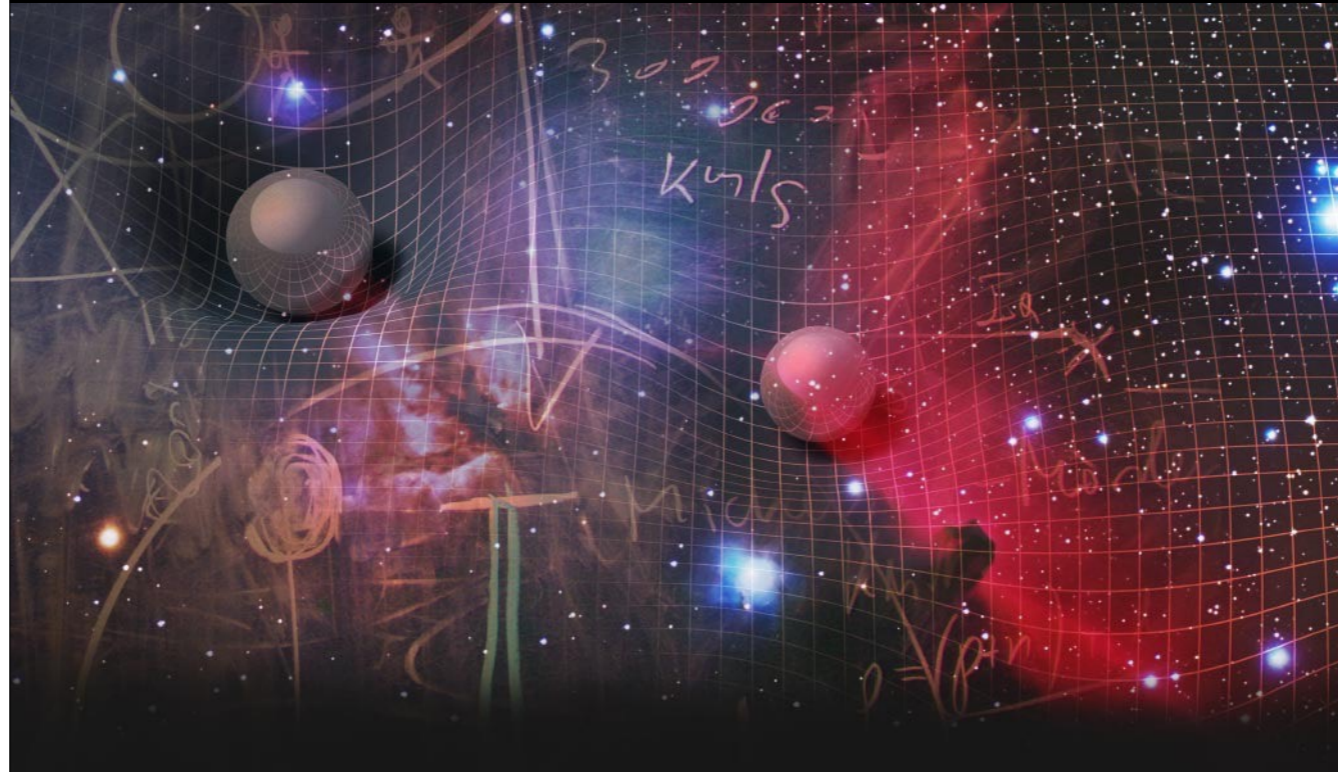


BOOK I: INTRO TO SCIENCE PRACTICES



THE ART OF ASKING QUESTIONS
& REASONING ANSWERS

CHAPTER 1: 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 him seems likely to yield the correct answer. In his attack on his specific problem he suffers no inhibition of precedent or authority, but is completely free to adopt any course that his ingenuity is capable of suggesting to him.”

