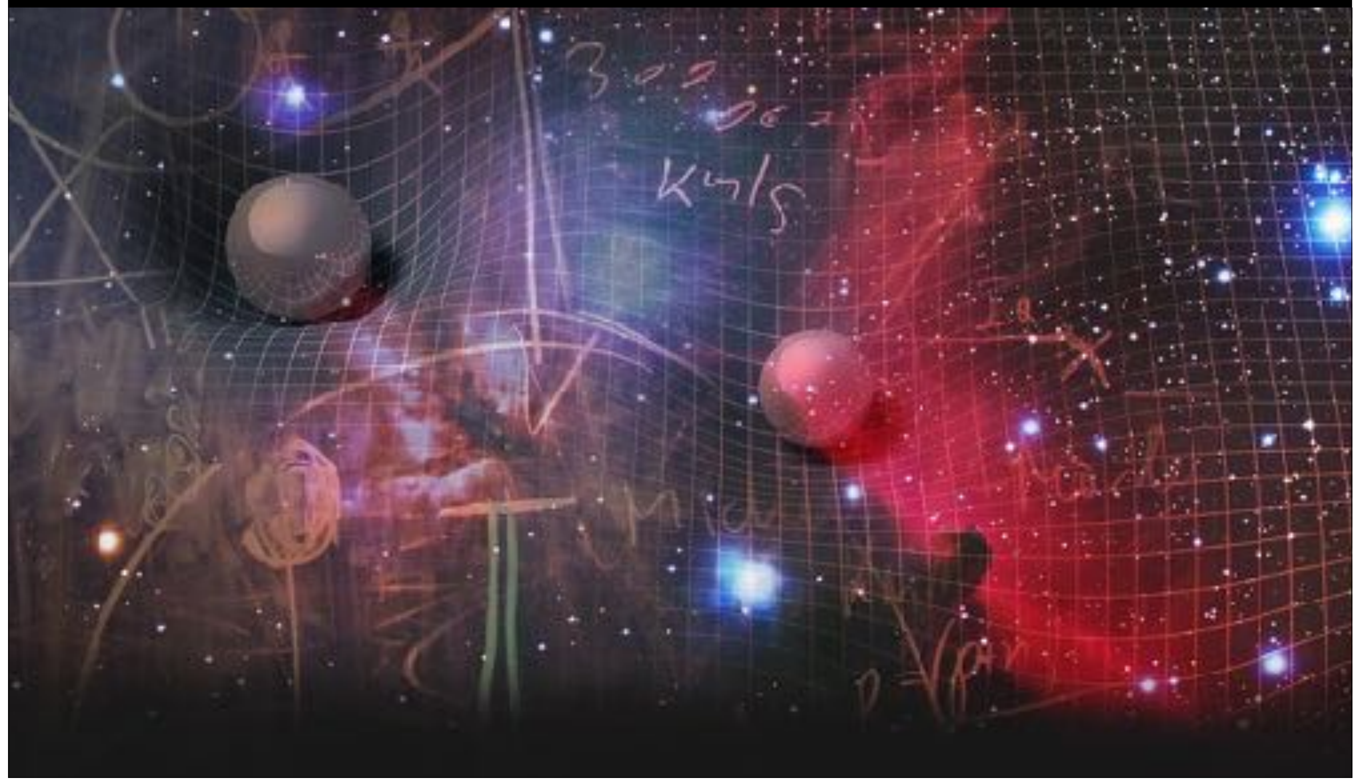
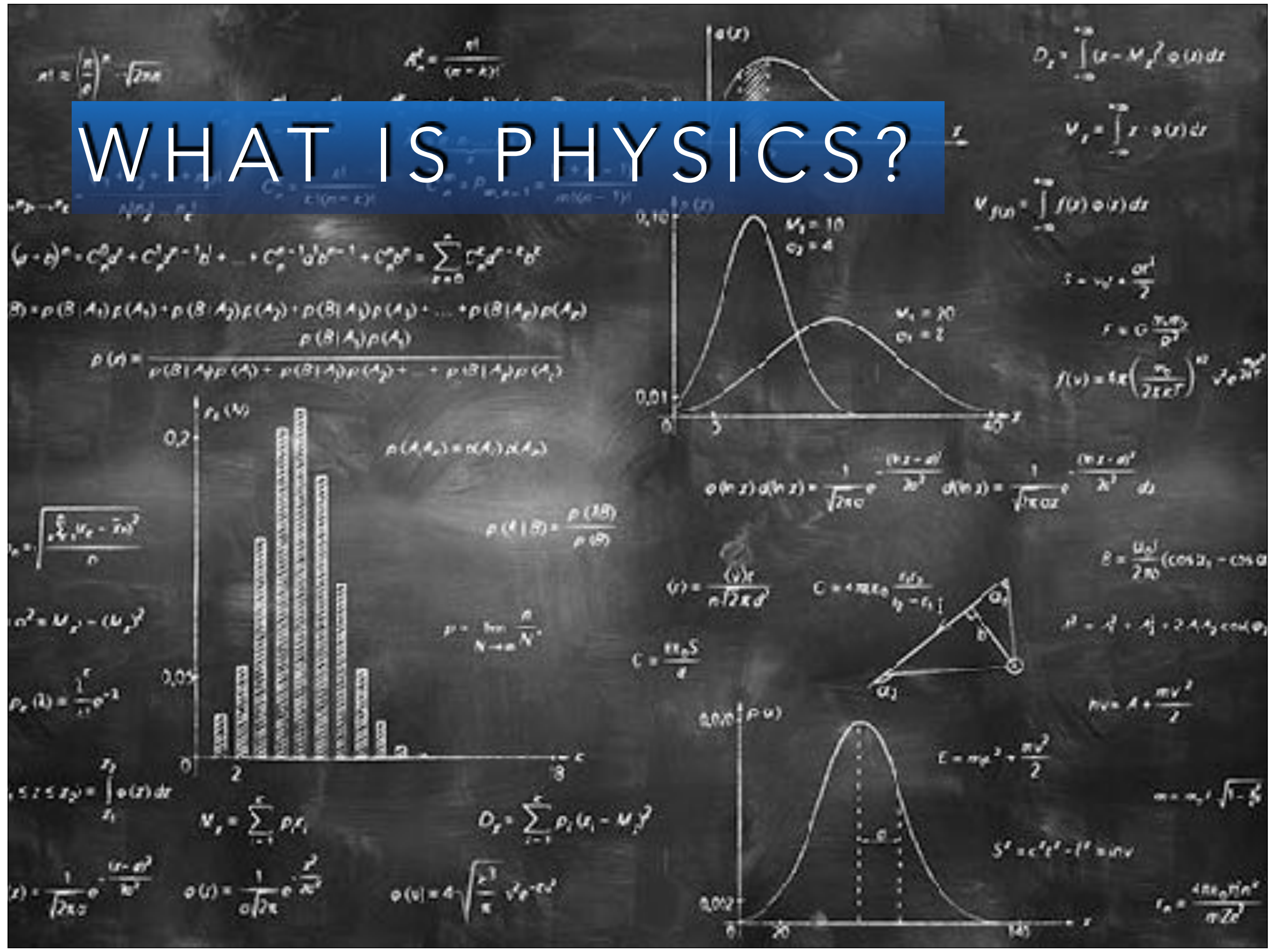
THINKING LIKE A SCIENTIST & THE TOOLS OF THE TRADE

ACT I: INTRO TO SCIENCE PRACTICES



WHAT IS PHYSICS?



DICTIONARY DEFINITION

- PHYS•ICS
- /ˈFIZIKS/
- NOUN
  - the branch of science concerned with the nature and properties of matter and energy. The subject matter of physics, distinguished from that of chemistry and biology, includes mechanics, heat, light and other radiation, sound, electricity, magnetism, and the structure of atoms.

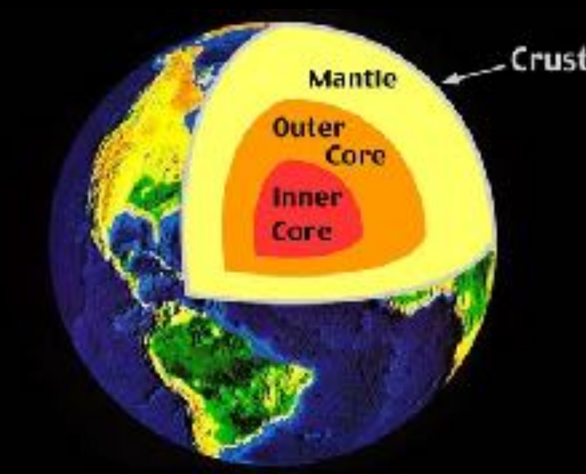
OUR DEFINITION

- Physics is the branch of science consisting of the fundamental principles upon which the physical world is built


HOW DO WE KNOW WHAT WE KNOW?
“The most exciting phrase to hear in science, the one that hails new discoveries, is not ‘Eureka!’ but ‘That’s funny…’” — Isaac Asimov

THE COMPOSITION OF EARTH

- Outer Crust
  - 30-40 km thick
- Mantle
  - 2,900 km thick
  - silicate rocks + magnesium and iron
- Outer Core
  - 2,300 km thick
  - liquid iron-nickel-sulfur
- Inner Core
  - radius of 1,200 km
  - solid iron-nickel alloy
  - 10,800 °F (as hot as the surface of the Sun!)



THE DEEPEST HOLE IN THE WORLD

- Kola Superdeep Borehole
- Kola Peninsula, Russia
- 12,262 meters (40,230 ft) deep!
- https://www.youtube.com/watch?v=zz6v6OfoQvs

