Chapter 01

What is Science?

HAIL SCIENCE

So, what *is* science?

A) A search for order and explanation of our physical surroundings.

B) A method of gathering, categorizing, analyzing, and using information to explain the physical universe.

C) A static collection of unchanging facts.

D) A rigid set of unchanging rules.

E) A and B, but not C and D.

Section 1.1

Objects and Properties

Objects: Concrete vs Abstract

- Is it a ***thing*** or an ***idea***? An object is a thing.

- A thing is made of atoms; a thing actually exists (whether or not you personally can make it or touch it or see it is not actually relevant here)

- An idea is an abstraction; it may represent and actual object without being the object, or it may just be a thought without physical reality

Properties: Describe and Define

What am I thinking of???

- "Qualities or attributes that, taken together, are usually peculiar to an object."

- Play 20 Questions: Animal, vegetable, or mineral? Is it bigger than a breadbox?

- Start with the most general, move towards the specific.

- What kind of information do you want?

Properties: Describe and Define

- Animal, vegetable, or mineral?

  ✓ Animal

- Is it bigger than a tabletop?

  ✓ Fits on a table

- Is it alive?

  ✓ Yes

- How many legs does it have?

  ✓ Twelve

- How many questions does it take to reach the *specific* conclusion: A basket of three chocolate labradoodle puppies?

Section 1.2
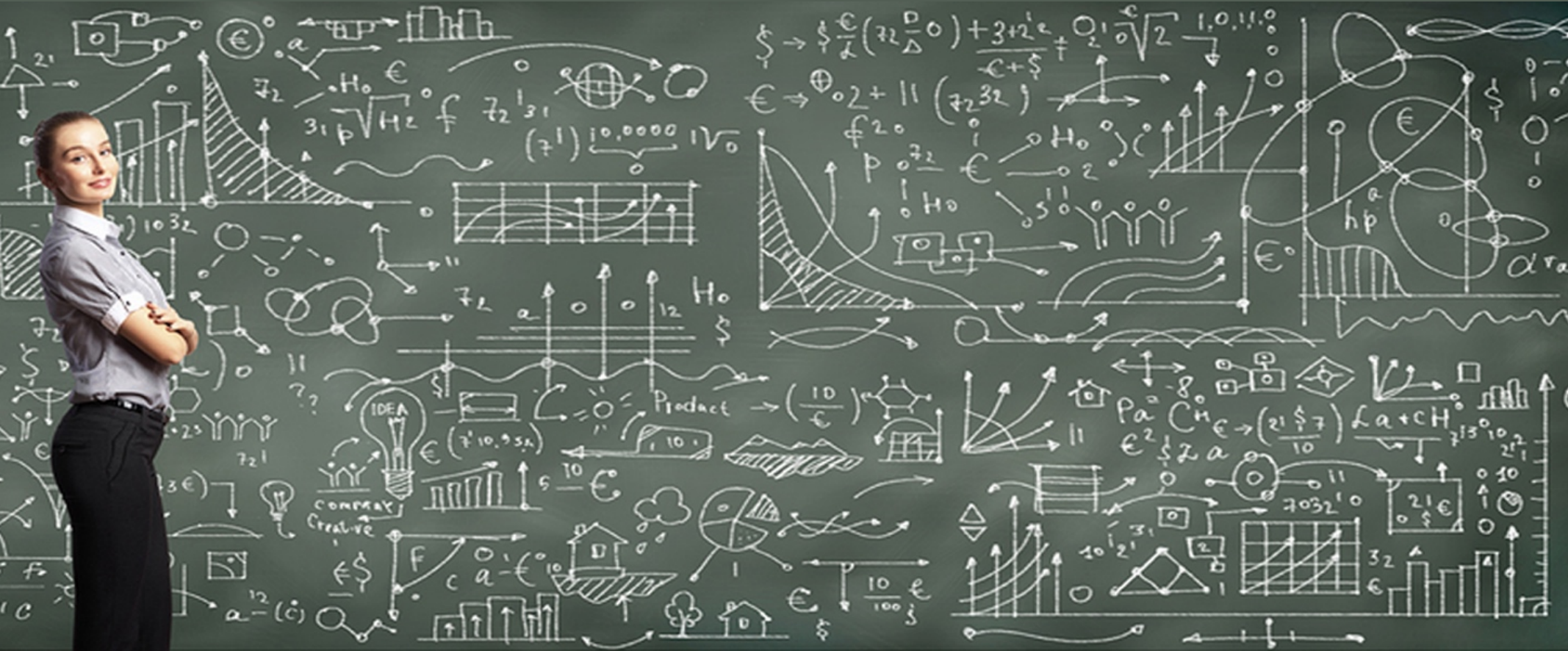
Quantifying Properties

True or
False:

Ben-Hur is
the greatest
movie of all
time!

What is measurable? What really can't be objectively measured?

- You can't objectively measure or quantify something like "What's the best movie of all time?"

- You *can* objectively measure or quantify something like, "What movie has won the most Academy Awards?"

- The fact that *Ben-Hur*, *Titanic*, and *LOTR: Return of the King* each won 11 Oscars does not make them the greatest films of all time

Pro Tip: Units Matter!

- In general, measurements need units

- Question: How long was Titanic?

- Answer: 195 or maybe 3.25; both 882.75 and 269.06 could be correct
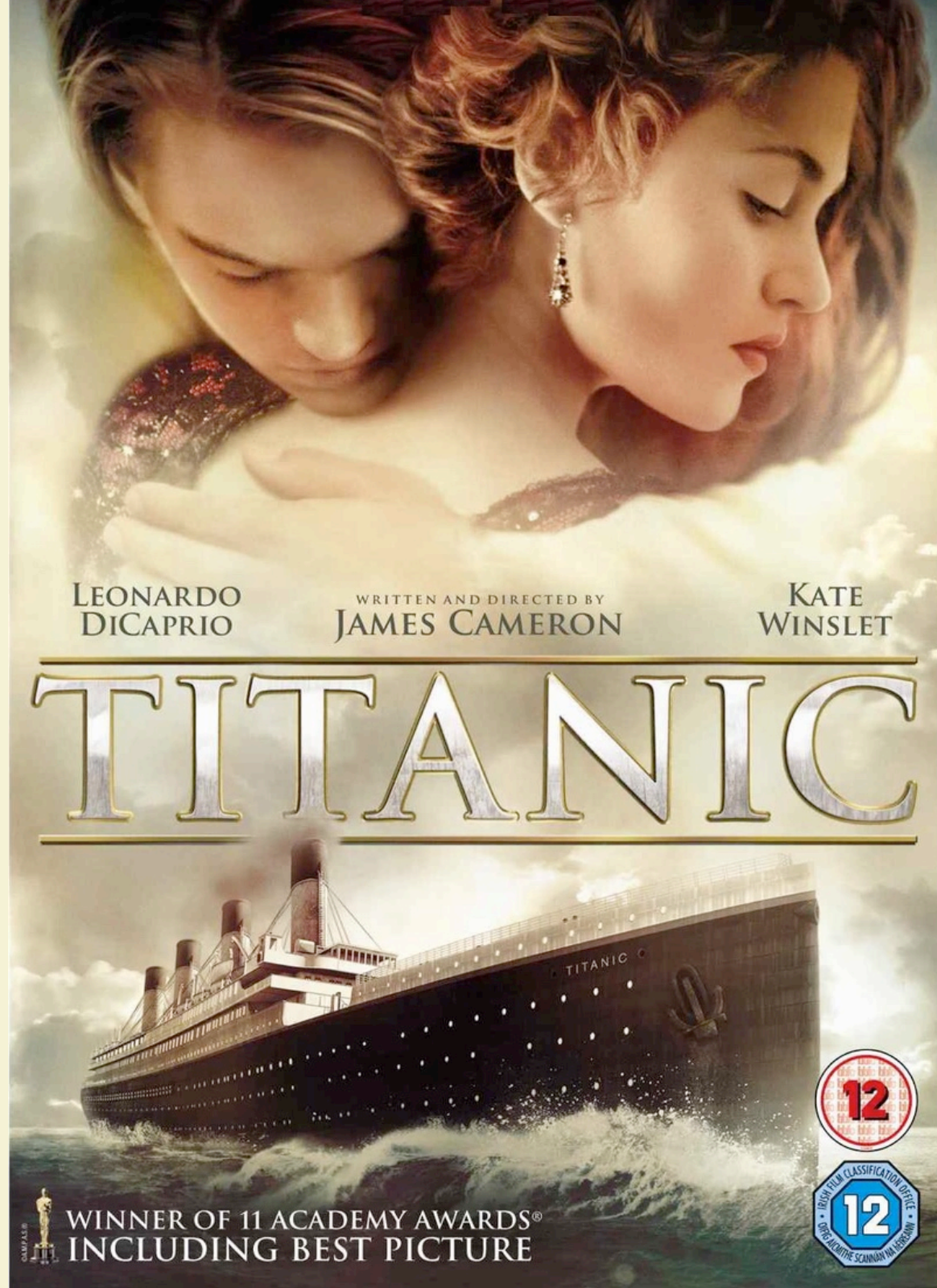
Section 1.3

