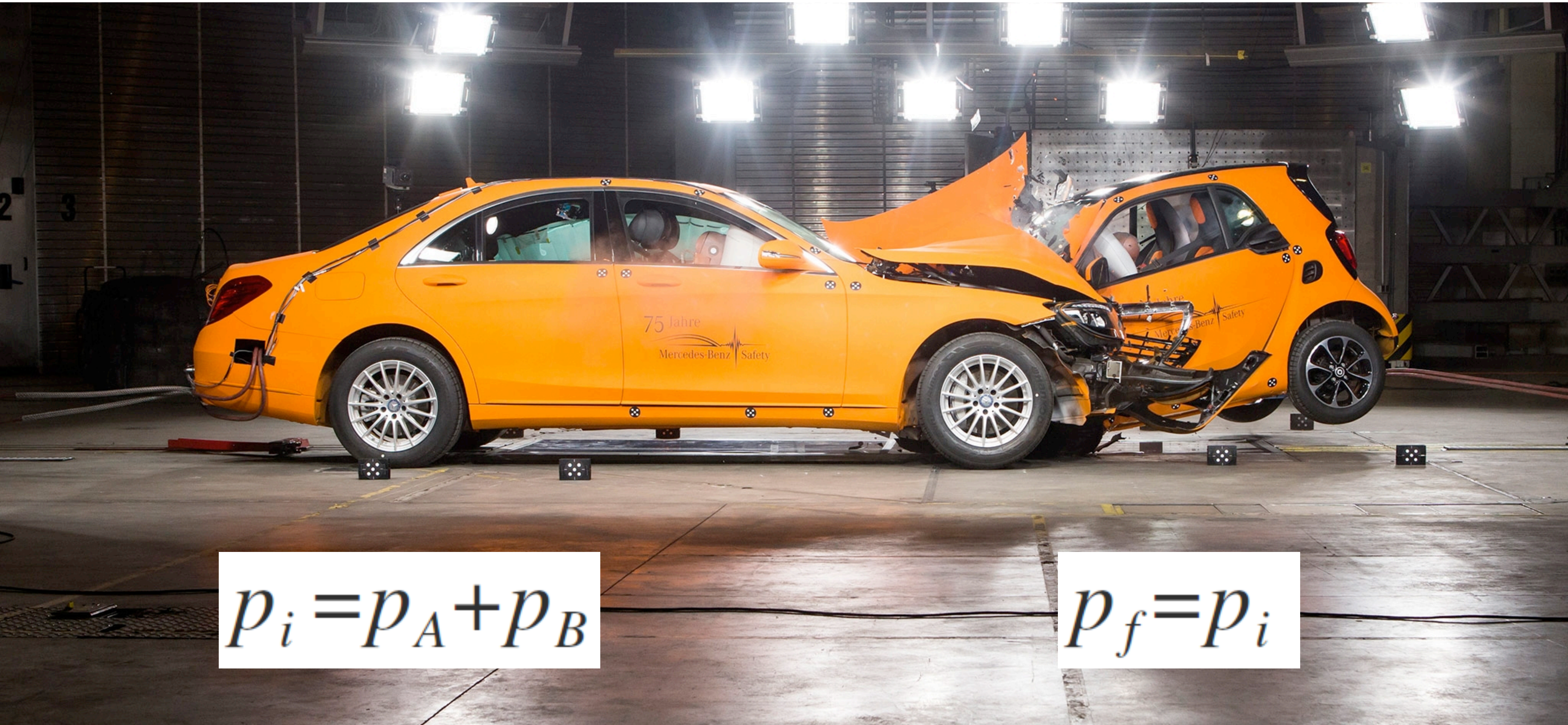
Impulse-Momentum Theorem



- $F\Delta t = m\Delta v$
  $mv_i + F\Delta t = mv_f$
- mv_i: An object exists, and it has some state of motion
- $F\Delta t$: Something happens the the object; it interacts with ?????
- mv_f: As a result, the object now has a new state of motion

Conservation of Momentum

- "The total momentum of a group of interacting objects remains the same in the absence of external forces."
- System momentum is conserved: objects might swap (A gains, B loses), but total will not increase or decrease
- Why is this important? Because it lets us look at collisions! Also, the whole Newton #3 thing.



$$p_i = p_A + p_B$$

$$p_f = p_i$$

Automobile A has initial momentum p_A = (+10 kg·m/s). Auto B has initial momentum p_B = (–15 kg·m/s). Before any collision occurs, what is the total system momentum p?

A) p = –25kg·m/s

B) p = –10 kg·m/s

C) p = –5 kg·m/s

D) p = 0 kg·m/s

E) p = +5 kg·m/s

F) p = +10 kg·m/s

G) p = +25 kg·m/s

Automobile A has initial momentum $p_A = (+10\ kg \cdot m/s)$. Auto B has initial momentum $p_B = (-15\ kg \cdot m/s)$. After a collision occurs, what is the total system momentum p?