THIS BEGS THE QUESTION…

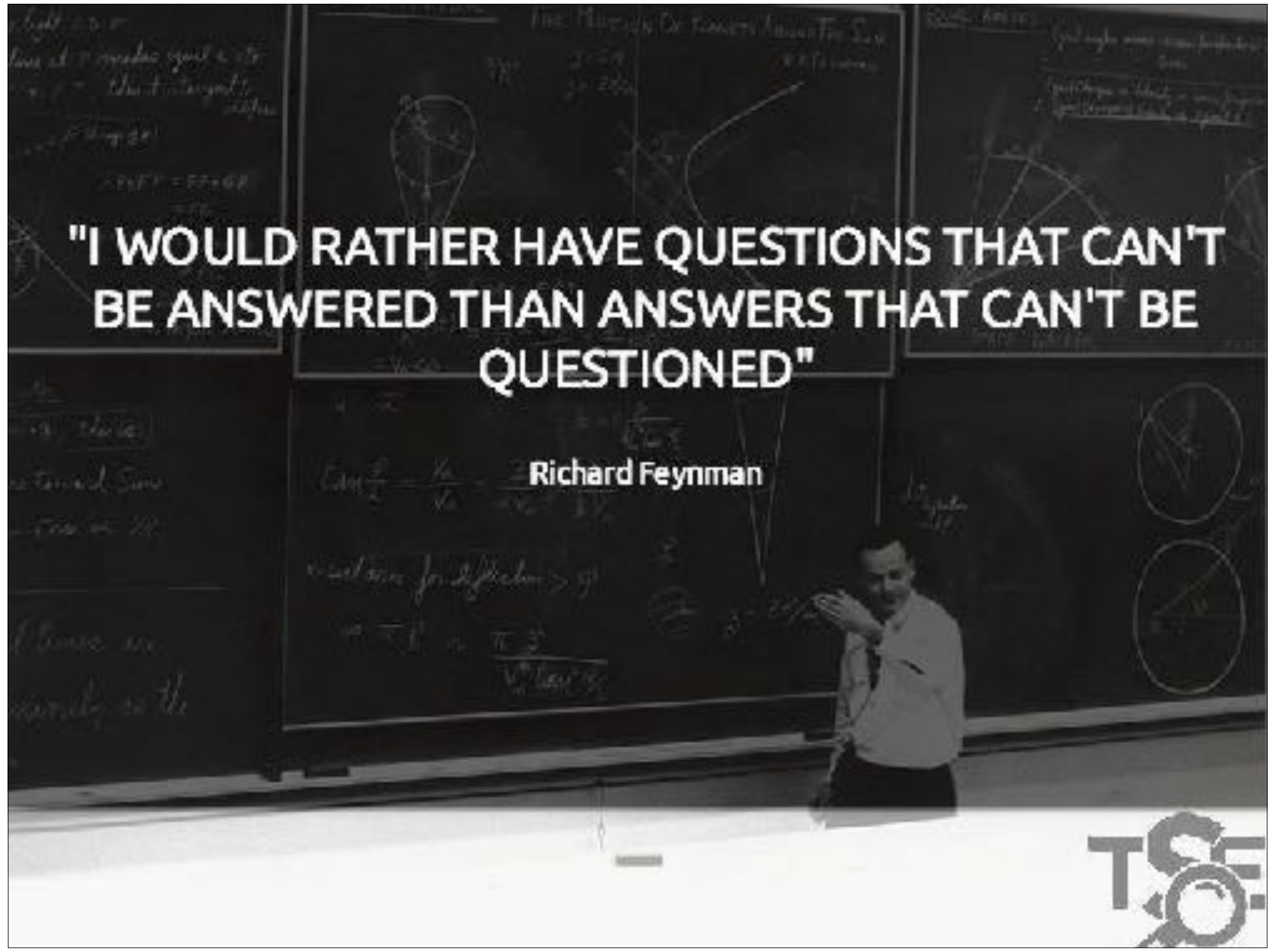
- If we've never even come close to visiting the inner layers of Earth, how do we know what's there?

IN THIS CLASS, WE WILL…

- Learn to see the unseen, and in some case the unseeable
- Gain the tools to understand the inner-workings of the physical world
- Acquire a foundational knowledge upon which the Universe has been built
- (How *do* we know what the Earth is made of? To find out, click here)

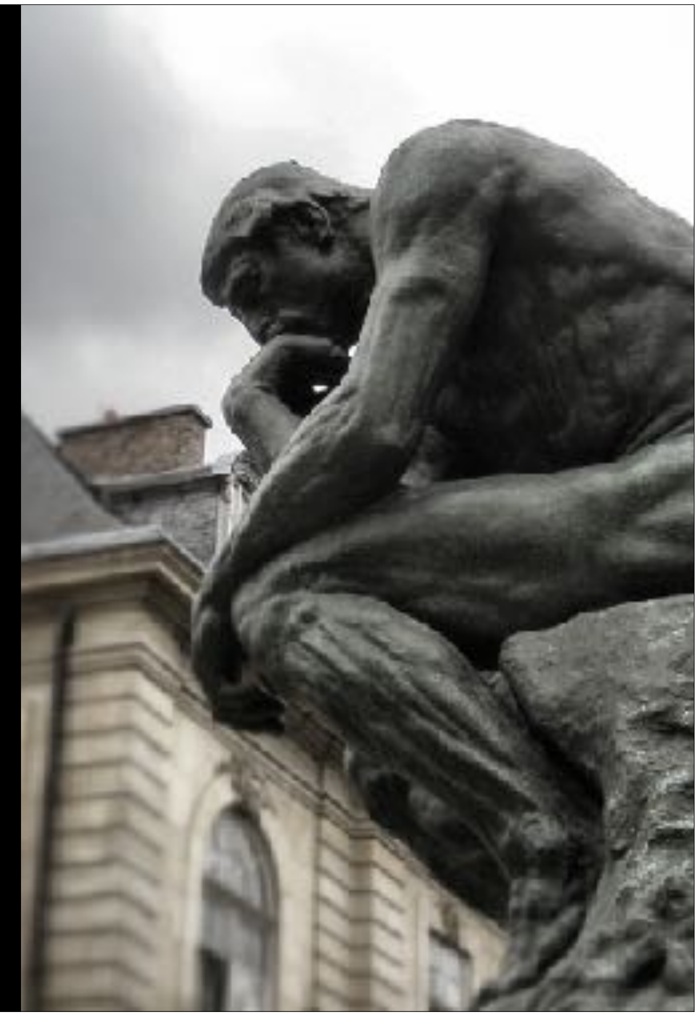
MOST IMPORTANT RULE IN SCIENCE

- Ask questions!
- It's the only way we learned any of this to begin with


"I WOULD RATHER HAVE QUESTIONS THAT CAN'T BE ANSWERED THAN ANSWERS THAT CAN'T BE QUESTIONED"
Richard Feynman

THE ART OF ASKING QUESTIONS
& REASONING ANSWERS

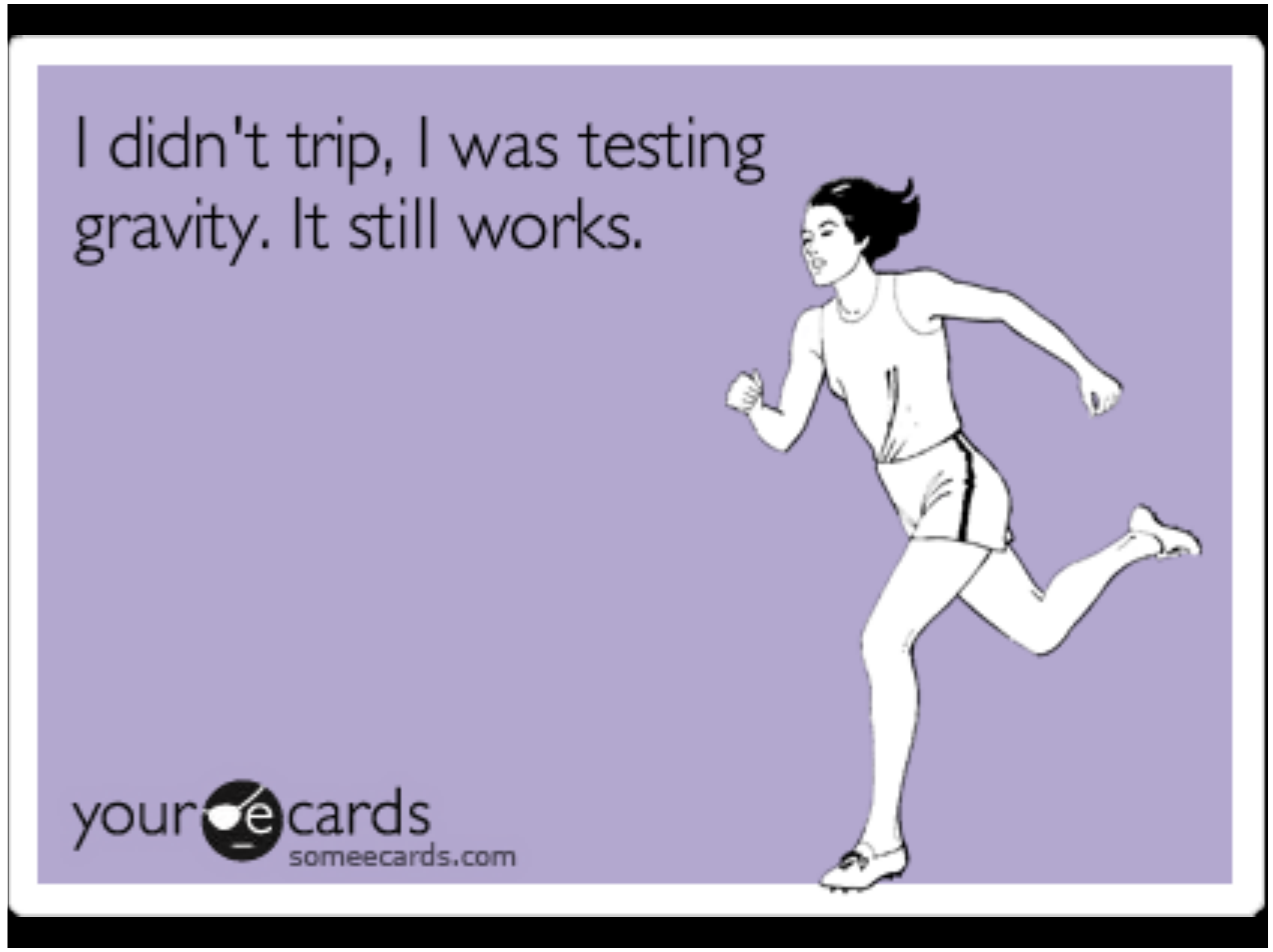
SCENE I: THINKING LIKE A SCIENTIST



> "There are as many scientific methods as there are individual scientists… [The scientist] is not consciously following any prescribed course of action, but feels complete freedom to utilize any method or device whatever, which in the particular situation before her seems likely to yield the correct answer. In her attack on her specific problem she suffers no inhibition of precedent or authority, but is completely free to adopt any course that her ingenuity is capable of suggesting to her."
>
> –PERCY BRIDGMAN

- Percy Williams Bridgman was an American physicist who won the 1946 Nobel Prize in Physics for his work on the physics of high pressures
- He reminds us that science is a creative endeavor, unrestricted by cookbook methodology

Inductive Reasoning — the logic of developing generalizations, hypotheses, and theories from specific observations and experiments



- Physicists have repeated measured the acceleration due to gravity at sea level to be 9.8 m/s^2, and this value is now an accepted constant, even though it hasn't been tested everywhere that is at sea level on Earth's surface
- Inductive reasoning always leaves room for error or uncertainty

SCIENTISTS HAVE NOTED:

1. ice in Greenland is melting faster than it is forming
2. the Northwest Passage is navigable for the first time in history, and
3. Antarctic ice is receding

- Based on these and other observations, scientists infer that global temperature is rising

FINDING PATTERNS IN SEISMIC AND VOLCANO DATA

- With your table groups, plot the distribution of the world's most famous volcanoes and the largest earthquakes since 1900 on your world map
- Mark volcanoes with x's of one color and mark earthquakes with dots of a different color
- On the same chart, plot the epicenters of earthquakes from the month as reported by the U.S. Geological Survey

Deductive Reasoning — the logic of developing specific conclusions from general principles or premises

Premise — a previous statement or proposition from which another is inferred or follows as a conclusion