–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

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

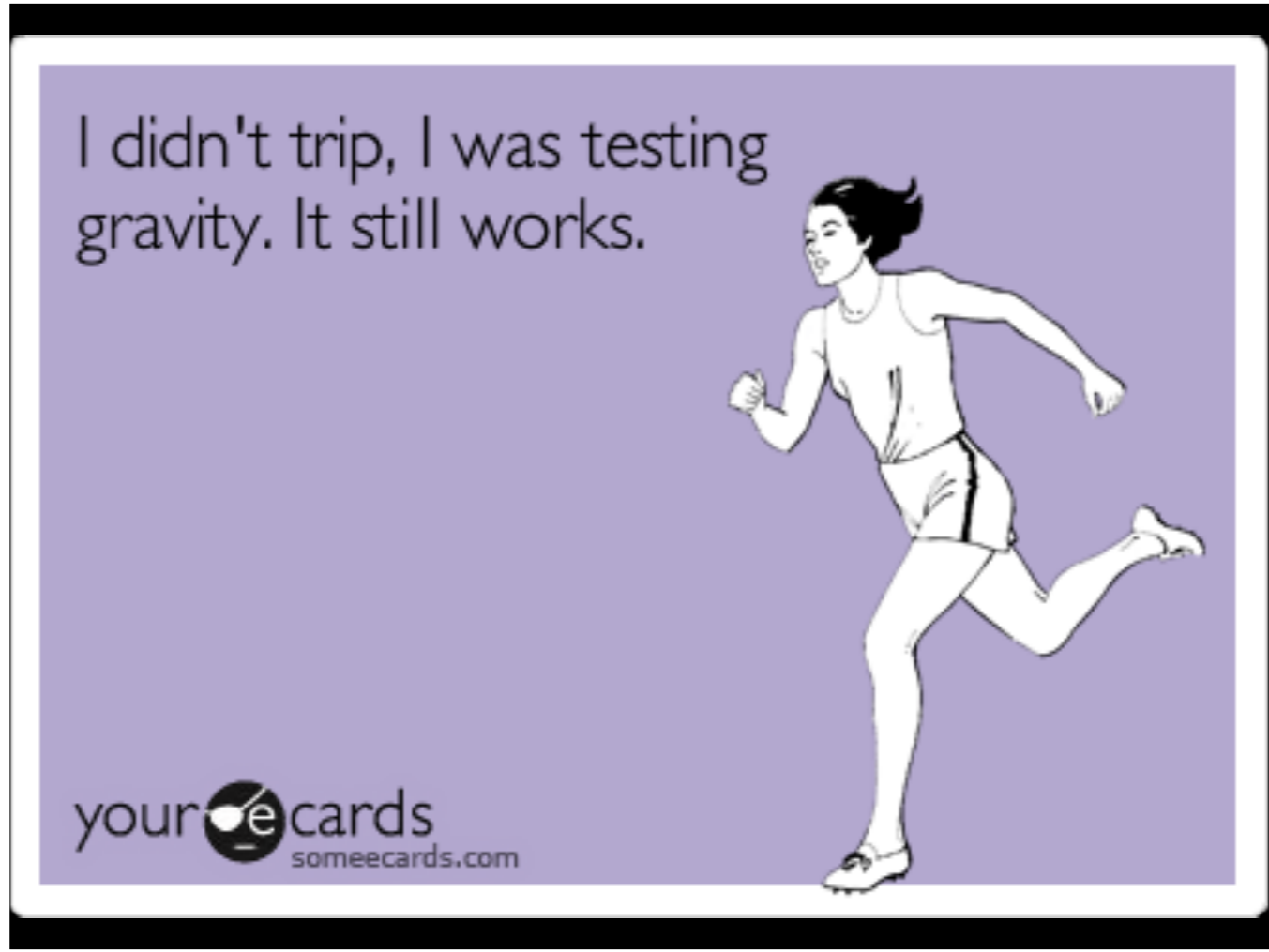
Inference — a conclusion drawn from evidence or reasoning based on observations