A) $p = -25 kg \cdot m/s$

B) $p = -10\ kg \cdot m/s$

C) $p = -5\ kg \cdot m/s$

D) $p = 0\ kg \cdot m/s$

E) $p = +5\ kg \cdot m/s$

F) $p = +10\ kg \cdot m/s$

G) $p = +25\ kg \cdot m/s$

Because of the collision, what happens to the momentum of car A?

A) Nothing; it was +10 kg·m/s before the collision, and it will be exactly the same after.

B) Something; Car B will transfer some momentum to Car A. The individual momentum of each will change, but the total stays constant.

C) Everything. Car A will absorb all of Car B's momentum. It will, in fact, absorb all of the momentum of every single thing it touches. Car A is dangerous. Don't be like Car A.

Section 2.9

Newton's Law of Gravitation

The force of gravity

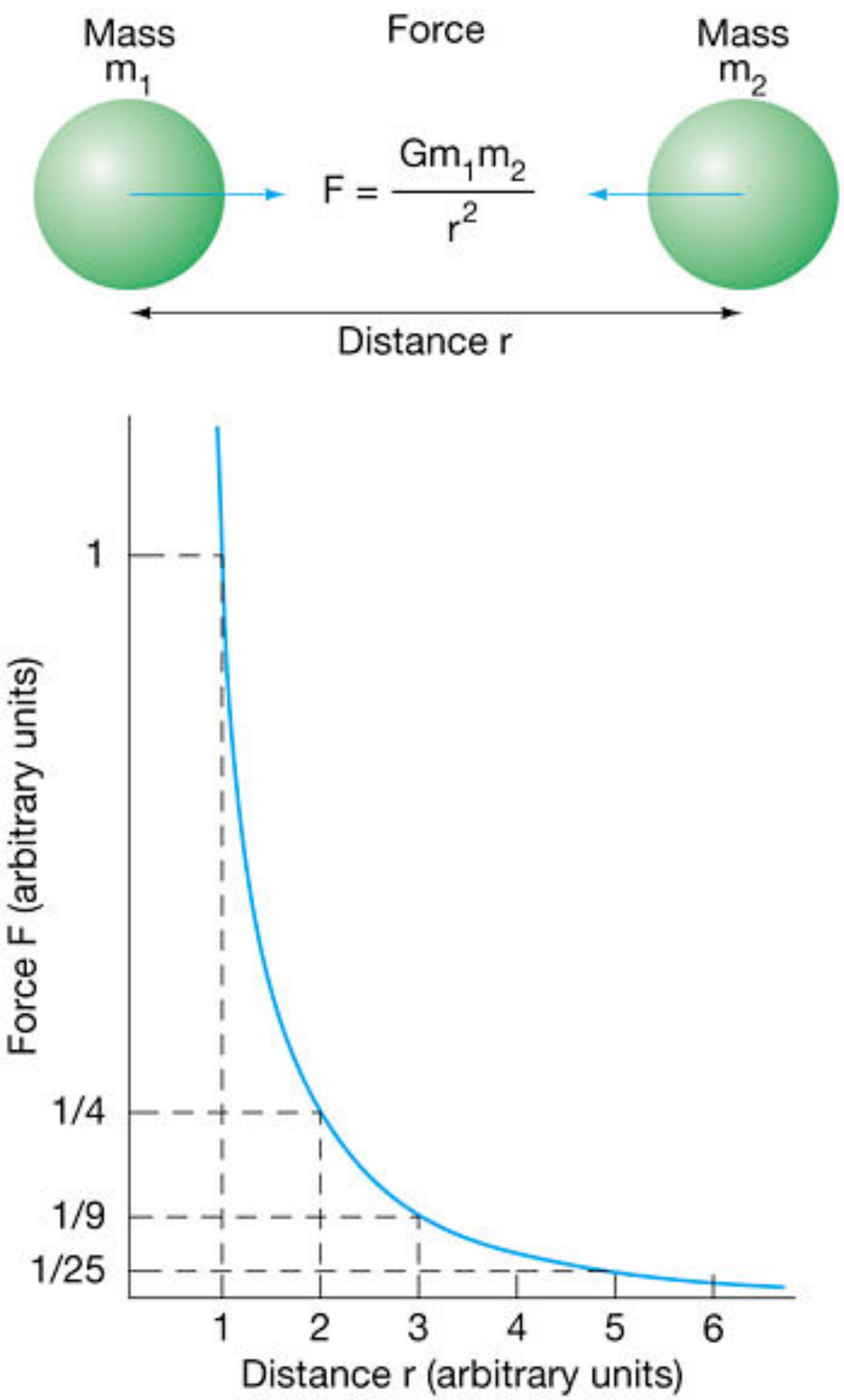
A) is exclusively attractive.