- Unlike inductive reasoning, which always involves uncertainty, the conclusions from deductive inference are always certain provided the premises are true
- Scientists use inductive reasoning to formulate hypotheses and theories and deductive reasoning when applying them to specific situations

DEDUCTIVE REASONING: ELECTRIC CIRCUITS

- *First premise*: the current in an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance ($I \propto V/R$)

- *Second premise*: the resistance in a circuit is doubled

- *Inference*: therefore, the current is cut in half

DEDUCTIVE REASONING: PLANETARY MOTION

- *First premise*: the ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the Sun ($T_1^2/T_2^2 = d_1^3/d_2^3$)
- *Second premise*: Earth is closer to the Sun than Mars
- *Inference*: therefore, Earth orbits the Sun faster than Mars

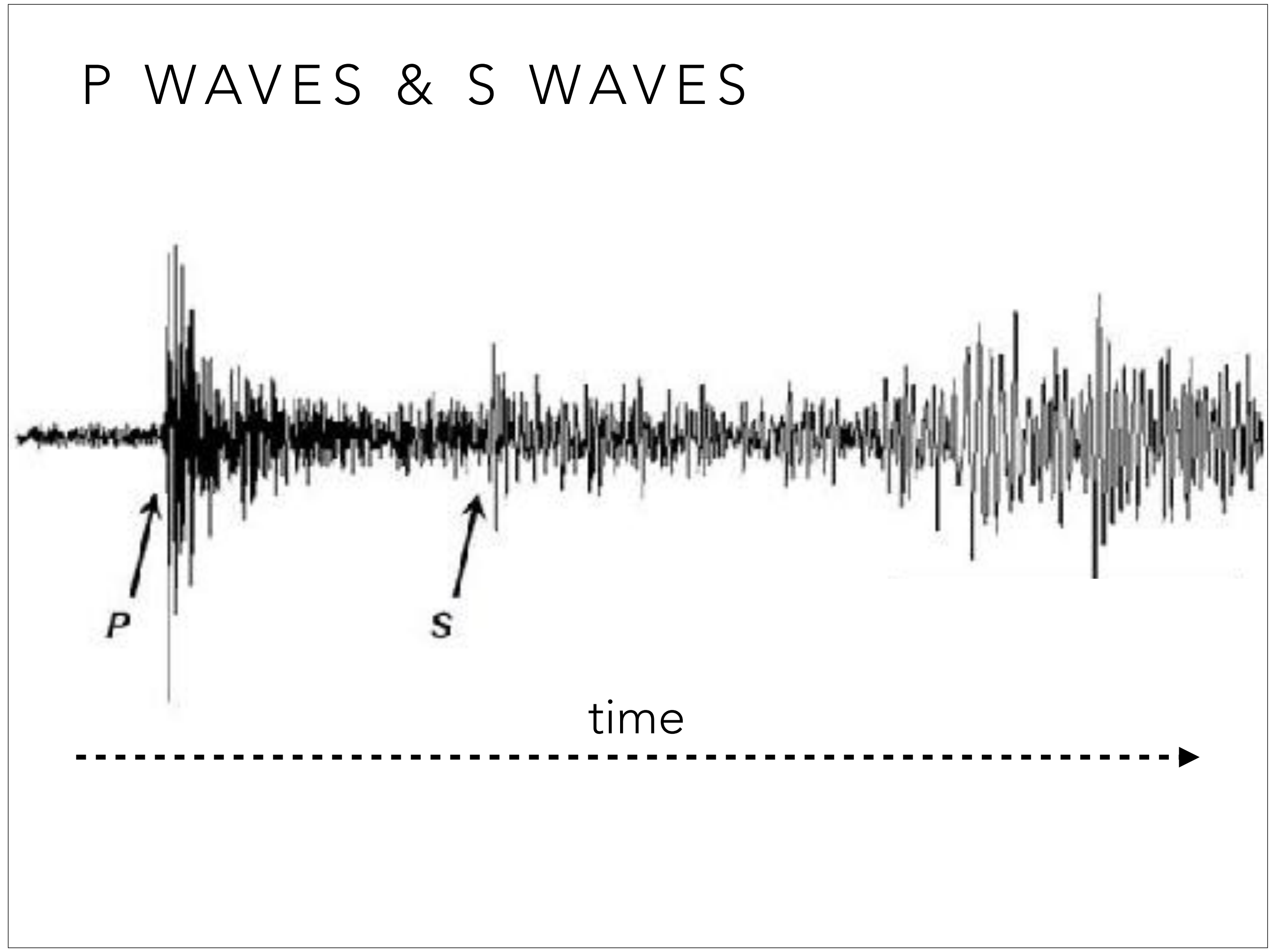
DEDUCTIVE REASONING: EARTHQUAKE EPICENTER

- *First premise*: earthquakes release compression waves (P-waves) that travel at 7 km/s in Earth's crust (this value varies depending upon crust composition)

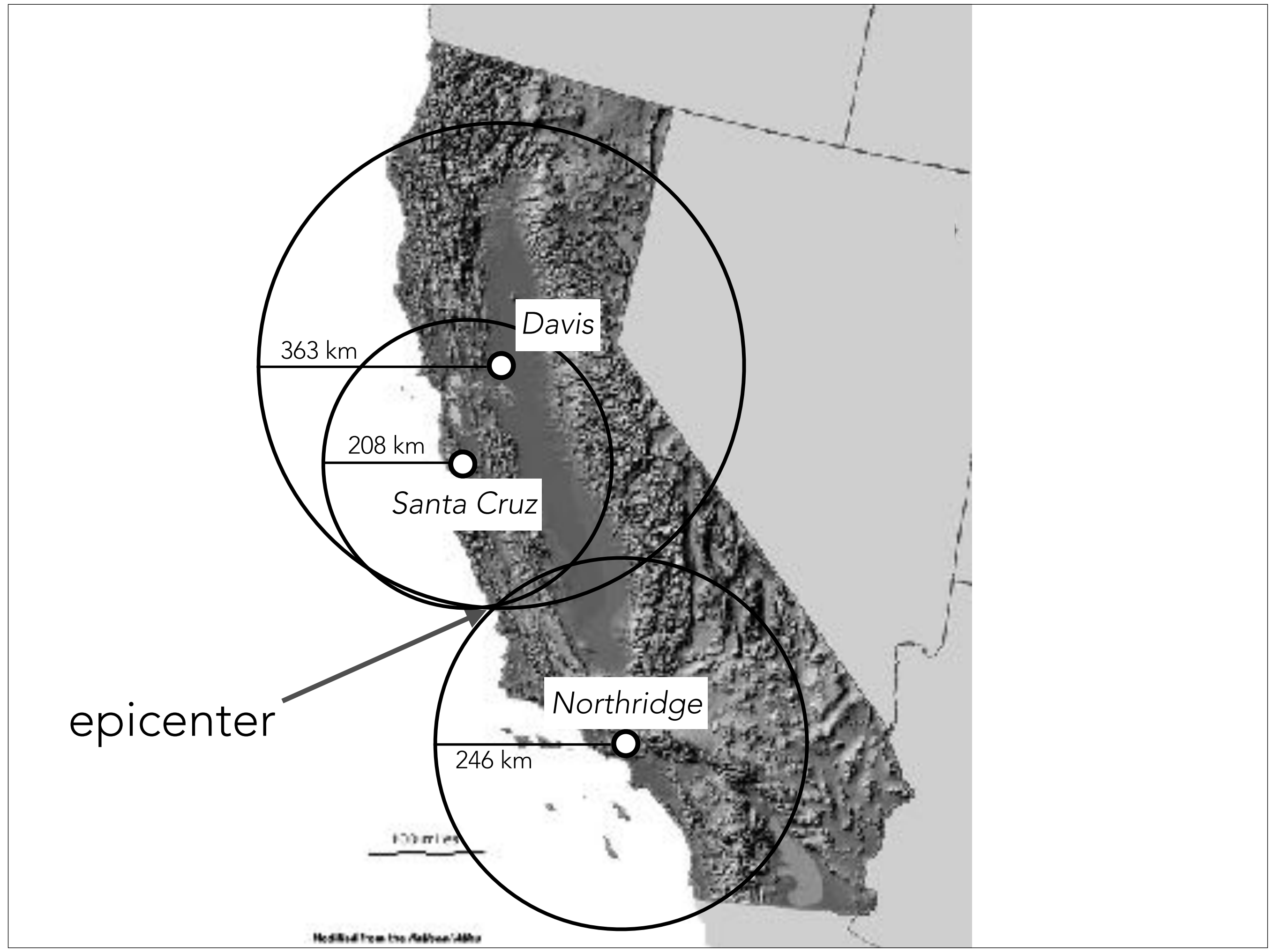
- *Second premise*: earthquake emit shear waves (S-waves) that travel at 58% the speed of P-waves, or 4 km/s

- *Inference*: the distance to the epicenter can be calculated by the formula:

$$d = \frac{(t_2 - t_1)(r_s r_p)}{r_p - r_s}$$



- The diagram shows that p-waves travel faster and reach the seismograph sooner than s-waves



- Receiving the earthquake signal from one or even two stations isn't enough to determine the epicenter — it takes three (hence *triangulation*)

Observation — a record resulting from the study of an event or an object

Inference — a conclusion drawn from evidence or reasoning based on observations

- Demo #1: Students record as many observations about the “plant” as possible. Share observations. Pass “plant” around class. BAM! Turns out it’s fake.
- Demo #2: In secret, hydrate raisins for 20 minutes before placing them in a glass of clear carbonated drink (give fizzing time to subside). Present “Raisidia” to the class and record student observations on the board. After students complete observations, drink the glass

Lateral Thinking — the ability to approach problems from a variety of perspectives rather than only from the single most obvious approach

LATERAL THINKING

- Example 1: On January 5, 2006, a jet traveled east from Quito, Ecuador, at 800 km/hr. How far did it travel in 3 hours?

- Simple distance = rate x time?
- Relative to Earth's rotation?
- Relative to the Sun?
- Are we including wind speed?

LATERAL THINKING

- Example 2: An explorer travels 1 km due south, then 1 km west, followed by 1 km north to arrive back at the place where he started. Where is this explorer?

- Answer: the North Pole



- Many problems in science are solved only when researchers drop their assumptions and adopt a novel approach
- For example, vitamins were discovered only after researchers stopped looking for a pathogenic cause for beriberi and started looking for the absence of some essential material

LATERAL THINKING RIDDLES

RIDDLE 1

- A chemistry stockroom technician is 188 cm (6’2”) tall. What does he weigh?

Answer: Chemicals

RIDDLE 2

- A rope ladder is hung over the side of a research vessel in the Bay of Funday so that the bottom rung just reaches the water. If the rungs are 20 cm apart, how many rungs will be under water when the tide rises 3 m?

Answer: None. The boat rises with the tide, and so does the rope ladder

RIDDLE 3

- A research ecologist drank heavily from the punch bowl at a research picnic in the Himalayan Mountains. He left the party early and was surprised to find that all of his team came down with giardiasis (a waterborne disease) the next day, even though nothing was added to the punch after he left and no one had drunk anything since the party. What happened?