Observations & Inferences

Observations and Inferences - Teacher's Pet 2014

Click here to watch the video: <https://www.youtube.com/watch?v=fBIR7taW9jk>

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

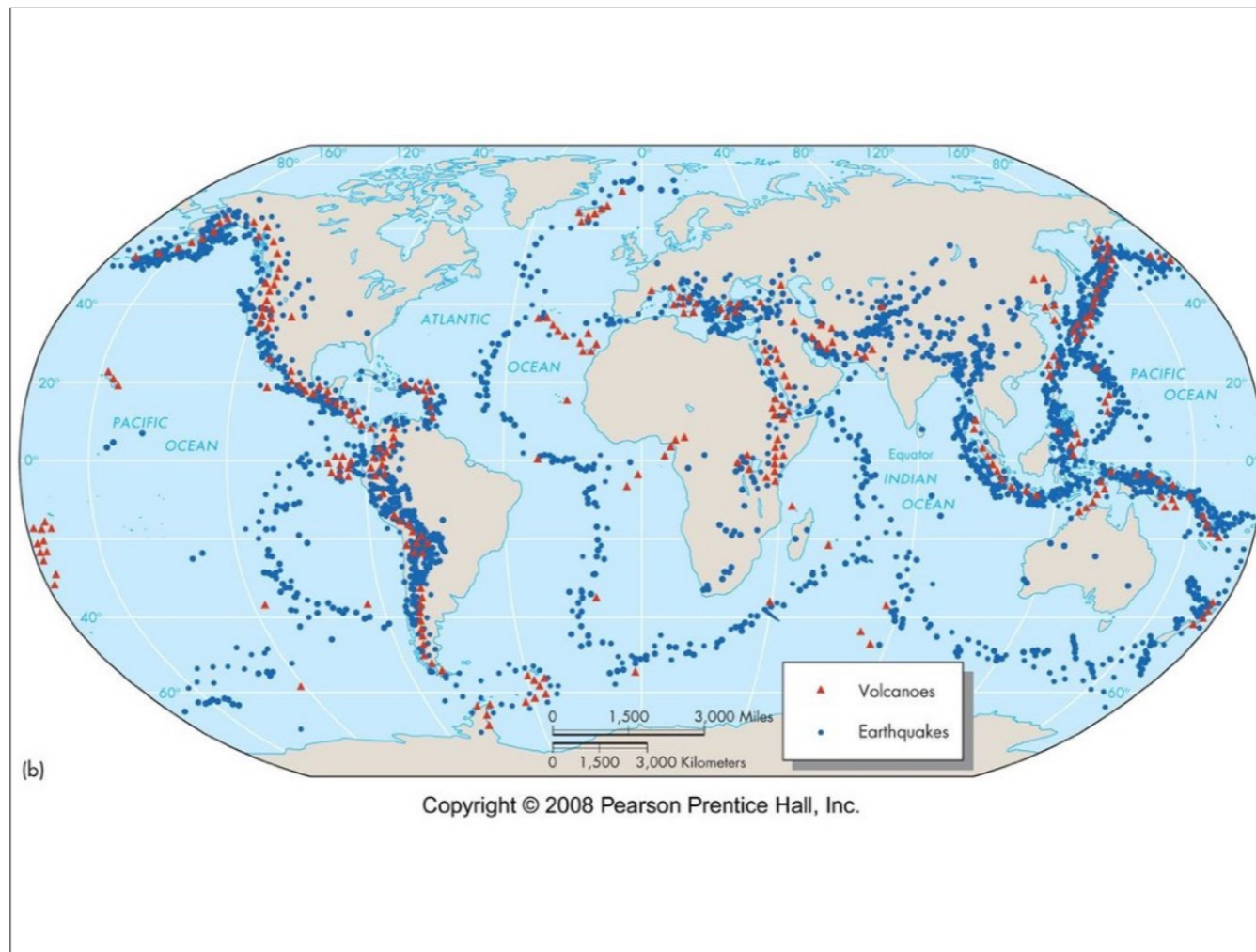


- Physicists have repeatedly measured the acceleration due to gravity at sea level to be 9.8 m/s^2 , and this value is now an accepted constant, even though it hasn't been tested everywhere that is at sea level on Earth's surface
- Inductive reasoning always leaves room for error or uncertainty

SCIENTISTS HAVE NOTED:

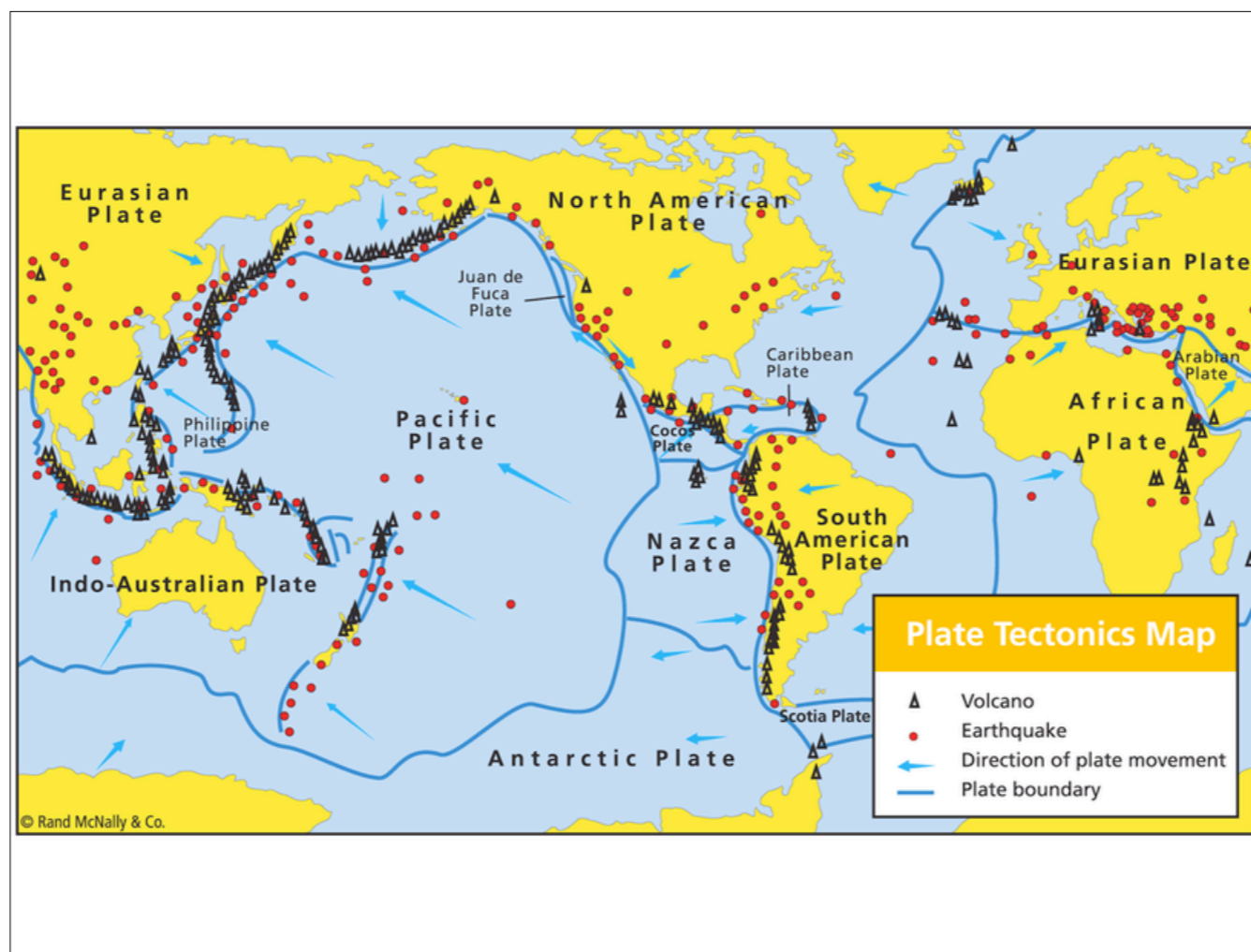
1. Ice in Greenland is melting faster than it is forming
2. The Northwest Passage is navigable for the first time in history, and
3. Antarctic ice is receding