Measurement Systems

Referent Refers to What?

- *Exactly*

- Everyone has to agree on the same referent, or a measurement is completely meaningless

- It doesn't have to be high-tech (the pyramids were not, in fact, built by aliens)

The unit of length known as the foot is derived from

A) the actual length of a typical human foot.

B) the average length of a human stride.

C) the distance between your feet if you stand with them centered over your hipbones.

D) the standard length of a roll of paper (*foolscap*, used in the late Renaissance).
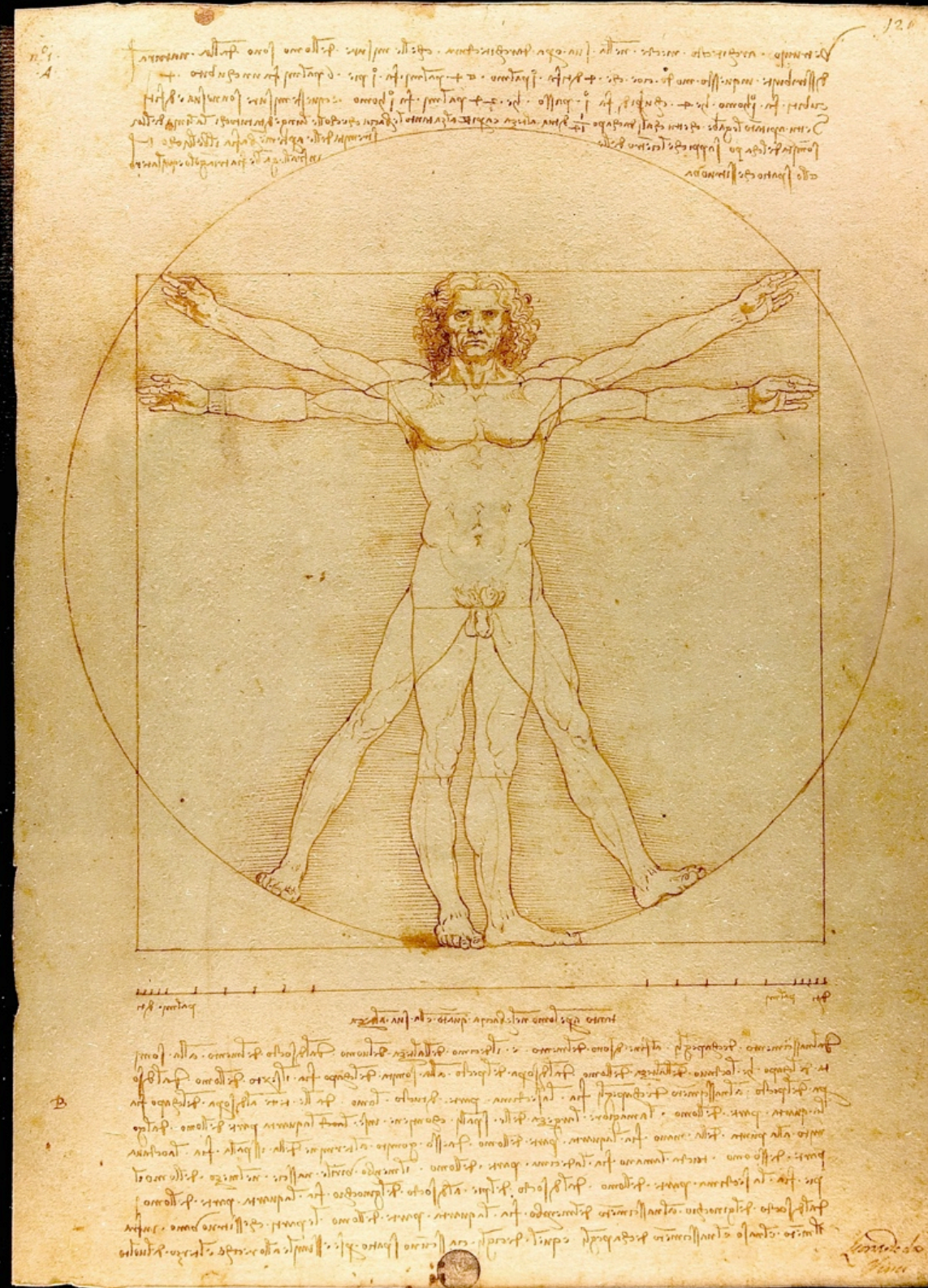
English (Imperial) System of Units

- Developed over centuries

- Convenient (but inconsistent) human body referents

Metric System (Système Internationale, or SI)

- Decimals! So easy, even 16th century mathematicians can use them!

- Like everything, developed gradually over time

- Thanks for the units, now off with your head!*

*Not kidding: Antoine Lavoisier, 1743-1794. *Thanks a lot*, Robespierre!

Usage des Nouvelles Mesures.

J.P. Delion 6..... inv.   Labrousse Sculp.

1. le Litre (*Pour la* Pinte)   4. l'Are (*Pour la* Toise)
2. le Gramme (*Pour la* Livre)   5. le Franc (*Pour une* Livre Tournois)
3. le Mètre (*Pour l'* Aune)   6. le Stere (*Pour la* Demie Voie de Bois)

Section 1.4

Standard Units

True or false:

The unit of force (the Newton) is a fundamental unit.