Answer: The punch was cooled with ice cubes from a local water supply. The protozoan that causes giardiasis was released to the punchbowl as the ice melted. Since the researcher left the party early, there was insufficient giardia in the water to give him the disease

RIDDLE 4

- The younger of two twins celebrates her birthday 2 days before her older twin. How can this be if both twins are celebrating their birthdays on the calendar days on which they were born?

- Answer: The mother of the twins was on a Pacific cruise at the time she delivered her twins. The older one was born in the Eastern Hemisphere on March 1, just before the boat crossed the international dateline. The younger twin was born minutes later on February 28 in the Western Hemisphere. On leap years, the younger twin will celebrate her birthday two days earlier because of the introduction of February 29

RIDDLE 5

- A mineralogist examines seven crystals that are identical except that one has slightly less mass than the other six. How can the mineralogist determine which is the smallest crystal using just a double pan balance and only two measurements?

- Answer: The mineralogist should put three crystals on one side of the balance and three on the other side. If the masses are equal, the crystal still on the table is the smaller one. If they are not equal, the smaller crystal is on the side with less mass, and the mineralogist should clear pans, take two from this side, and place them on opposite pans. If these two crystals are of equal mass, the smaller crystal is the third member of this group. If the masses are unequal, the crystal on the pan that registers less mass in the smaller one

RIDDLE 6

- Why do civil engineers design round manhole covers rather than square ones?

- Answer: Round manhole covers will not fall in the hole, while square ones can if they are tilted diagonally. Round manhole covers do not need to be aligned as they are put in place, while square ones do. Round manhole can be easily rolled to and from their destination, while square ones must be carried. In addition, round manhole covers are easier to manufacture than square or rectangular ones

RIDDLE 7

- A botanist is growing plants in three sealed, windowless growth chambers, but can't remember which of three light switches controls the light in chamber C, 100 m away. To minimize disturbance to the plants, she can open the chamber only once for 5 seconds. How can she determine which switch controls the light in chamber C?

- Answer: The botanist can turn on switch 1 for a couple minutes, then turn it off and turn on switch 2 and go immediately to chamber C. If the light bulb is off and the bulb is warm, the light is controlled by switch 1. If the light is on, the light is controlled by switch 2, and if the light is off and the bulb is cool, the light is controlled by switch 3

MATHEMATICS & UNITS OF MEASUREMENT

SCENE II: TOOLS OF THE TRADE

$$F_g = \frac{GMm}{r^2}$$

- Newton's Law of Gravitation

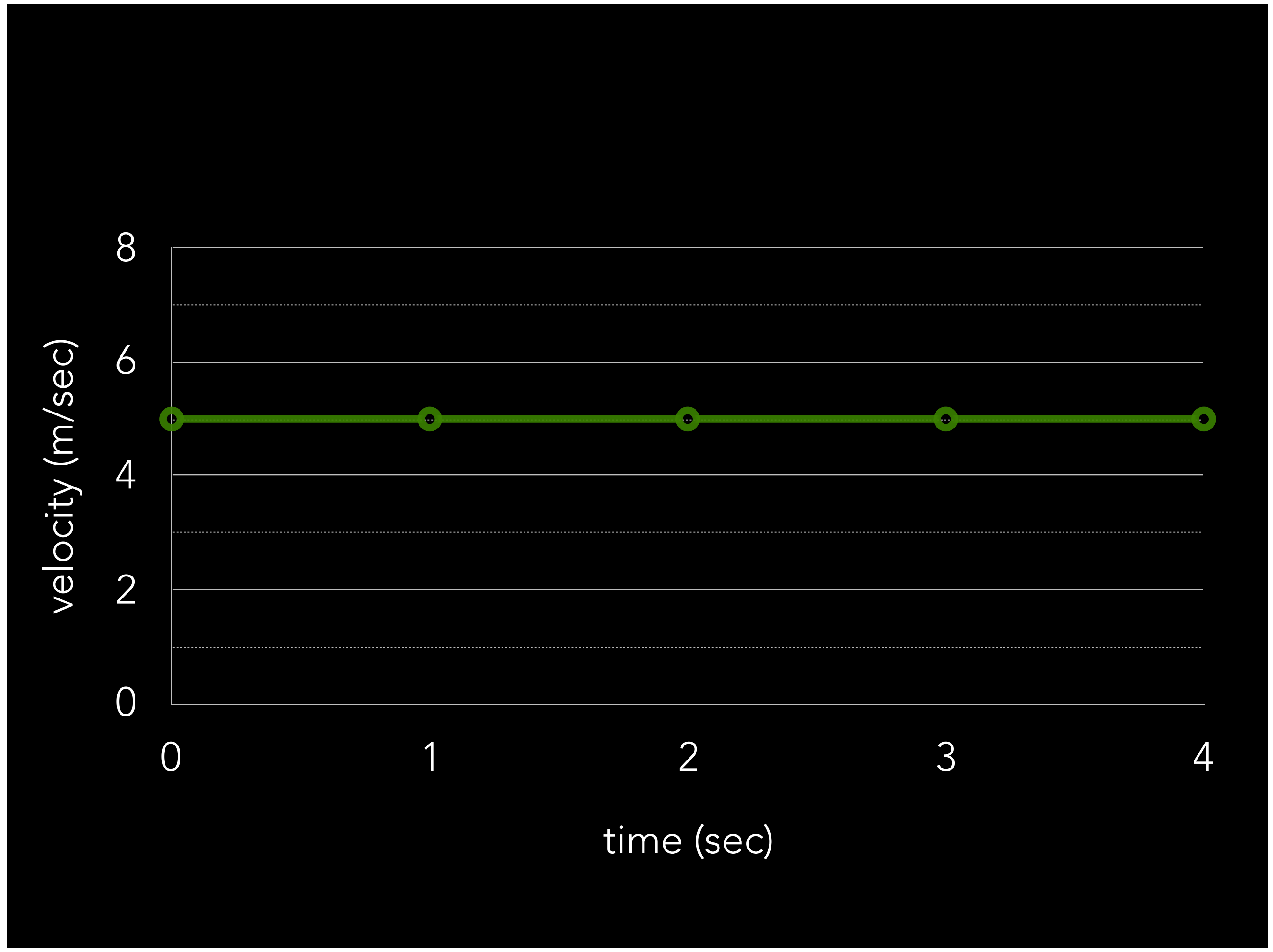
The force of gravity is proportional to the product of the masses of two objects and inversely proportional to the square of the distance between them, and also the bodies react to forces by changing their speeds, or changing their motions, in the direction of the force by amounts proportional to the force and inversely proportional to their masses.

- Really, I've said the same thing as on the last slide

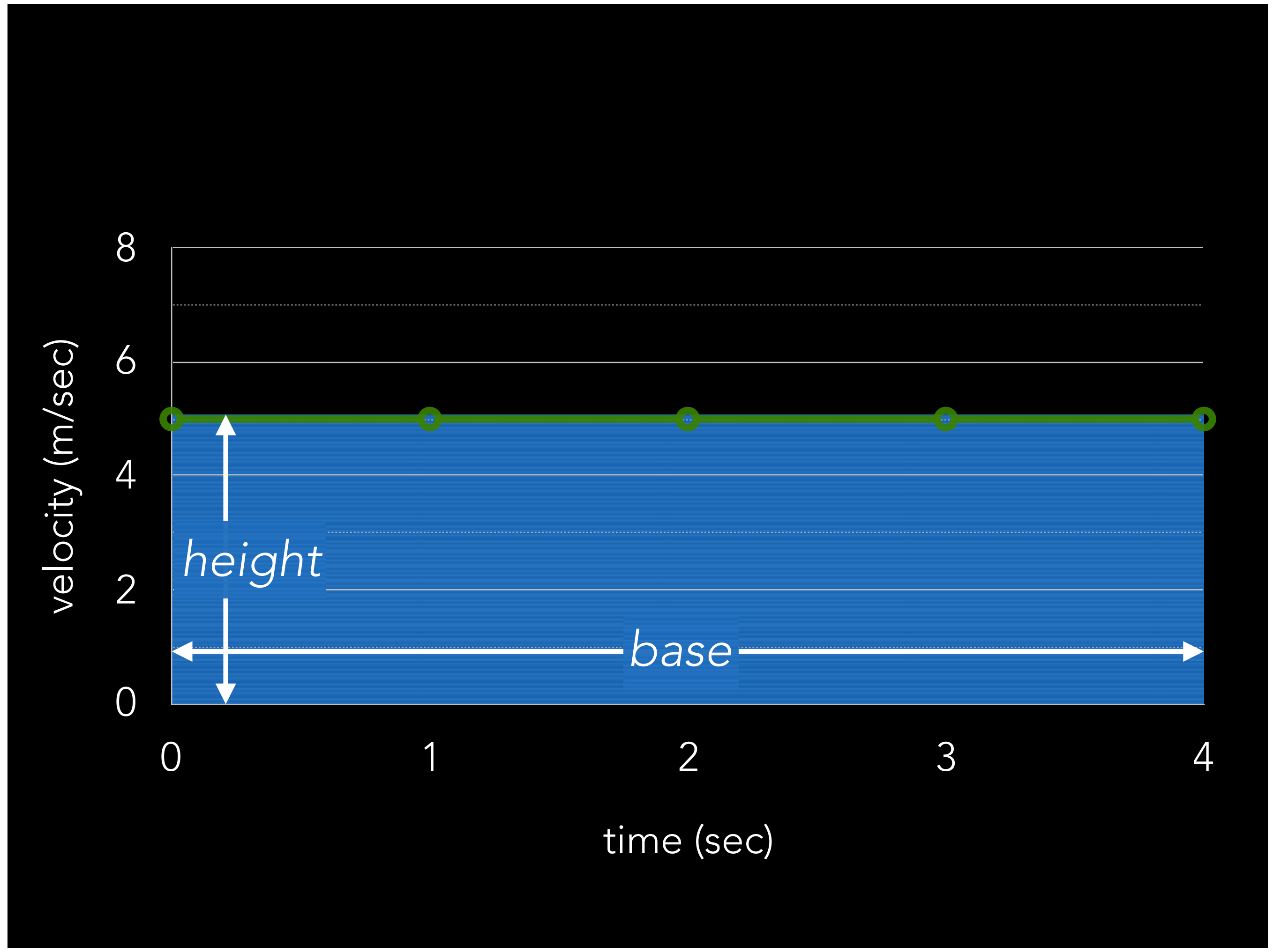
"It tells you *how* it moves. That should be enough.
I have told you how it moves, not why."