- Based on these and other observations, scientists infer (using inductive reasoning) that global temperatures are rising



Volcanoes and Earthquakes, World Map

Notice any relationship between the locations of volcanoes and earthquakes around the world?



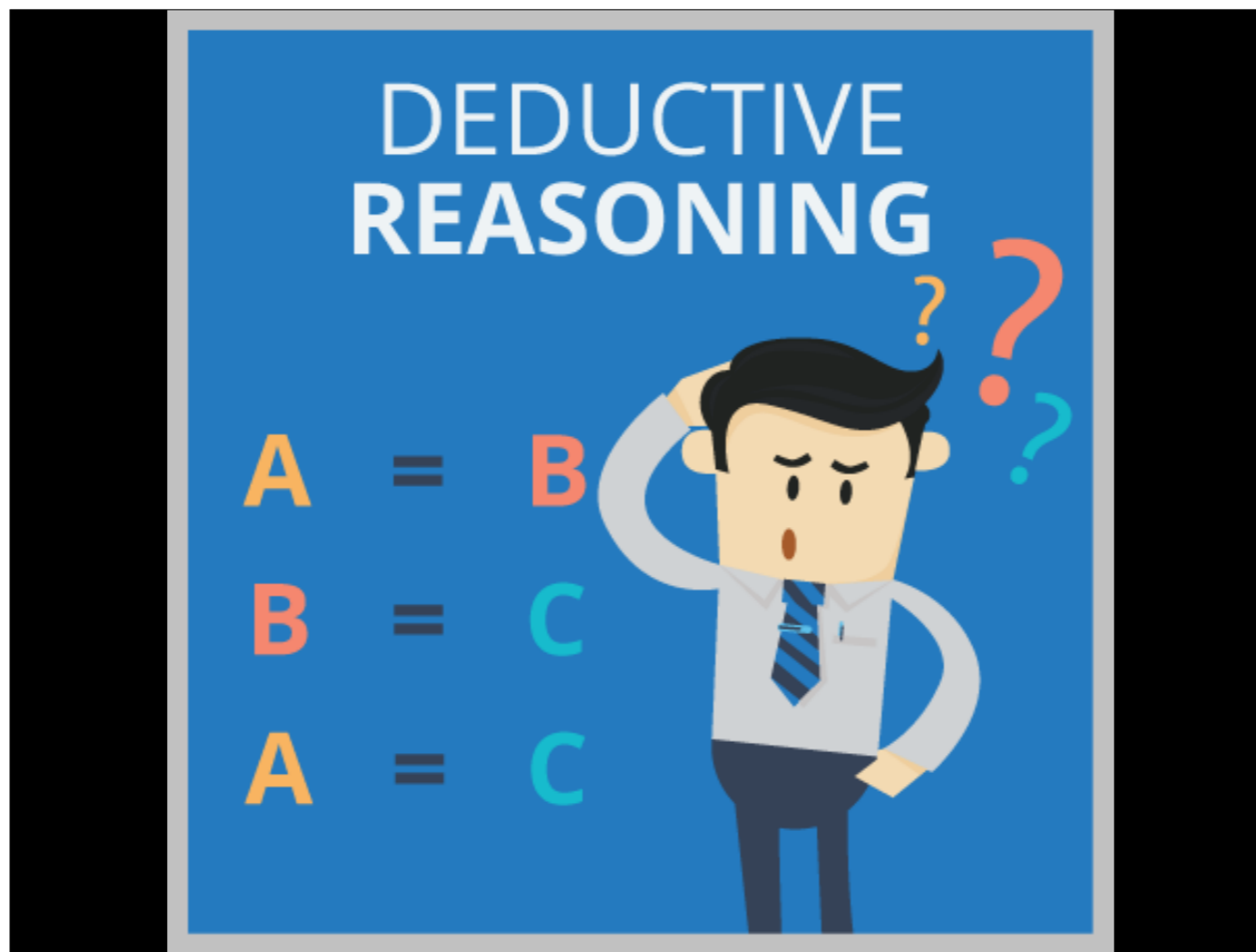
Volcanoes, Earthquakes, and Tectonic Plates, World Map

Can you inductive reasoning to generate a hypothesis to explain the relationship between the locations of volcanoes, earthquakes, and tectonic plates?