Fundamental vs Derived Units

QUANTITY	SYMBOL	UNIT	ABBREVIATION
Length	l, d, h, s, x, y	meter	m
Time	t	second	s
Mass	m	kilogram	kg
Amount of Substance	n	mole	mol
Temperature	T	kelvin	K
Electric Current	I	ampere	A
Luminous Intensity	l_v	candela	cd

- Fundamental Units: length, mass, time, electric charge

- Derived Units: velocity, force, energy, current, voltage

Length

- 1 meter = 39.4 inches = 3.28 feet
- Area= $l{\times}w$ = L^2 = m^2
- Volume = $l{\times}w{\times}d$ = L^3 = m^3

METRE

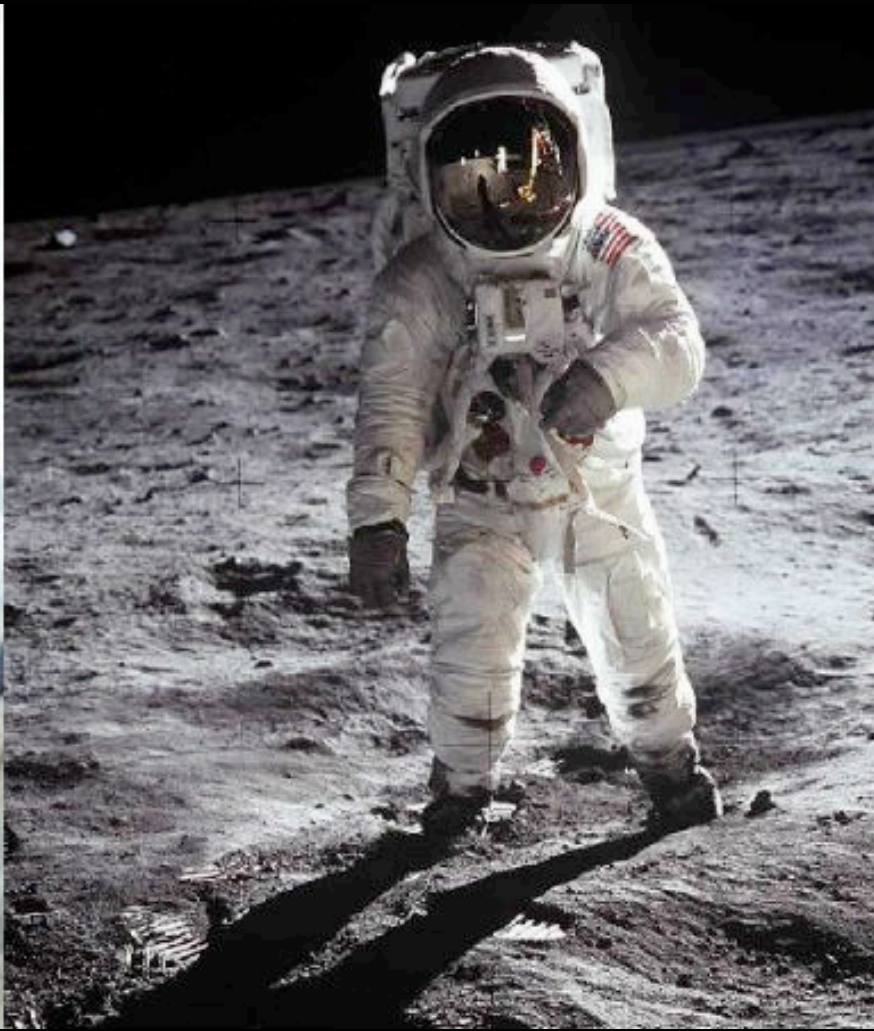# Mass

- 1 kilogram = 2.2 pounds
- This is a pretty poor equivalence!
- Mass (kg) $\neq$ weight (lbs)

An astronaut on Earth weighs 170 lbs, making his mass 77kg. On the moon, he has

A) the same mass, but less weight.

B) the same mass and the same weight.

C) a different mass, but the same weight.

D) a different mass and a different weight.

Time

- How long is 1 metric second?