B) is exclusively repulsive.

C) might either attract or repel, it depends on how the force is applied.

D) is simply a suggestion for cats.

The Force of Gravity



- Force is always attractive; mass pulls mass, never pushes it away
- Directly proportional to mass: 2× the mass, 2× the force
- Inverse–square of distance: 2× the distance, only ¼ the force

The force of gravity between masses m_1 and m_2 is 20N. If you double m_1 (leaving m_2 alone), the new force between the masses will be

A) 5N

B) 10N

C) 15N

D) 20N

E) 40N

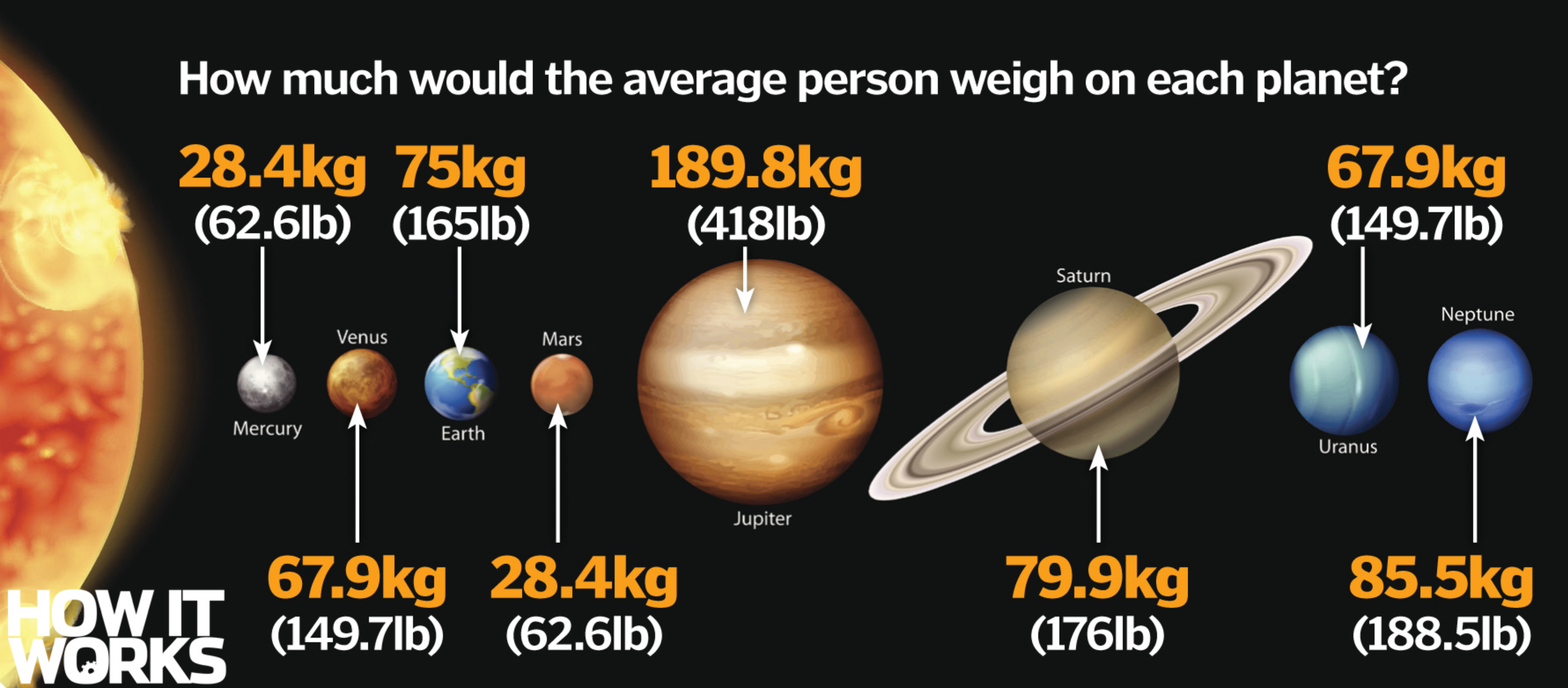
F) 80N

The force of gravity between masses m_1 and m_2 is 20N. If you move m_1 closer to m_2, cutting the distance between the masses in half ($r_f = ½r_i$), the new force will be

A) 5N
B) 10N
C) 15N
D) 20N
E) 40N
F) 80N

Big G, Little g

- $G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$
  G = universal constant
- $g = 9.81\ \mathrm{m/s^2}$ = specific to Earth
- Moon: $g = 1.62\ \mathrm{m/s^2}$
- Mars: $g = 3.71\ \mathrm{m/s^2}$



Weightlessness

- Apparent weightlessness: gravity never gets switched off
- Free-fall produces the sensation of weightlessness, but objects are not truly free from the force of gravity