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



For more on deductive reasoning, check out <http://www.ilas.nagoya-u.ac.jp/~nilep/deductive.html>

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?
- Each of these are valid considerations which can change the answer dramatically

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 Fundy 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 is 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

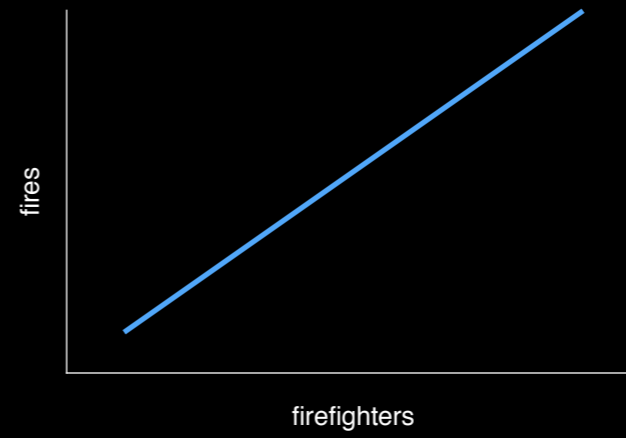
MATHEMATICS & UNITS OF
MEASUREMENT

CHAPTER 2: TOOLS OF THE TRADE



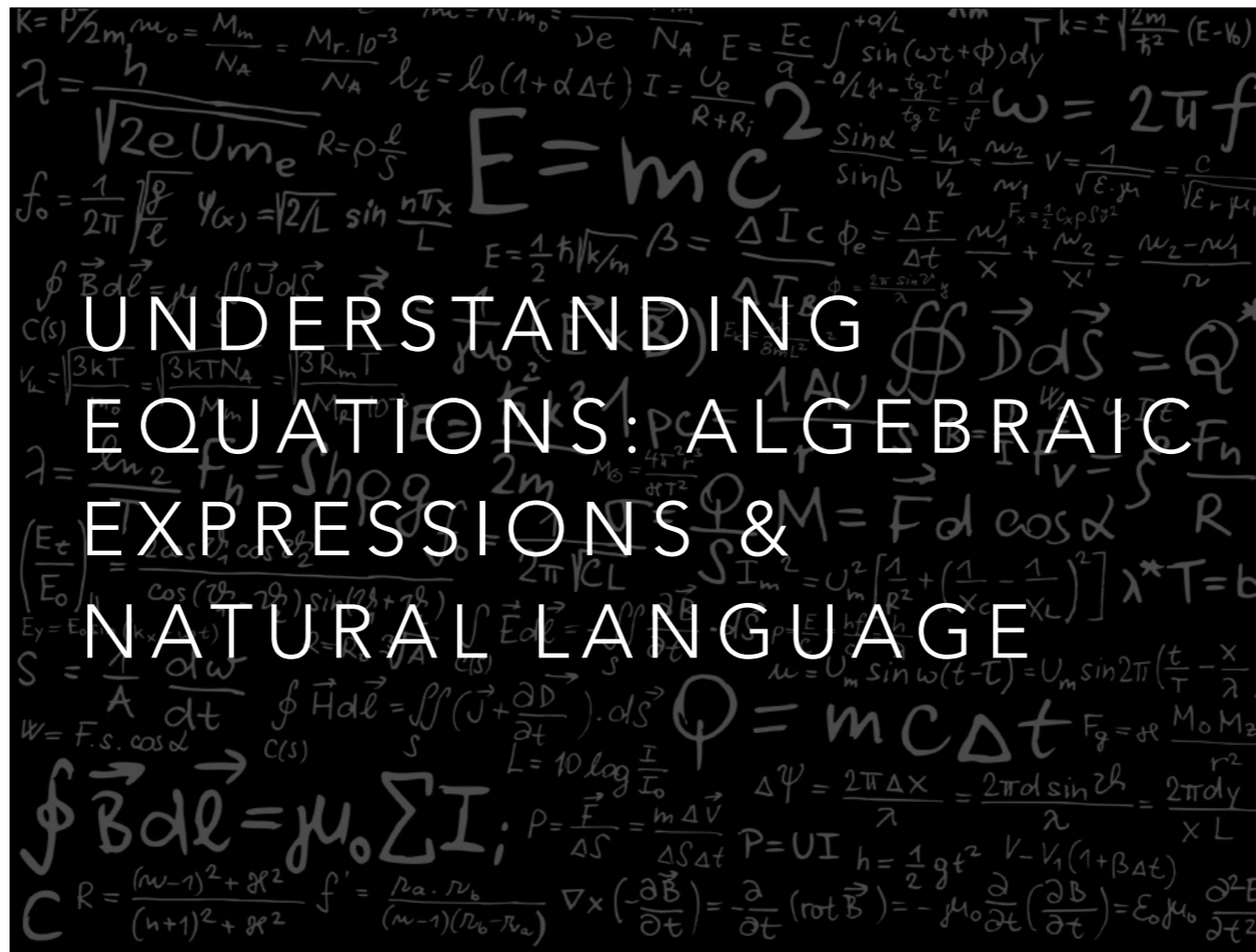
INTERPRETING GRAPHS

You're on the city council, and the fire commissioner comes to request more funding to hire additional firefighters. On the basis of this data, do you hire more firefighters?