- Trick question! A second is a second is a second

- 1 second = the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom

size/m

particle tracks

ring of iron atoms

printed circuit board

two humans

The Wash

the northern half of the sky
at microwave wavelengths

a cluster of galaxies

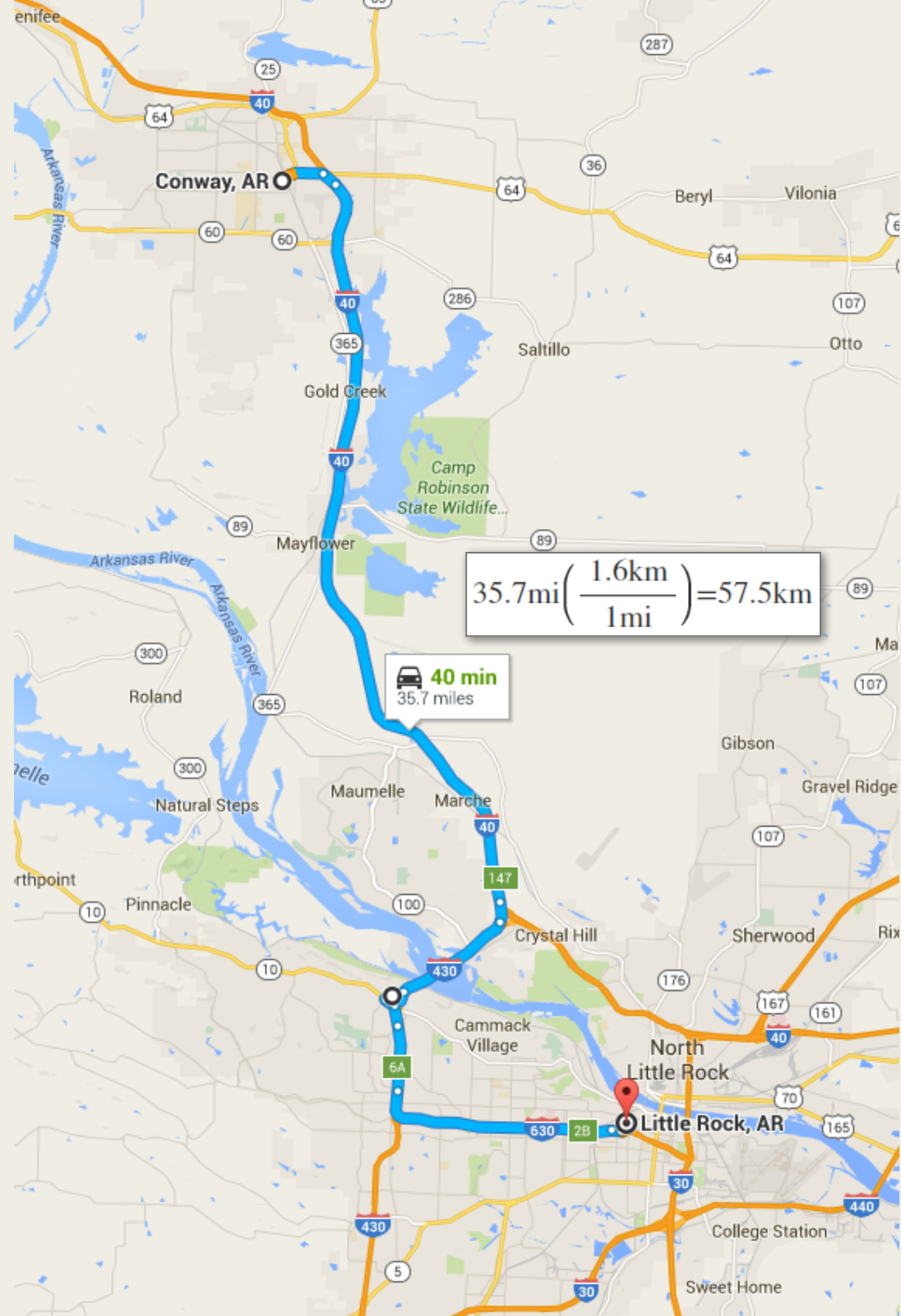a spiral galaxy

The Earth
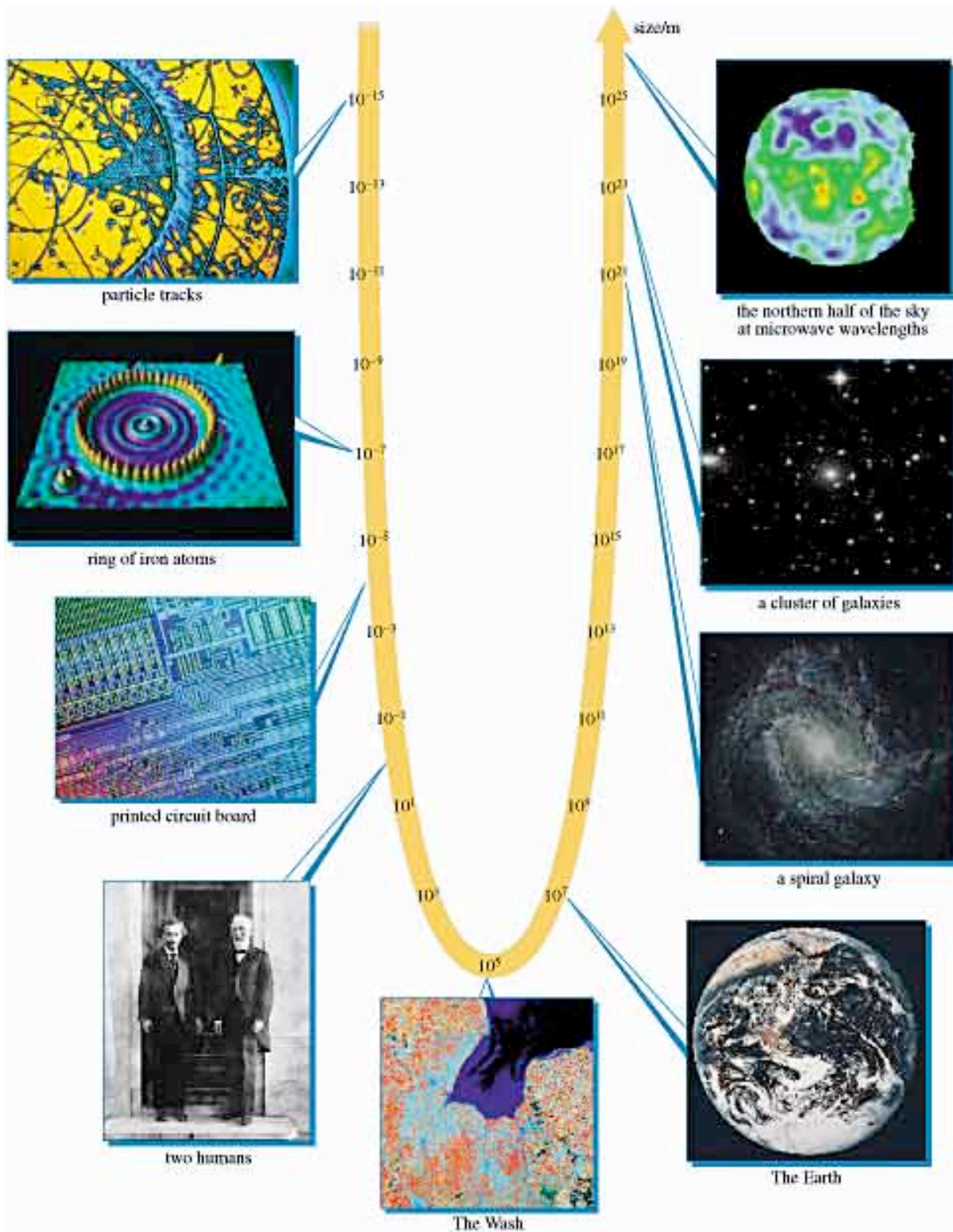
Section 1.5

Metric Prefixes

Scale the Unit to the Measurement

- What's the distance from here to Little Rock?

- Why not express that in feet? Inches?

- Imperial conversions are hard! (Metric is easy!)

$$35.7\text{mi}\left(\frac{1.6\text{km}}{1\text{mi}}\right)=57.5\text{km}$$

40 min
35.7 miles

Learn a Few Easy Prefixes

AGAVE
1–2 METERS

1 METER =
1,000,000,000 NANOMETERS

1m

SNOWFLAKE
2–6 MILLIMETERS

1 MILLIMETER =
1,000,000 NANOMETERS

1mm

POLLEN
6–100 MICROMETERS

1 MICROMETER =
1,000 NANOMETERS

1μm

NANOSTRUCTURE
10 NANOMETERS
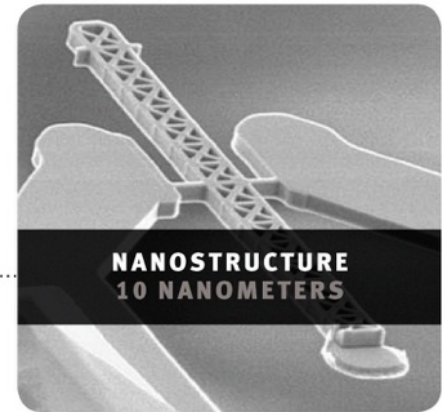
1 NANOMETER =
10^{-9} METERS

1nm

- nano = 0.000000001 = 10^{-9}
- milli = 1/1000 = 0.001 = 10^{-3}
- centi = 1/100 = 0.02 = 10^{-2}
- deci = 1/10 = 0.1 = 10^{-1}

- kilo = thousand = 1000 = 10^{3}
- mega = million = 1,000,000 = 10^{6}
- giga = billion=1,000,000,000=10^{9}
- tera = trillion = 10^{12}

You want to measure the length and width of a floor tile. What units would be most appropriate?

AGAVE 1–2 METERS	**SNOWFLAKE** 2–6 MILLIMETERS	**POLLEN** 6–100 MICROMETERS	**NANOSTRUCTURE** 10 NANOMETERS
1 METER = 1,000,000,000 NANOMETERS	1 MILLIMETER = 1,000,000 NANOMETERS	1 MICROMETER = 1,000 NANOMETERS	1 NANOMETER = 10^{-9} METERS
1m	**1mm**	**1µm**	**1nm**