–ISAAC NEWTON

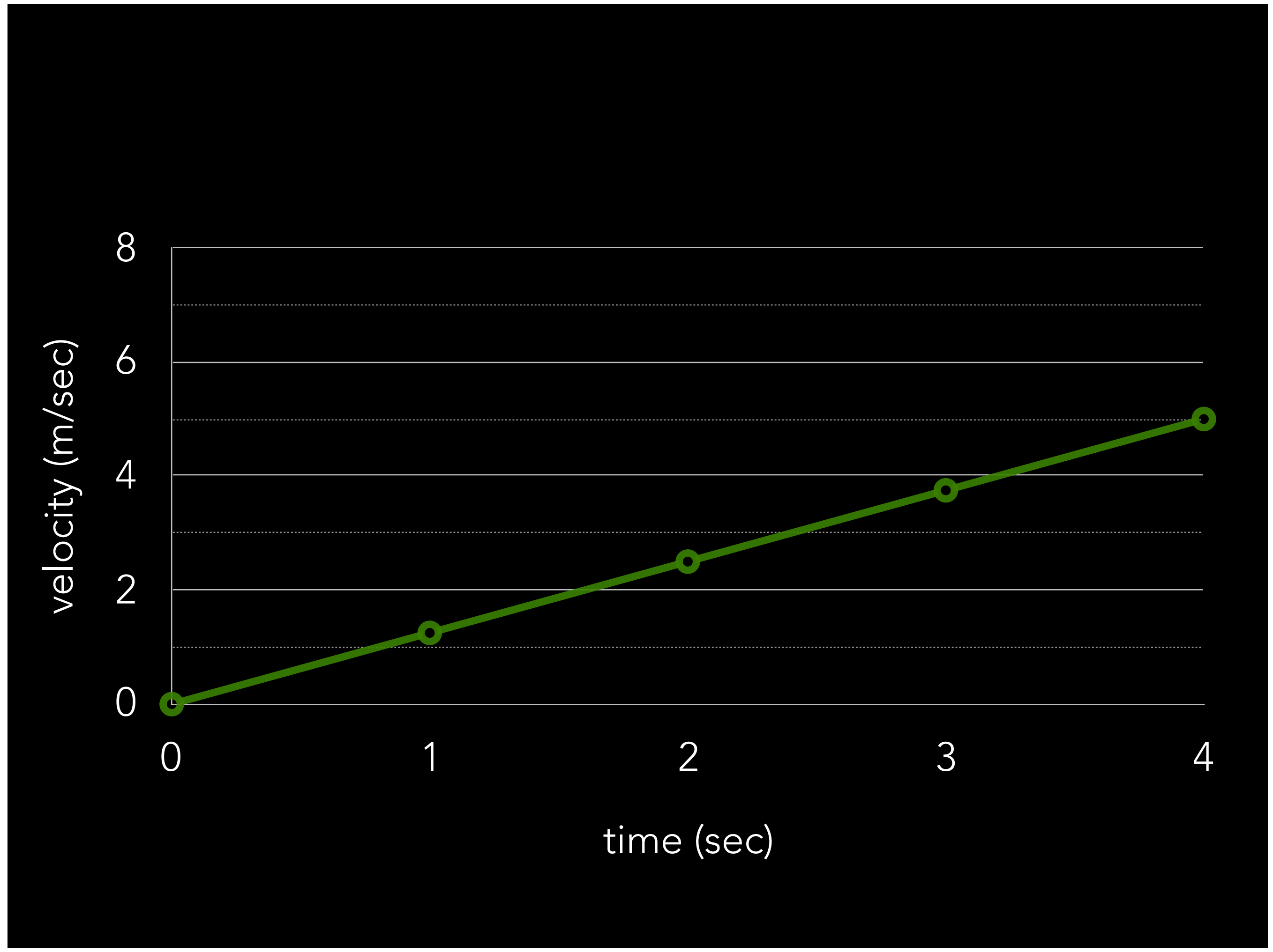
- It's not as though a planet checks it's distance from the Sun and runs the numbers through it's internal calculator to figure out far it should move
- That said, the utility of an equation is in its predictive power



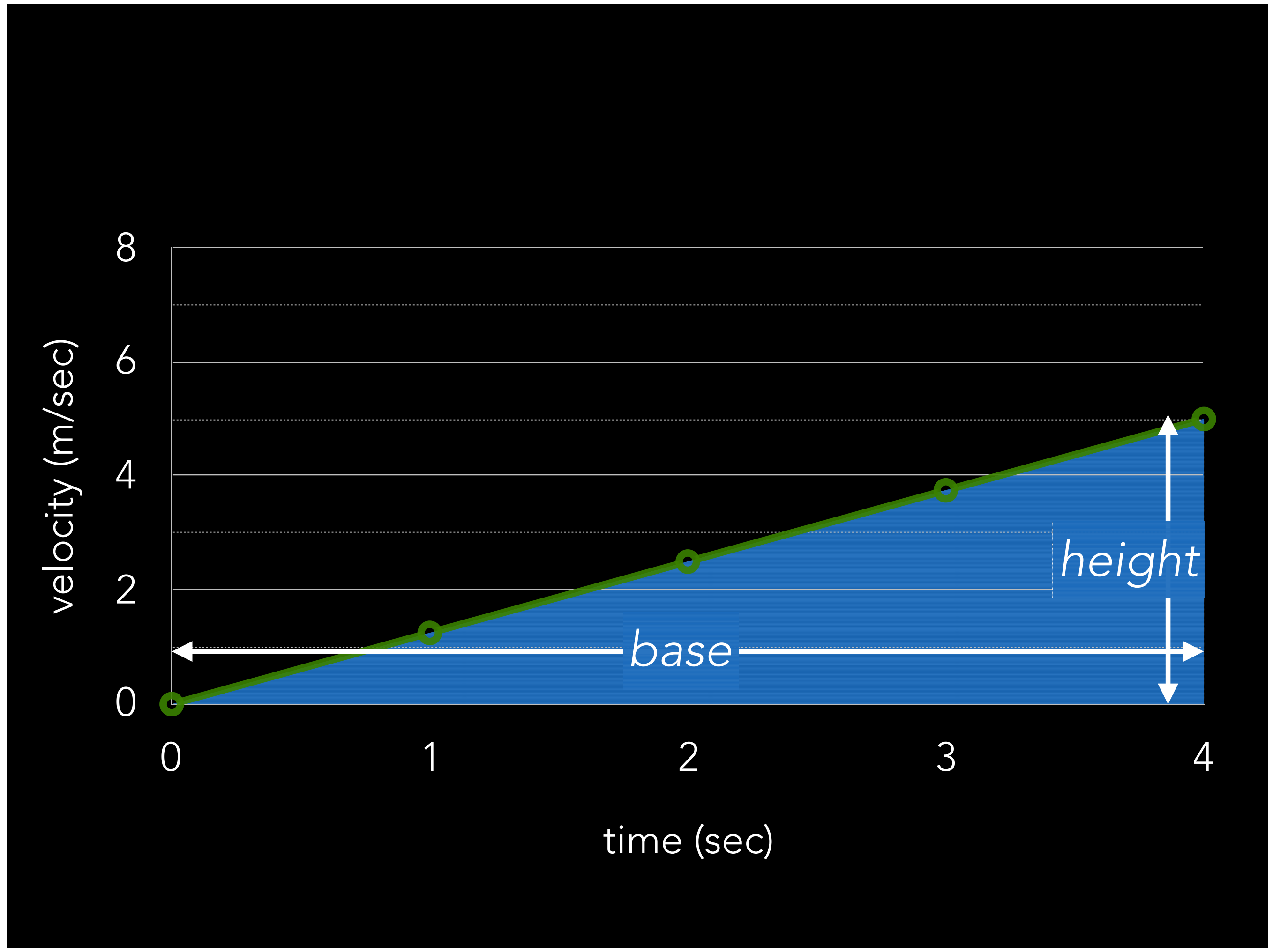
- This might be a runner jogging at 5 meter per second for 4 seconds, it might be a bird flying at the same rate — it doesn't matter. Either way, our goal is to figure out how far they traveled.



- At first glance, it may not seem obvious where to find that distance represented on the graph, but in fact it’s been there all along. It’s the area under the graph!
- In this case, we’re looking at the area of a rectangle, which we know is *base* times *height*
- d = 20 m



- That trick of finding the area under the graph may seem trivial, but it becomes more useful when we look at an example where the velocity is changing.
- In this case, our runner (or bird or car or whatever) starts from rest and gradually speeds up to 5 m/sec. In a case like this, $d = rt$ can't help us find the distance traveled because that only works for a constant speed.



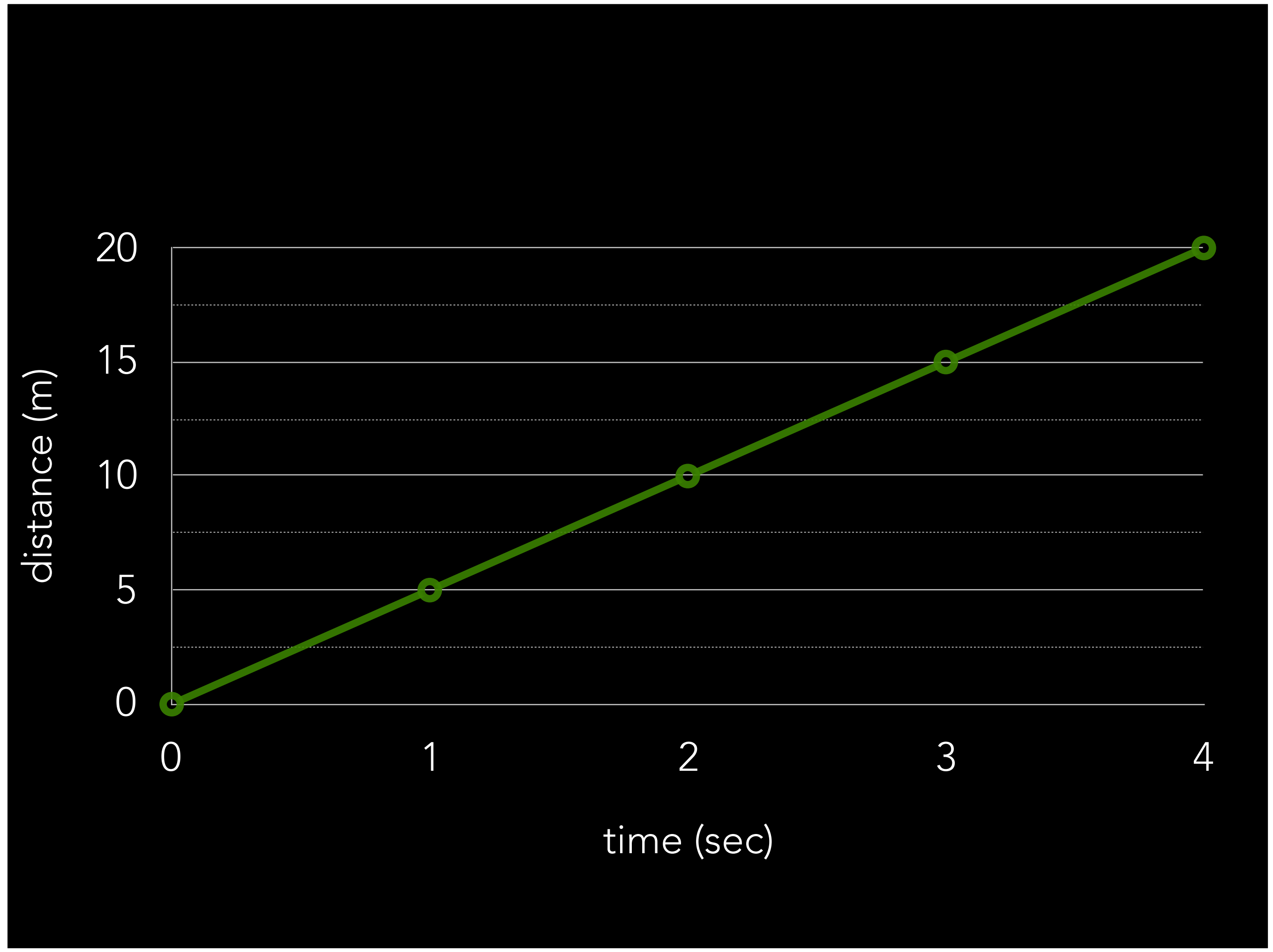
- However, using the area under the graph to find the distance traveled works exactly the same as before!
- Now we're not trying to find the area of a rectangle but want the area of a triangle instead. But that's easy, too! The area of a triangle equals ½ (*base*) × (*height*)
- *d* = 10 m