Much confusion can be generated by not following the standard convention for plotting data. By convention, the independent variable should be plotted on the x-axis and the dependent variable on the y-axis.

- *Independent variable* — written on the x-axis of a graph. An independent variable is one that is unaffected by changes in dependent variable (e.g. when the influence of temperature on photosynthesis is examined, temperature on the independent variable because it doesn't depend on photosynthetic rate)
- *Dependent variable* — written on the y-axis of a graph. A dependent variable is dependent on changes in the independent variable (e.g. photosynthesis is dependent on temperature)
- *Constants* — factors held constant or unchanged while the dependent variable is tested (e.g. if a food scientist is studying the relationship between the concentration of preservative and the growth rate of bread mold, it is important that temperature, humidity, light, and other factors be the same for all bread used in the study)
- *Controls* — a specimen that is not subjected to procedures affecting the rest of the experiment, thus acting as a standard against which the results are compared



UNDERSTANDING EQUATIONS: ALGEBRAIC EXPRESSIONS & NATURAL LANGUAGE

Equations use the language of mathematics to describe the relationship between quantities. As with any other language, when you first start learning it, it can stand a little translation

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

- Newton's Law of Gravitation, written as an algebraic expression

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. Translating from natural language to algebraic expression transforms this block of text into a short line that contains all the same information

“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 its distance from the Sun and runs the numbers through its internal calculator to figure out far it should move
- That said, the utility of an equation is in its predictive power. Once you know *how* the planets move, you can predict where they'll be even thousands of years into the future

S.I. UNITS

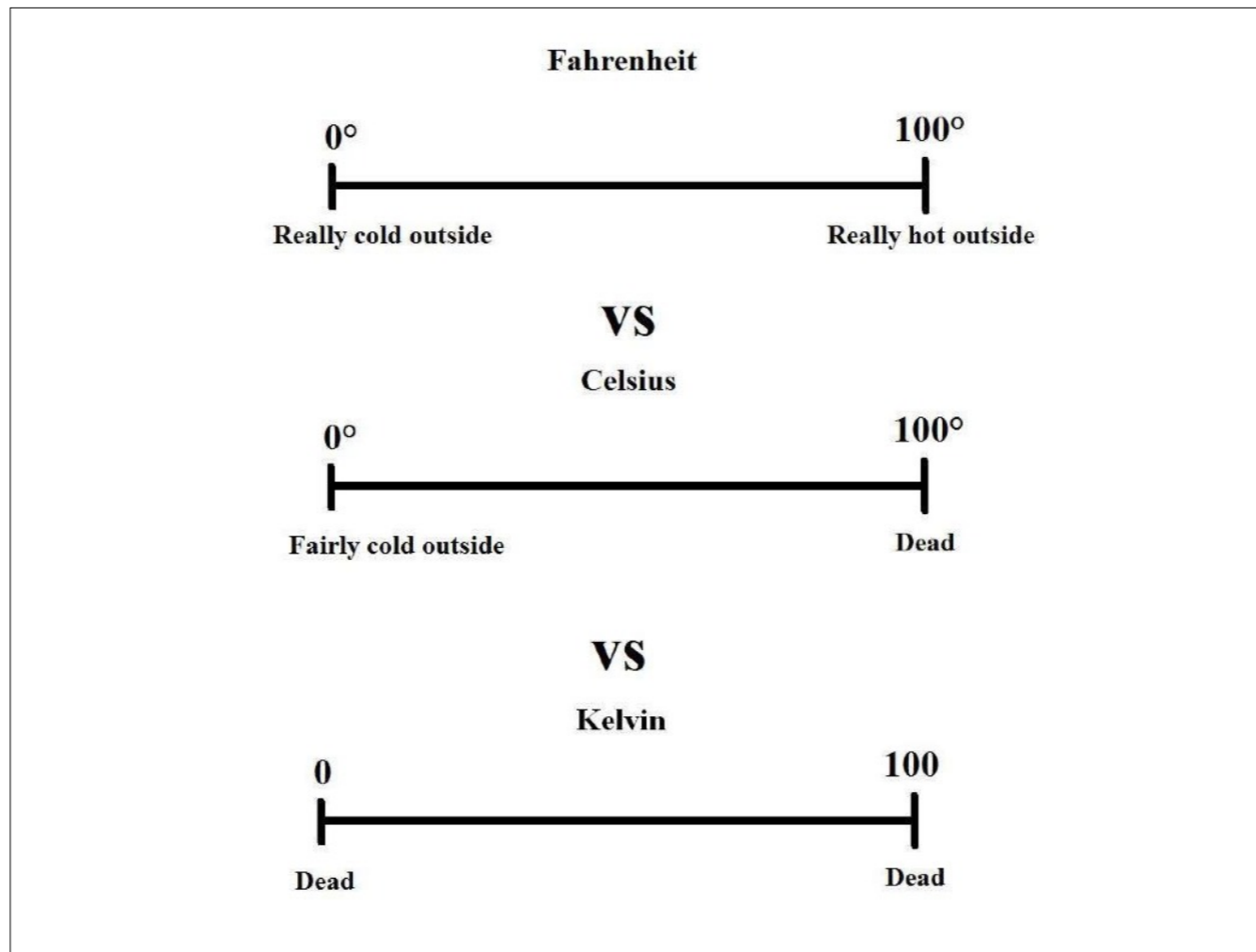
- Common, agreed upon units of measurement
 - Length: meter (m)
 - Mass: kilogram (kg)
 - Electric charge: coulomb (C)
 - Temperature: kelvin (K)
 - Time: second (s)
- And a bunch of derived units that we'll learn as we go along