A) nanometers = 10^{-9}m

B) centimeters = 10^{-2}m

C) kilometers = 10^{3}m
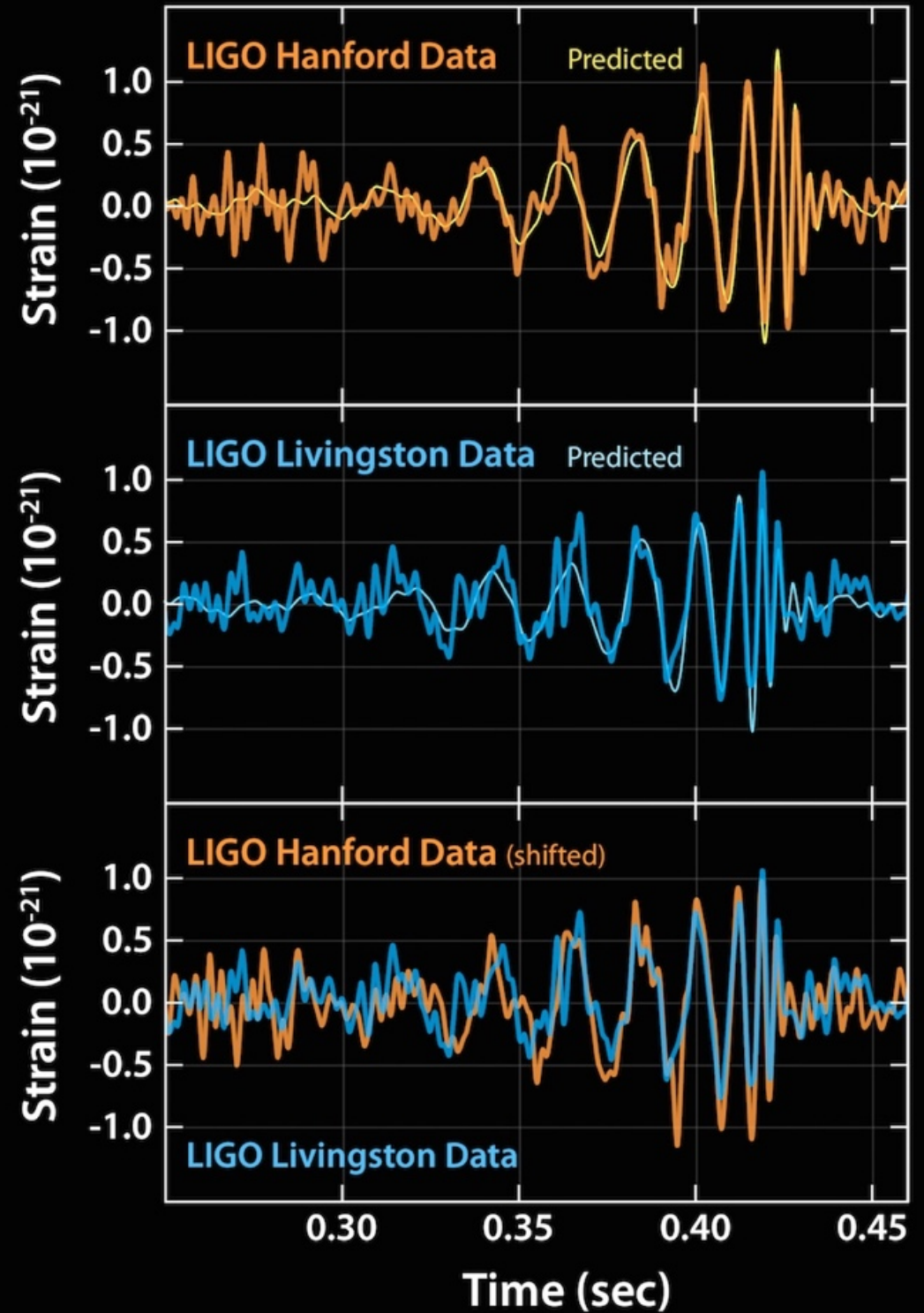
D) kilograms = 10^{3}g

E) megabytes = 10^{6}bytes

F) gigabytes = 10^{9}bytes

Section 1.6

Understanding From Measurements

And Now I Bring You...the Weather

- How do you make sense of all those numbers!?!?!

- Units: temperature in °F, barometric pressure in mb (millibars), etc.

- Context: your experience informs how you interpret the numbers

Data

- A collection of information: might be qualitative or quantitative

- One piece of data is a snapshot; you need multiples to extract meaning

- Cross-sectional: same snapshot at the same time for a large number of subjects

- Longitudinal: same snapshot of the same subjects, repeated over a period of time

TABLE 2. Doctorates awarded, by major field of study: 1995–2004
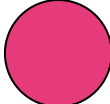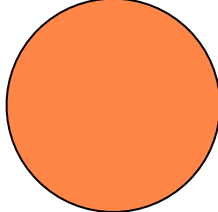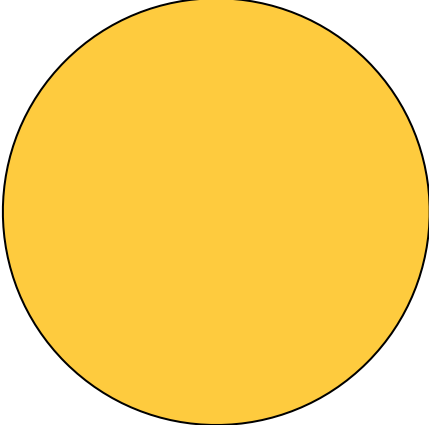
Field	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
All fields	41,750	42,439	42,541	42,647	41,092	41,365	40,824	39,989	40,770	42,155
Science and engineering	26,536	27,241	27,232	27,278	25,933	25,966	25,548	24,588	25,289	26,275
Science	20,528	20,932	21,117	21,354	20,603	20,645	20,043	19,512	20,011	20,499
Agricultural sciences	1,117	1,118	1,078	1,110	1,065	1,038	975	1,009	1,061	1,046
Biological sciences	5,376	5,724	5,789	5,845	5,582	5,854	5,691	5,690	5,697	5,937
Computer sciences	997	920	909	927	856	859	826	807	865	949
Earth, atmospheric, and ocean sciences	699	711	782	741	706	663	630	673	646	672
Mathematics	1,190	1,122	1,123	1,177	1,083	1,050	1,007	918	994	1,075
Physical sciences	3,841	3,839	3,769	3,824	3,579	3,407	3,394	3,212	3,325	3,353
Astronomy	173	192	198	206	159	185	186	144	168	165
Chemistry	2,162	2,149	2,148	2,216	2,132	1,989	1,981	1,923	2,041	1,987
Physics	1,479	1,485	1,401	1,378	1,271	1,204	1,197	1,127	1,080	1,186
Other physical sciences	27	13	22	24	17	29	30	18	36	15
Psychology	3,429	3,495	3,557	3,675	3,668	3,618	3,442	3,199	3,281	3,336
Social sciences	3,879	4,003	4,110	4,055	4,064	4,156	4,078	4,004	4,142	4,131
Engineering	6,008	6,309	6,115	5,924	5,330	5,321	5,505	5,076	5,278	5,776
Aeronautical/astronautical engineering	252	287	273	241	206	214	203	209	200	201
Chemical engineering	708	798	767	776	674	725	729	705	648	723
Civil engineering	656	698	655	650	584	556	594	626	674	675
Electrical engineering	1,731	1,741	1,720	1,596	1,478	1,544	1,576	1,395	1,466	1,649
Industrial engineering	284	259	246	229	211	176	206	230	213	217
Materials/metallurgical engineering	588	574	582	565	469	451	497	396	474	509
Mechanical engineering	1,025	1,052	1,022	1,022	855	864	953	827	814	853
Other engineering	764	900	850	845	853	791	747	688	789	949
Non-science and engineering	15,214	15,198	15,309	15,369	15,159	15,399	15,276	15,401	15,481	15,880
Education	6,650	6,785	6,574	6,571	6,546	6,430	6,337	6,487	6,632	6,635
Health	1,329	1,324	1,421	1,500	1,407	1,592	1,622	1,653	1,636	1,730
Humanities	4,691	4,712	5,034	5,116	5,034	5,213	5,161	5,010	5,015	5,017
Professional/other/unknown	2,544	2,377	2,280	2,182	2,172	2,164	2,156	2,251	2,198	2,498

NOTES: Categories are grouped differently from questionnaire and summary reports in that linguistics, history of science, American studies, and archaeology are included in social science and not in humanities, and public administration is included in social science and not in professional fields.
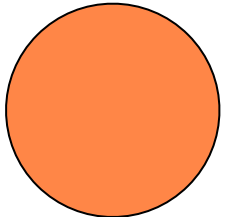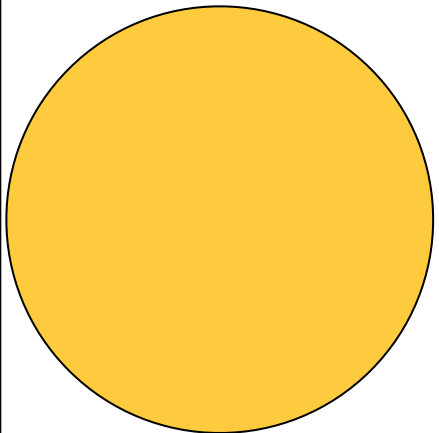
SOURCE: National Science Foundation/Division of Science Resources Statistics, Survey of Earned Doctorates, 2004 .