Integrate — find the area under the graph

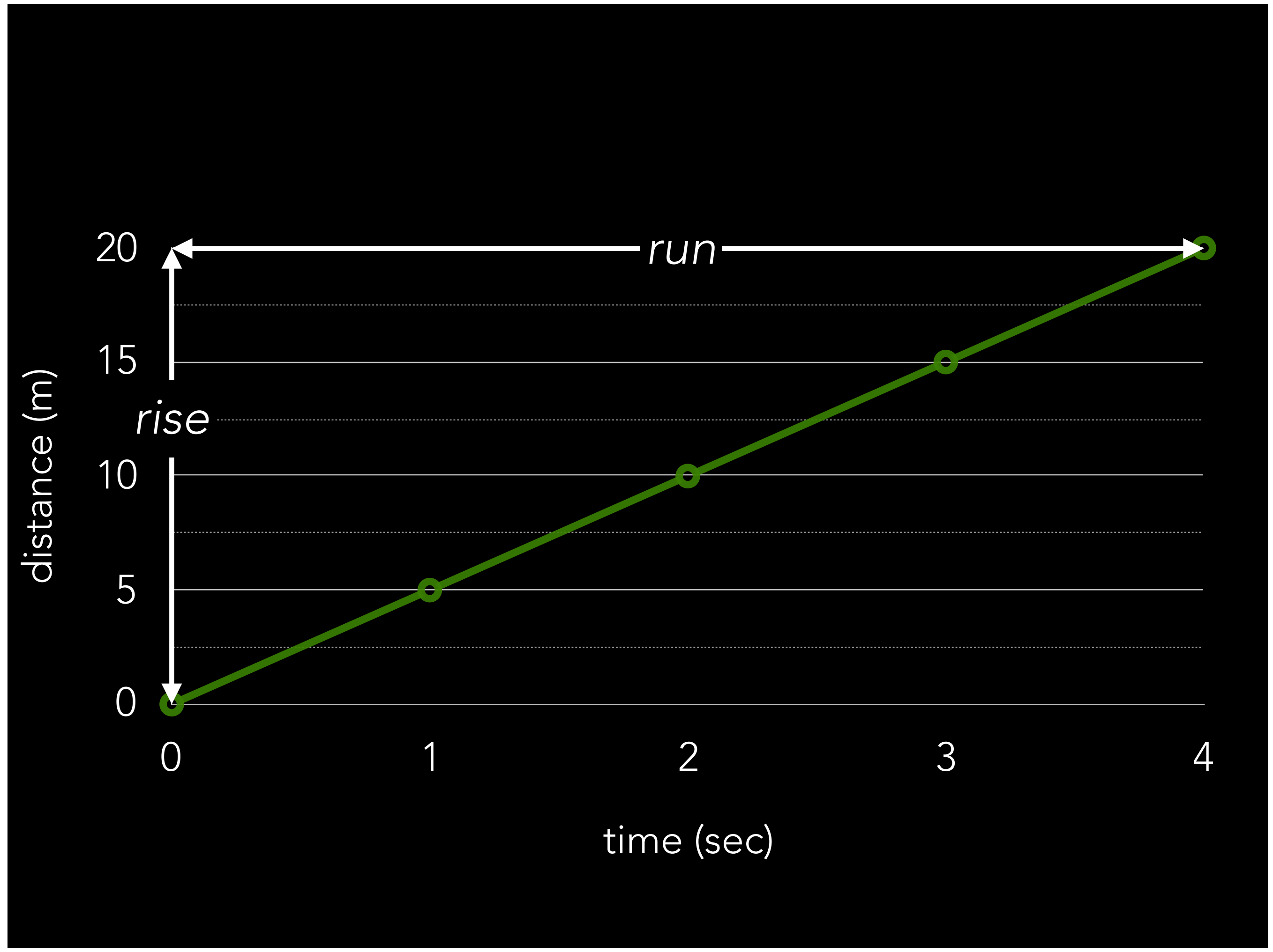
$\int$ — math symbol for integration

$$d = \int v \, dt$$

distance = **velocity** integrated over **time**



- Let's return to *d* = *rt*, but this time let's plot out the distance vs. time graph.
- We know velocity represents the rate at which distance changes, but can we deduce the velocity from the graph? Of course!
- In a graph, rate of change is represented by the slope!



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- We know velocity represents the rate at which distance changes, but can we deduce the velocity from the graph? Of course!
- In a graph, rate of change is represented by the slope!
- $v = 5$ m/sec

Derivative — the rate of change; the slope of a graph

$$v = \frac{dx}{dt}$$

velocity = rate at which **position** changes with **time**

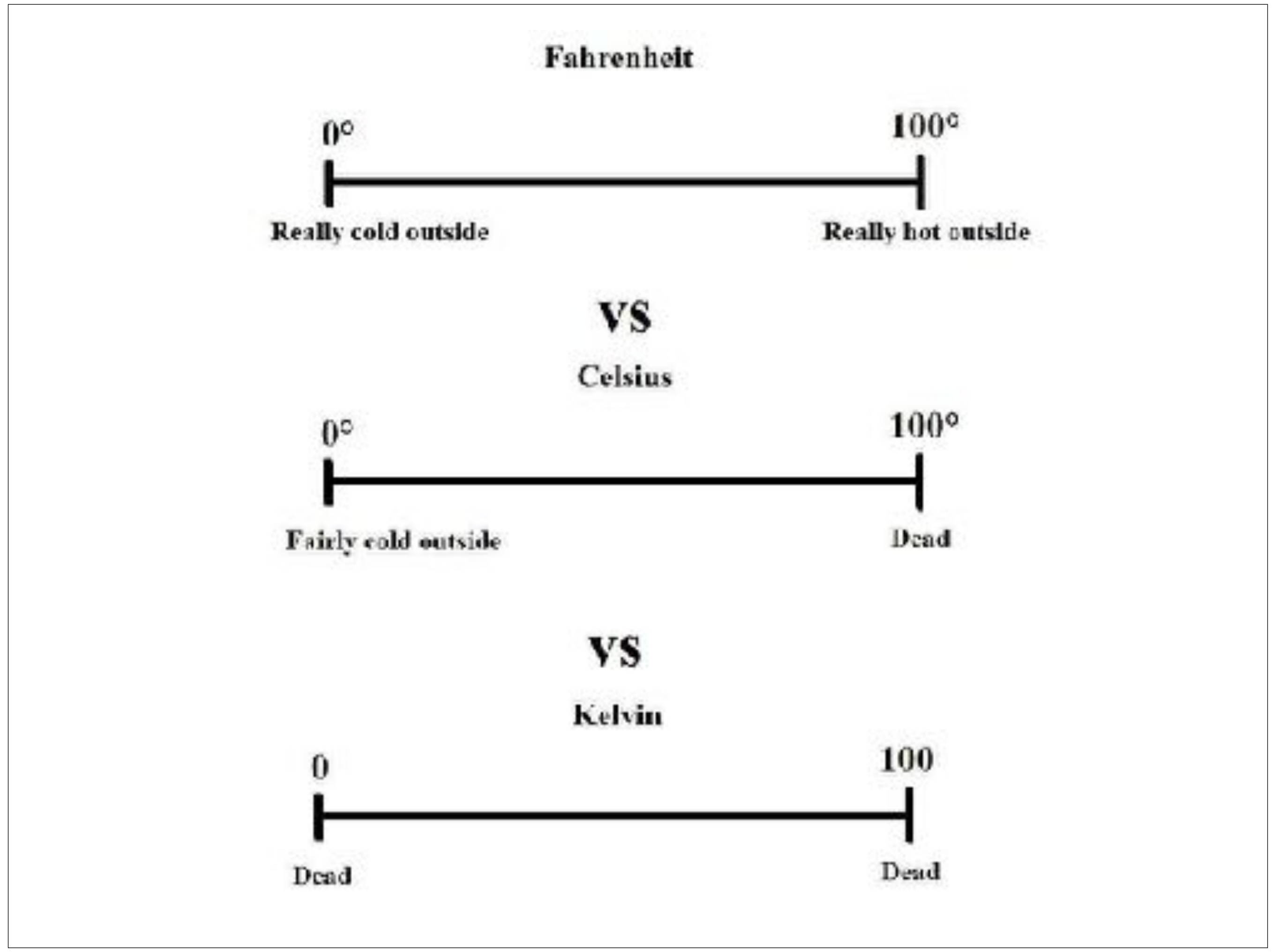
S.I. UNITS

- Common, agreed upon units of measurement
  - Length: meter (m)
  - Mass: kilogram (kg)
  - Electric current: ampere (A)
  - Temperature: kelvin (K)
  - Time: second (s)
- And a bunch of derived units that we'll learn as we go along

METRIC PREFIXES

PREFIX	ABBREVIATION	VALUE
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	**M**	**10^{6}**
kilo	**k**	**10^{3}**
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	**c**	**10^{-2}**
milli	**m**	**10^{-3}**
micro	**μ**	**10^{-6}**
nano	**n**	**10^{-9}**
pico	**p**	**10^{-12}**
femto	f	10^{-15}
atto	a	10^{-18}

- 1 m = 100 cm = 1000 mm = 0.001 km
- 1 g = 100 cg = 1000 mg = 0.001 kg



- Establish new reference points
- When you hear “26 ºC,” instead of thinking “That’s 79 ºF” think “That’s warmer than a house but a little cool for swimming”

CURB YOUR INTUITION

TEMPERATURE	
60°C	Earth's hottest
45°C	Dubai heat wave
40°C	S. US heat wave
35°C	N. US heat wave
30°C	Beach weather
25°C	Warm room
20°C	Room
10°C	Jacket weather
0°C	Snow!
-5°C	Cold day (Boston)
-10°C	Cold (Moscow)
-20°C	itscolditscolditscold
-30°C	Aaaagggggghhhh!
-40°C	Spit goes "click"