The International System of Units (**SI**, abbreviated from the French *Système International (d'unités)*) is the modern form of the metric system. It is the only system of measurement with an official status in nearly every country in the world. (That's *nearly* every country. Can you guess who's still holding out?)

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}

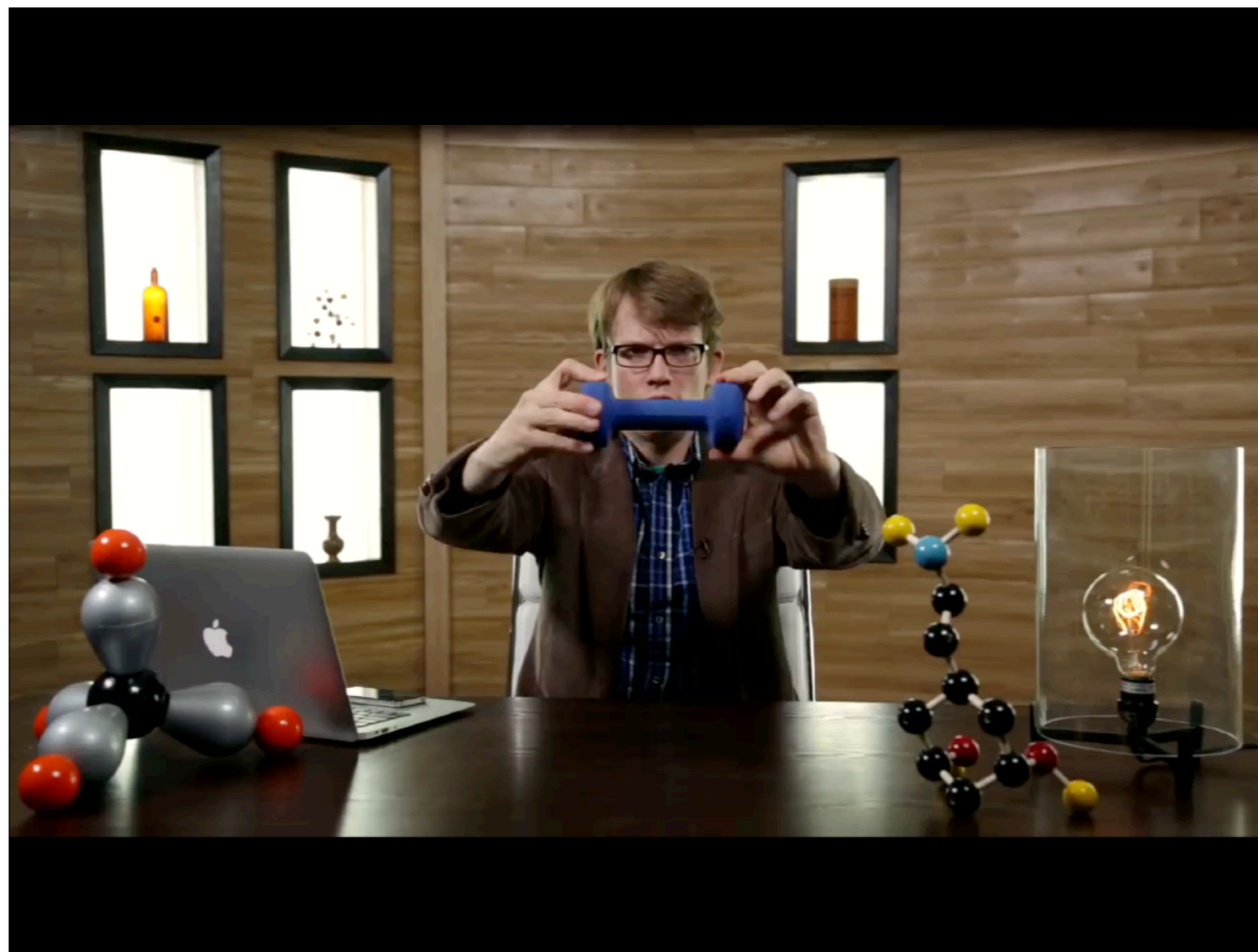
- 1 m = 100 cm = 1000 mm = 0.001 km
- 1 g = 100 cg = 1000 mg = 0.001 kg