Ratios and Generalizations

- The first rule of generalizations is don't over-generalize

- A ratio (fraction) is just a comparison: how does A compare to B?

- Looking at many instances, making the same comparison, lets you start to extract the general relationship of trend

Circle	Radius (px)	Circumference (px)	ratio: c/r (unitless!)
	10	63	63/10 = 6.30
	20	126	126/20 = 6.30
	40	251	251/40 = 6.28
	80	503	503/80 = 6.29
	160	1005	1005/160 = 6.28

Predict the circumference of a circle with a radius of 60 px. Round (up or down) to the nearest integer.

Circle	Radius (px)	Circumference (px)	ratio: c/r (unitless!)
	10	63	63/10 = 6.30
	20	126	126/20 = 6.30
	40	251	251/40 = 6.28
	80	503	503/80 = 6.29
	160	1005	1005/160 = 6.28

If the ratio c/r is constant, then c = (ratio)×r. What value do you want to use for the ratio? Looks to me like the average shown here is 6.29...

Why Babies Need Bundling

- Why are babies always wrapped up in blankets, even when you think it's pretty warm?

- Surface to volume ratio: example in textbook

- Double the length of the side, you get 4× the area and 8× the volume!

- Triple the length of the side, and you get 9× the area and 27× the volume!

Density: How Much Mass is Crammed Into That Cube?

$$\rho = \frac{m}{V}$$

- density = mass/volume

- Not everything has the same density

- Keep it simple: assume the matter is all equally distributed

Calculate the density of that cube of grapefruit in g/cm³. Answer numerically with 3 decimal places.
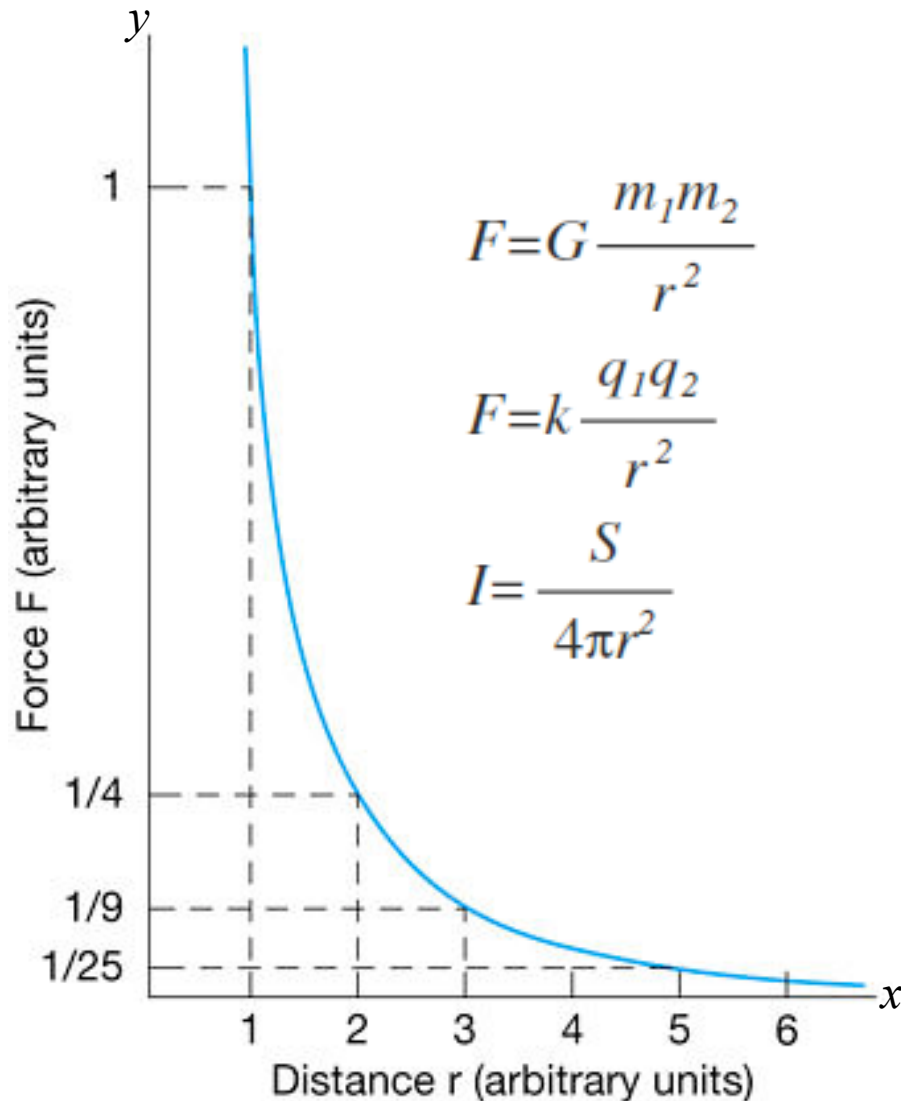
$$\rho = \frac{m}{V}$$

mass: $m = 7.82\text{g}$

length: $l = 2\text{cm}$

volume: $V = l^3$

Inverse-Square Relationship

$$F = G \frac{m_1 m_2}{r^2}$$

$$F = k \frac{q_1 q_2}{r^2}$$

$$I = \frac{S}{4\pi r^2}$$
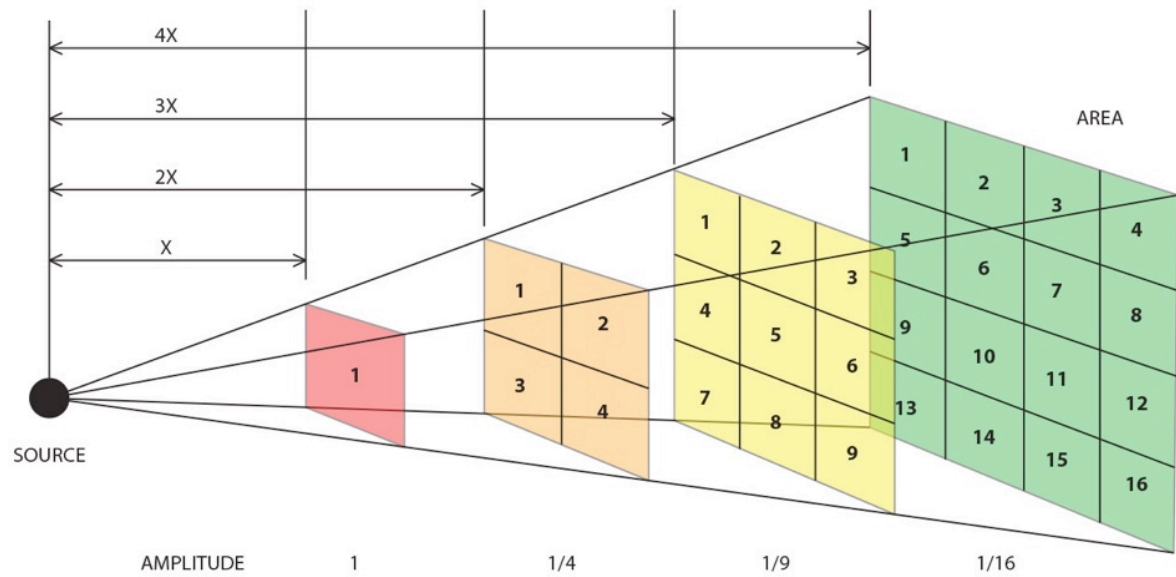
- This shows up all over physics; we will see it at least 3 or 4 times in different contexts

- In words: x and y are related. If you increase x, y gets smaller (that's the inverse part)

- However, y gets smaller faster than x gets bigger (that's the square part, and now you need to see this with some numbers to make it make sense!)

What happens if you *decrease* the distance from r to ½r?