LENGTH	
1 cm	Width of mircoSD
3 cm	Length of SD card
12 cm	CD diameter
15 cm	BiC pen
80 cm	Doorway width
1 m	Lightsaber blade
170 cm	Summer Glau
200 cm	Darth Vader
2.5 m	Ceiling
5 m	Car-length
16.04 m	Human tower of the *Serenity* crew

MASS	
3 g	Peanut M&M
100 g	Cell phone
500 g	Bottled water
1 kg	MacBook Air
2 kg	15" MacBook Pro
3 kg	Heavy Laptop
5 kg	LCD monitor
15 kg	CRT monitor
4 kg	Cat
60 kg	Lady
70 kg	Dude
150 kg	Shaq
200 kg	Your mom

BBC NEWS

News in Audio | News in Video | Newsdition

Thursday, September 30, 1999 Published at 18:53 GMT 19:53 UK

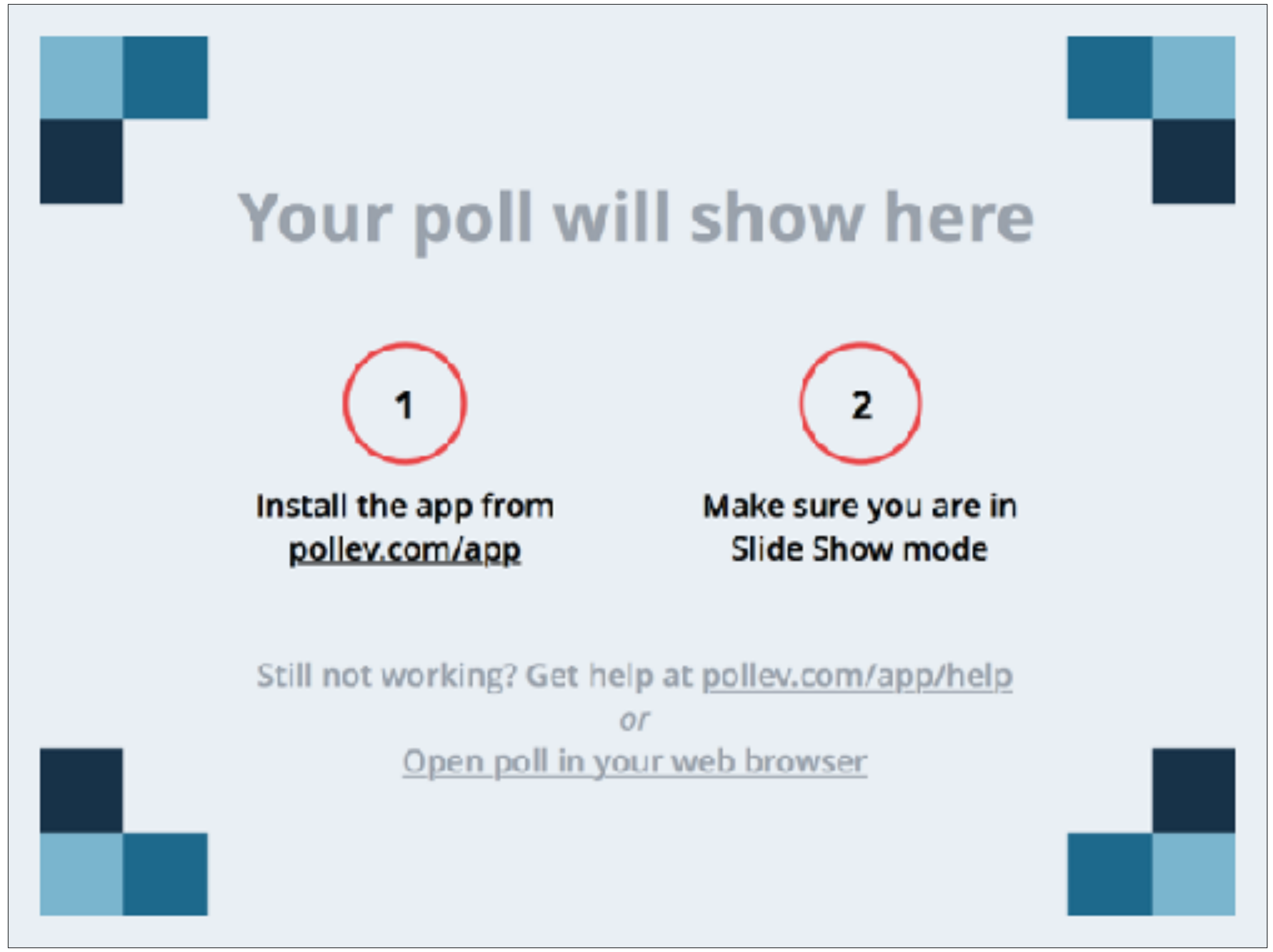
Sci/Tech

Confusion leads to Mars failure

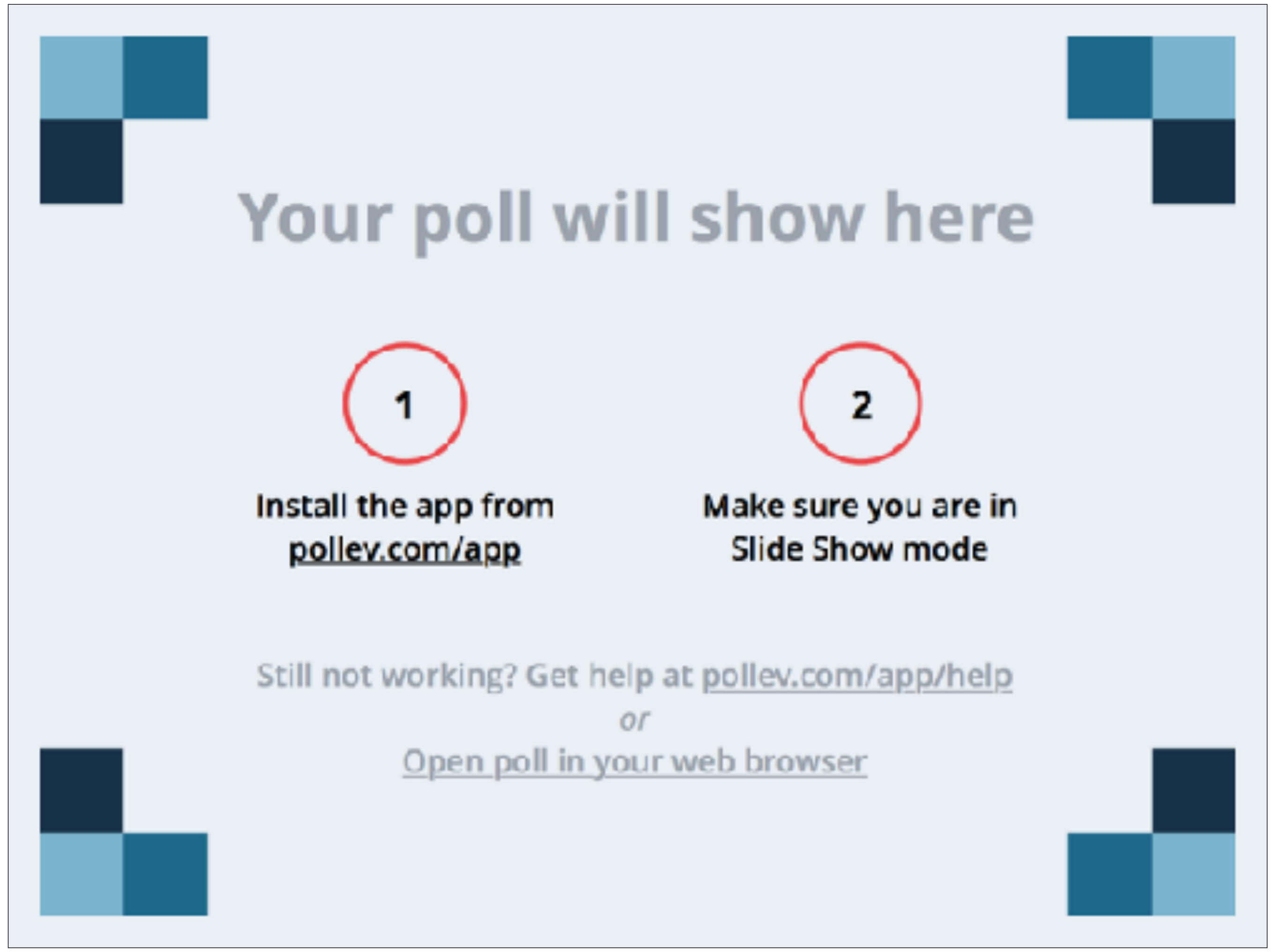
The Mars Climate Orbiter: Now in pieces on the planet's surface

The Mars Climate Orbiter Spacecraft was lost because one Nasa team used imperial units while another used metric units for a key spacecraft operation.

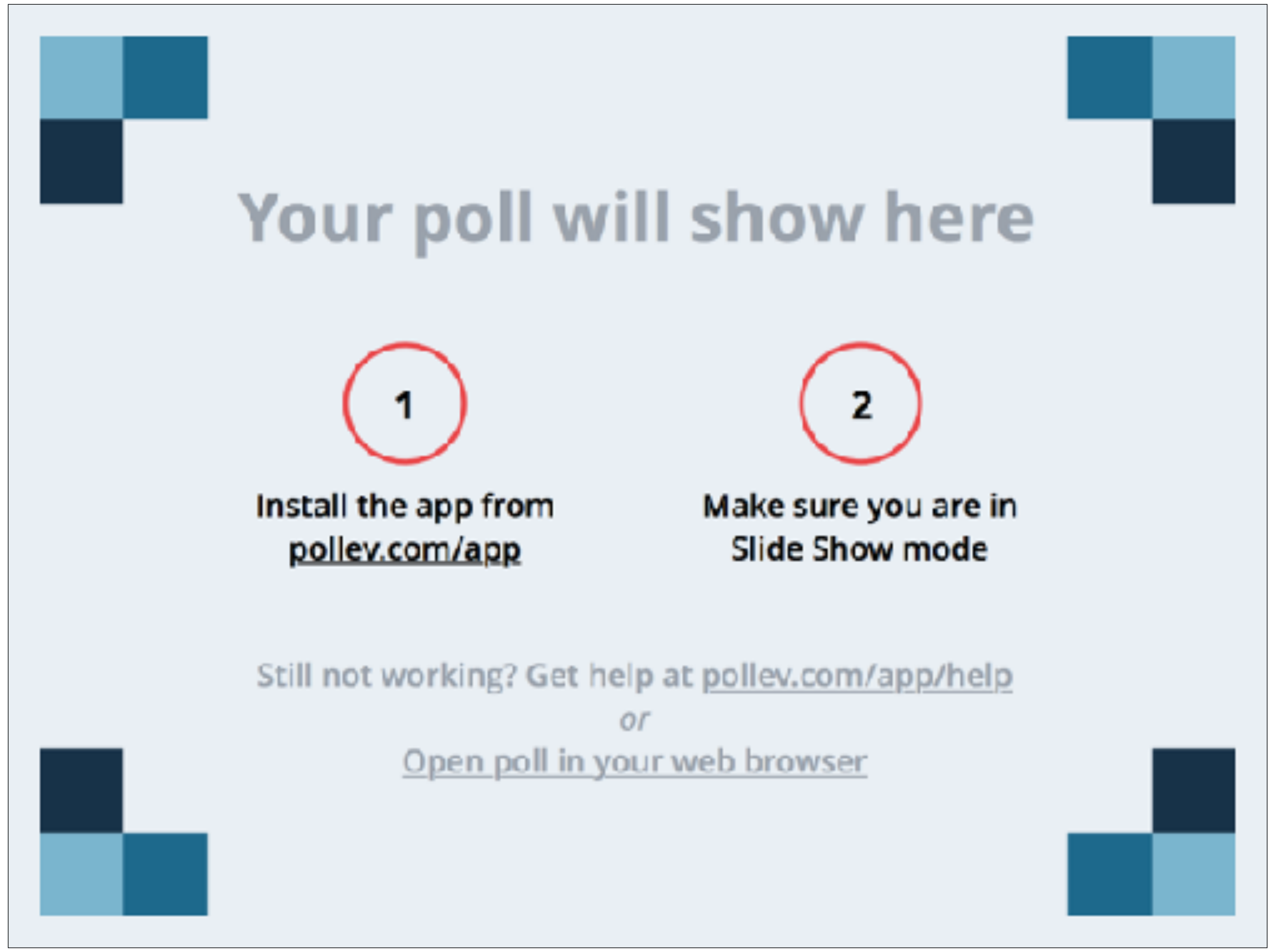
- http://www.cnn.com/TECH/space/9909/30/mars.metric.02/