- Establish new reference points
- When you hear "26 °C," instead of thinking "That's 79 °F" think "That's warmer than a house but a little cool for swimming"

CURB YOUR INTUITION

TEMPERATURE		LENGTH		MASS	
60°C	Earth's hottest	1 cm	Width of microSD	3 g	Peanut M&M
45°C	Dubai heat wave	3 cm	Length of SD card	100 g	Cell phone
40°C	S. US heat wave	12 cm	CD diameter	500 g	Bottled water
35°C	N. US heat wave	15 cm	BiC pen	1 kg	MacBook Air
30°C	Beach weather	80 cm	Doorway width	2 kg	15" MacBook Pro
25°C	Warm room	1 m	Lightsaber blade	3 kg	Heavy Laptop
20°C	Room	170 cm	Summer Glau	5 kg	LCD monitor
10°C	Jacket weather	200 cm	Darth Vader	15 kg	CRT monitor
0°C	Snow!	2.5 m	Ceiling	4 kg	Cat
-5°C	Cold day (Boston)	5 m	Car-length	60 kg	Lady
-10°C	Cold (Moscow)			70 kg	Dude
-20°C	itscolditscolditscold			150 kg	Shaq
-30°C	Aaaaggggghhhh!	16.04 m	Human tower of the <i>Serenity</i> crew	200 kg	Your mom
-40°C	Spit goes "clink"				



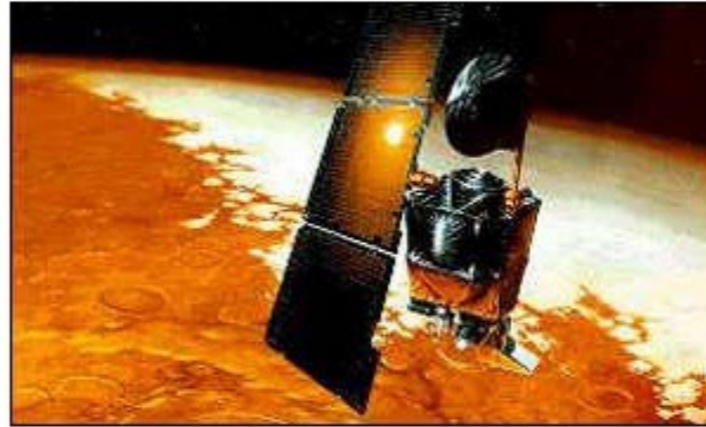
Unit Conversion & Significant Figures - Crash Course 2013

Click here to watch the video: <https://www.youtube.com/watch?v=hQpQ0hxVNTg>

P.S. These tools apply just as much to Physics as Chemistry. Unit conversions and sig figs have their place in all the sciences

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.

- A cautionary tale on the importance of units: <http://www.cnn.com/TECH/space/9909/30/mars.metric.02/>

A typical adult prescription of painkiller acetaminophen with codeine is 500 ____

- A. tablets
- B. grams
- C. milligrams
- D. ounces
- E. milliliters

- 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

The speed limit in school zones in
Canada is 30 ____

- A. miles/hour
- B. kilometers/hour
- C. feet/second
- D. meters/second
- E. yards/second

- Answer: kilometers/hour
- Consequences of being wrong: speeding in a school zone may result in an accident or a significant fine

The recommended air pressure in many mountain bike tires is 60 ____

- A. pascals
- B. kilopascals
- C. pounds per square inch
- D. torr
- E. millimeters mercury

- 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

Many physicians recommend that pregnant women take no more than 10,000 ___ of vitamin A per day

- A. grams
- B. milligrams
- C. ounces
- D. international units
- E. microliters

- 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

Food scientists recommend that produce companies store apples, cherries, apricots, and most berries at 2 ____

- A. degrees Fahrenheit
- B. Kelvin
- C. degrees Celsius
- D. degrees Rankine
- E. degrees Reaumur

- 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

- ***Dimensional analysis*** is a general problem solving method that uses the dimensions (units) associated with numbers as a guide in setting up and checking calculations.

Remember, units obey all the same rules of algebra as numbers or variables, so you can treat them the same way

$$d = r \cdot t \quad r = 5 \frac{\text{m}}{\text{s}} \quad t = 10 \text{ s}$$

$$d = 5 \frac{\text{m}}{\text{s}} \cdot 10 \text{ s} = \underbrace{5 \cdot 10}_{50} \cdot \frac{\text{m}}{\text{s}} \cdot \text{s} = 50 \text{ m}$$

$$r = 5 \frac{\text{m}}{\text{s}} \quad t = 1 \text{ h}$$

$$d = 5 \frac{\text{m}}{\text{s}} \cdot 1 \text{ h} = 5 \frac{\text{m}}{\text{s}} \cdot \frac{3600 \text{ s}}{1 \text{ h}} = 18000 \text{ m}$$

$$18,000 \text{ m} \cdot \frac{1 \text{ km}}{1000 \text{ m}} = \underline{18 \text{ km}}$$

Treating units algebraically and dimensional analysis - Khan Academy 2014

Click here to watch the video: <https://www.youtube.com/watch?v=hIAdCTNi1S8>