4X
3X
2X
X

SOURCE

AREA

AMPLITUDE   1   1/4   1/9   1/16

y

Force F (arbitrary units)

1

1/4

1/9

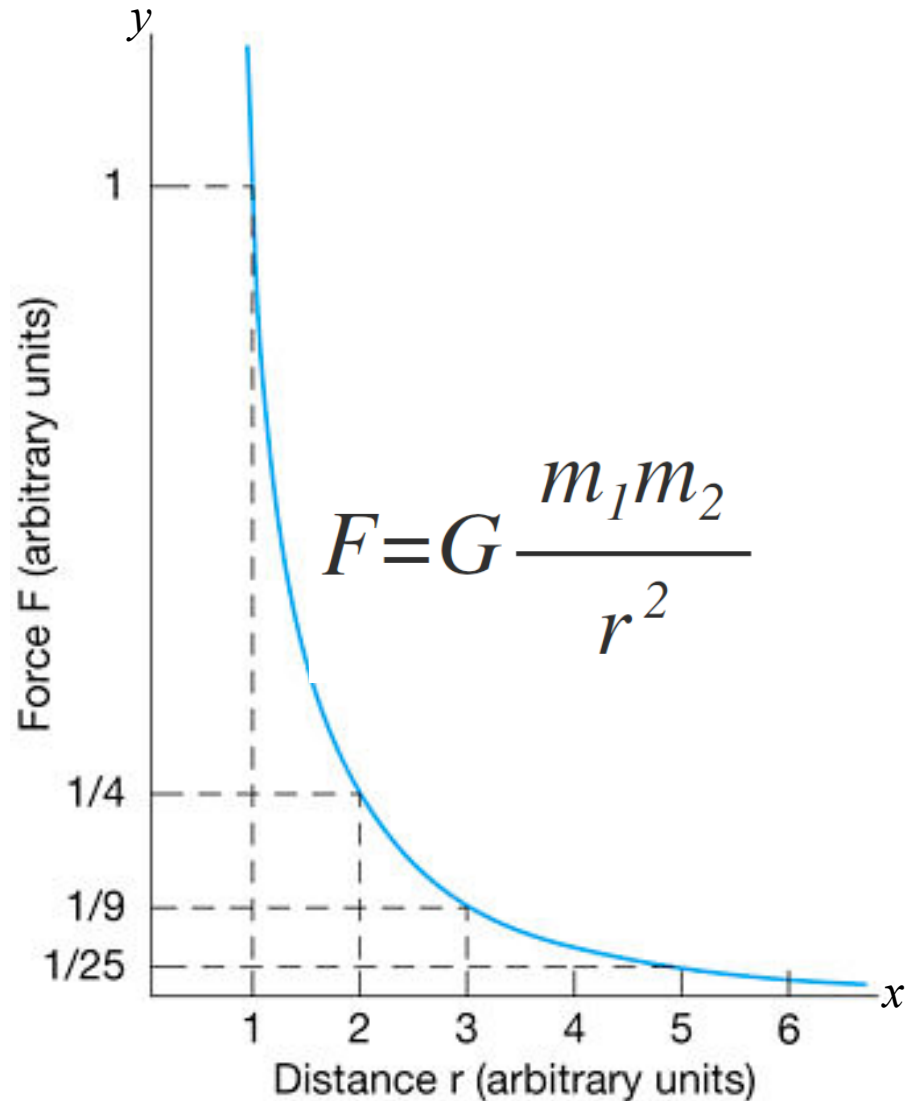1/25

$$F = G \frac{m_1 m_2}{r^2}$$

1   2   3   4   5   6   *x*

Distance r (arbitrary units)
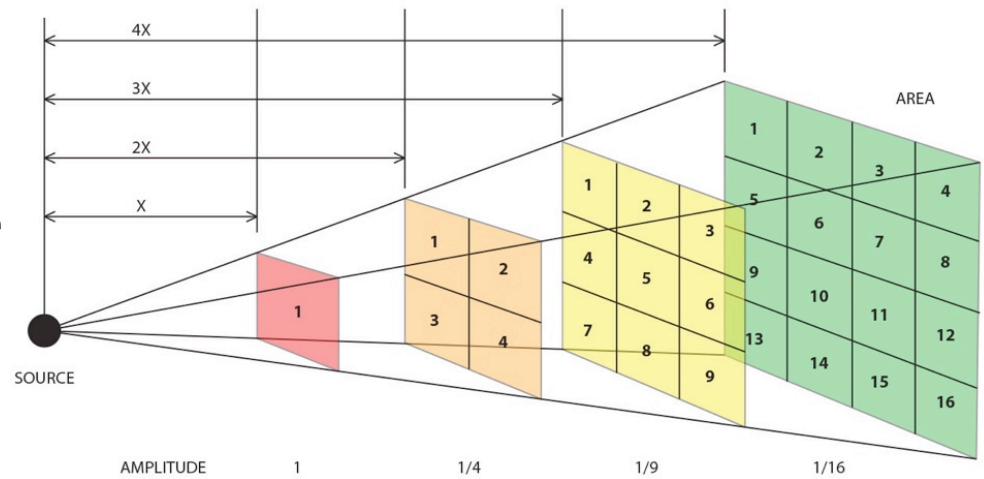
A) Half the distance, ½ the force.

B) Half the distance, ¼ the force.

C) Half the distance, 2× the force.

D) Half the distance, 4× the force.

E) Trick question; changing the distance has no effect on the force!