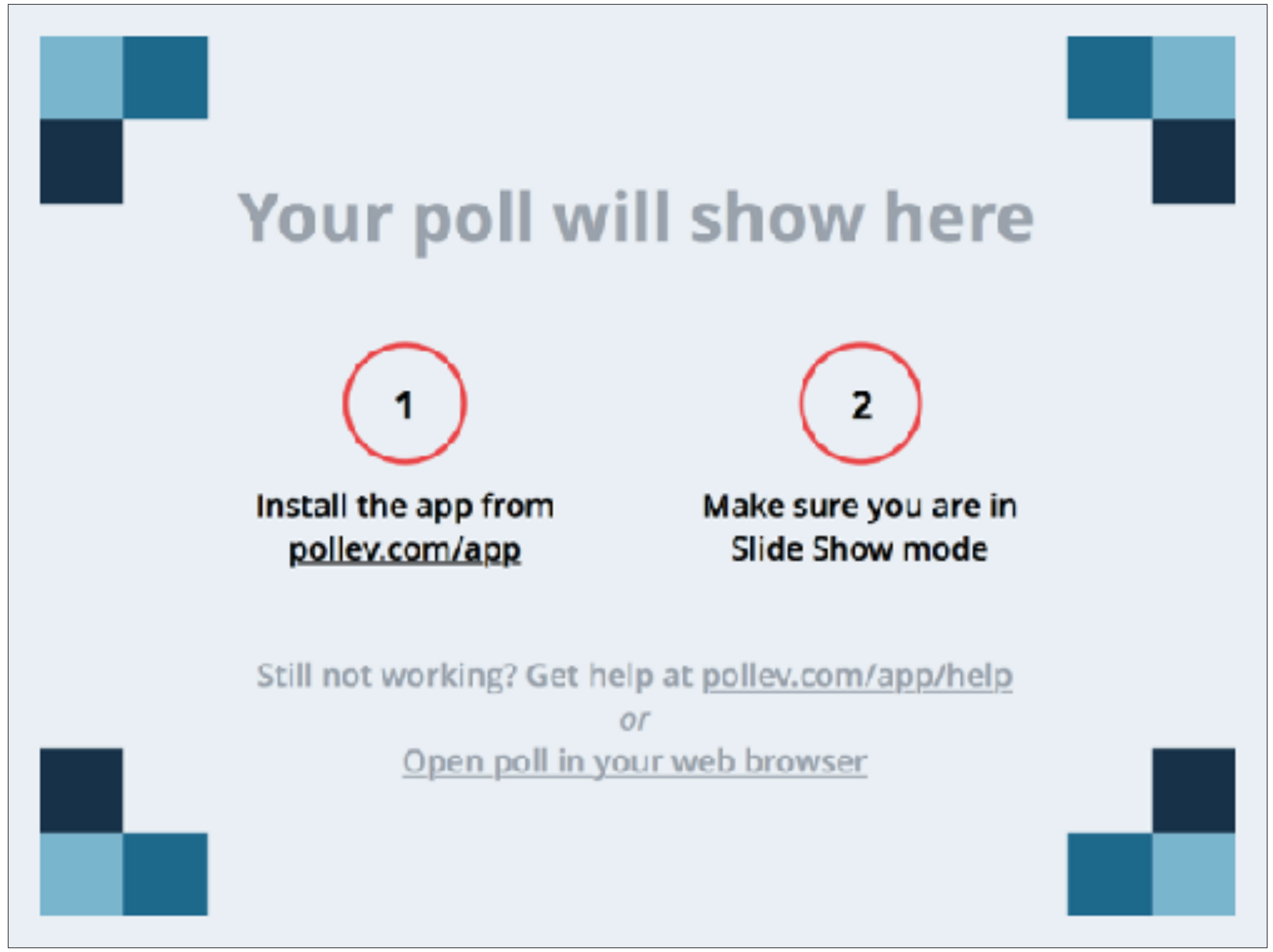
- A typical adult prescription of painkiller acetaminophen with codeine is 500 ___
- Answer: milligrams
- Consequences of being wrong: symptoms of overdose may include cold and clammy skin, extreme sleepiness progressing to stupor or coma, general bodily discomfort, heart attack, kidney failure, liver failure, low blood pressure, muscle weakness, nausea, slow heartbeat, sweating, and vomiting
- https://www.polleverywhere.com/multiple_choice_polls/pHPJvJvSzukkFrh



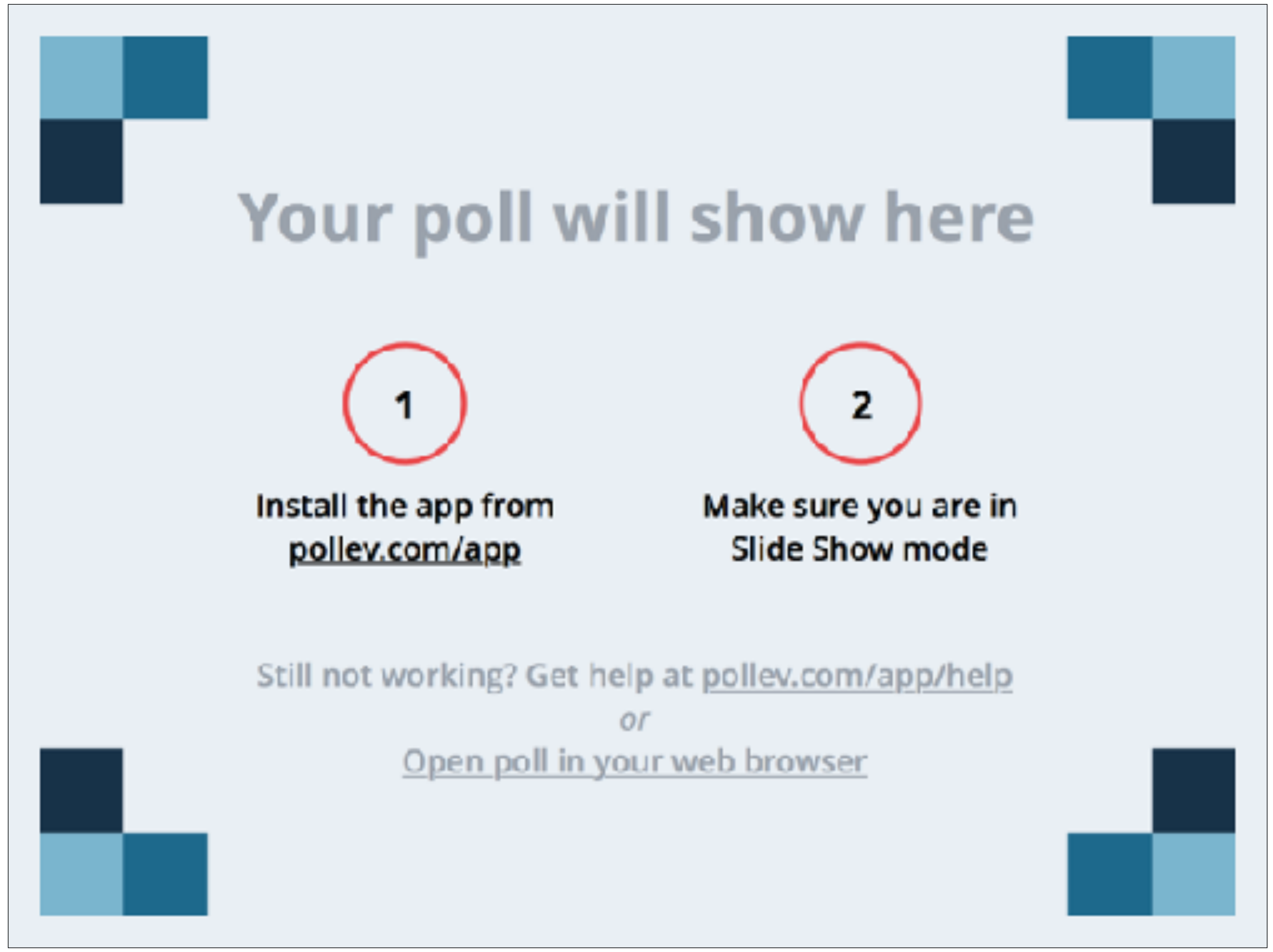
- The speed limit in school zones in Canada is 30 ___
- Answer: kilometers/hour
- Consequences of being wrong: speeding in a school zone may result in an accident or a significant fine
- https://www.polleverywhere.com/multiple_choice_polls/ZxJEa0DJFAHC4oi



- The recommended air pressure in many mountain bike tires is 60 ___
- Answer: pounds per square inch
- Consequences of being wrong: under-inflated tires puncture more easily, wear out faster, are more difficult to pedal, and don’t stop efficiently. Overinflated tires may blow out
- https://www.polleverywhere.com/multiple_choice_polls/ar3ZabF1GhP3KVQ



- Many physicians recommend that pregnant women take no more than 10,000 ___ of vitamin A per day
- Answer: international units
- Consequences of being wrong: excess vitamin A may give rise to birth defects, dry skin, scaly skin, headaches, fatigue, painful bones, and loss of appetite
- https://www.polleverywhere.com/multiple_choice_polls/wMFz6K36WoXBSFf



- Food scientists recommend that produce companies store apples, cherries, apricots, and most berries at 2 ___
- Answer: degrees Celsius
- Consequences of being wrong: storing these fruits at too high a temperature will result in ethylene production and early ripening. Storing them at too low a temperature will damage the integrity of the fruit
- https://www.polleverywhere.com/multiple_choice_polls/b3UzSL5s8jAsg0a