Section 1.7
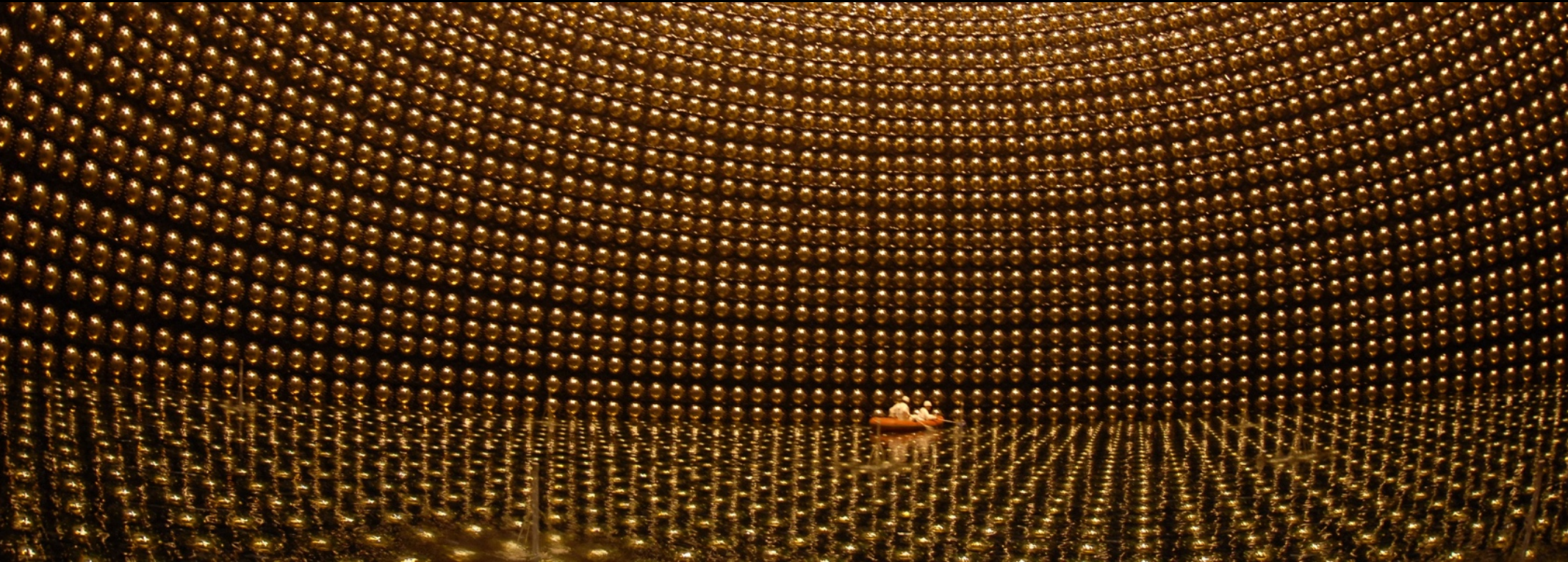
The Nature of Science

Everyone is a Scientist

- *"I don't know, but I'm trying to find out, ok?"*

- Science itself isn't hard; it's the discard that's difficult

- Everyone needs to be a better scientist

WE UNDERSTAND SO MUCH.
BUT THE SKY BEHIND THOSE LIGHTS—
MOSTLY VOID,
PARTIALLY STARS—
THAT SKY REMINDS US
WE DON'T UNDERSTAND
EVEN MORE.

The Scientific Method

"Any sufficiently advanced technology is indistinguishable from magic."
Arthur C. Clarke

intelligent HQ

- Observe
- Hypothesize
- Predict
- Test
- Modify
- Repeat
- Repeat
- Repeat
- Repeat

The Words Mean Something

- **Hypothesis**: best first guess; have a stab at explaining something, but the key word is testable. A scientific hypothesis must be testable.

- **Model**: tool used to visualize an hypothesis or theory. The better the model, the more it can account for.

- **Theory**: an explanation which has been tested–repeatedly and over time–and never been found to be false. Explains why it happens.

- **Law**: describes an important relationship that is observed in nature to occur consistently time after time. Describes what happens.

Cats born under the sign of Virgo are more intelligent and analytical than other cats.

A) Fun fact!

B) Testable hypothesis!

C) Scientific theory.

D) Old wives' tale.

E) So obvious it doesn't even need explaining!

The VIRGO Cat

"WHO RESCUED WHO?"

AUGUST.22 - SEPTEMBER.23

SYMBOL: THE VIRGIN
PLANET: MERCURY
ELEMENT: EARTH
GEMSTONE: SAPPHIRE
COLOR: DARK BLUE AND GRAY

Contrary to popular opinion, the Earth is not an oblate spheroid, but a flat disk.

A) Fun fact!

B) Testable hypothesis!

C) Scientific theory.

D) Old wives' tale.

E) So obvious it doesn't even need explaining!

Pseudoscience, or Please Don't Get Me Started

7 Ways to Identify Pseudoscience

1. The use of psychobabble —words that sound scientific and professional but are used incorrectly, or in a misleading manner.

2. A substantial reliance on anecdotal evidence.

3. Extraordinary claims in the absence of extraordinary evidence.

4. Claims which cannot be proven false.

5. Claims that counter established scientific fact.

6. Absence of adequate peer review.

7. Claims that are repeated despite being refuted.

Source: Frontiers in Psychology, Hauntings, homeopathy, and the Hopkinsville Goblins: using pseudoscience to teach scientific thinking by Rodney Schmaltz and Scott O. Lilienfeld
http://journal.frontiersin.org/Journal/10.3389/fpsyg.2014.00336/abstract

- Contrary to what you might see presented by the media, there are not "two sides to every story."

- Peer-review exists for a reason; it is not a perfect tool, but it works.

- Science works because we're all in on it; sometimes it doesn't work as fast as you want, but <insert historical context here>

Which of the following is an example of pseudoscience which has been refuted by the scientifically established peer-review process?
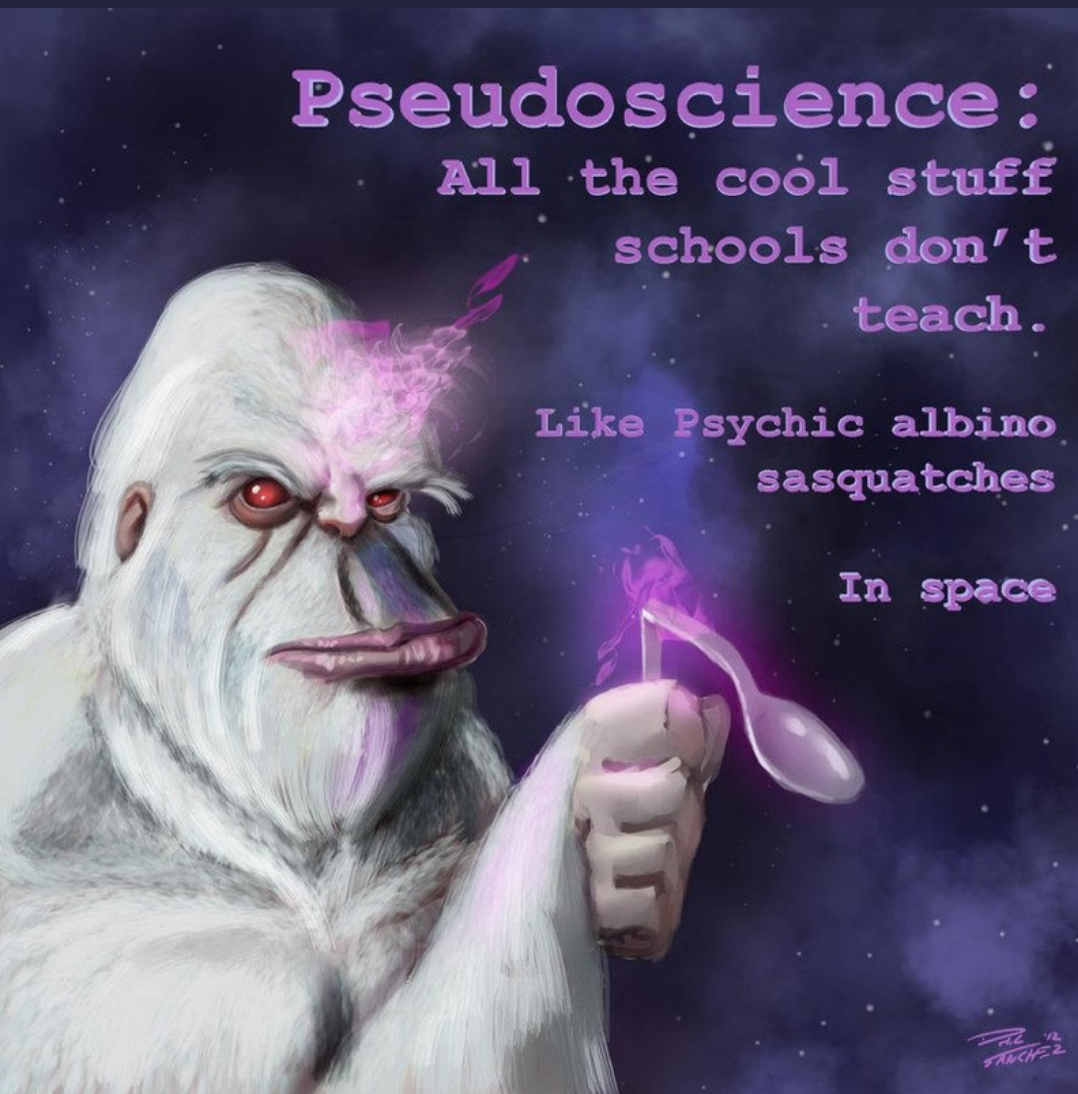
A) Astrology

B) Young-Earth creationism

C) Vaccine-induced autism

D) Climate change denial

E) All of the above