Chapter 1

Physics is the branch of science that describes matter, energy, space, and time at the most fundamental level possible.

> By fundamental, we usually mean that there aren't other laws or rules hidden or glossed over. In other words, the most basic (but not necessarily simple) laws!

Whether you are planning to study biology, architecture, medicine, music, engineering, chemistry, or art, many principles of physics are relevant to your field.

Who here has taken a physics course before?

If you have taken a physics course, did you enjoy it? Why?

If you have taken a physics course, who did not enjoy it? Why not?

Physicists look for patterns in the physical phenomena that occur in the universe.

They try to explain what is happening, and they perform experiments and tests (read: they make **measurements!**) to see if the proposed explanation is valid. Physics is an **experimental-driven** science.

The goal is to find the most basic laws that govern the universe and to formulate those laws in the most precise way possible.

Many terms that we use interchangeably have different, specific meanings in physics. And many terms that we use in everyday colloquial discussion have different or alternate meaning in physics

Important to know the distinctions so we are using the same language!

Who here has a definition of **energy**?

Who here has a definition of **energy**? (We'll get to a more precise definition later this semester)

Sometimes ***mass*** and ***weight*** are used interchangeably.
In physics, mass and weight are ***not*** interchangeable.
Again, we'll discuss this in more detail in a few weeks

In physics, a number to specify a quantity is useless unless we know the unit attached to the number.

When measuring the size of a poster, is it 16 cm high? 16 inches high? 16 meters? 16 miles?

Is the term paper due in 3 minutes, 3 days, or 3 weeks?

When you are sick, should you take 2 aspirin? What does that mean? **Any ideas?**

When you are sick, should you take 2 aspirin? What does that mean? **Any ideas?**

Should we be more specific? Is “2 aspirin pills” any better? Yes? No? Why? Why not?

A sign that your professor recently saw while traveling through the London airport (his research is done in Switzerland, so transfers in Europe are often necessary to get home). Does this make sense????

In the language of physics, the word **factor** is used frequently, often in rather specific ways.

If the power emitted by a radio transmitter has doubled, we might say that the power has "increased by a factor of 2."

If the weight you use in a lab experiment is 1/3 of what it was previously, we might say that the weight has "decreased by a factor of 3."

The ***factor*** is the number by which a quantity is multiplied or divided when it is changed from one value to another. In other words, the factor is really a ratio.

In the case of the radio transmitter, if P_0 represents the initial power and P represents the power after new equipment is installed, we write

$$\frac{P}{P_0} = 2$$

If someone’s heartbeat was 70 beats per minute and now it is 105 beats per minute, by what factor has it changed? Let’s do this together

If someone's heartbeat was 70 beats per minute and now it is 105 beats per minute, by what factor has it changed? Let's do this together

$$\text{Factor} = \frac{HR}{HR_0} = \frac{105bpm}{70bpm} = 1.4$$

If I said that the average grade in this class was to go down by a factor of 0.9, would that be … good or bad? Raise your hand if you'd like that

It is also common to talk about "increasing 5%" or "decreasing 20%." If a quantity increases n%, that is the same as saying that it is multiplied by a factor of $1 + (n/100)$.

If a quantity decreases n%, then it is multiplied by a factor of $1 - (n/100)$.

For example, an increase of 5% means something is 1.05 times its original value, and a decrease of 4% means it is 0.96 times the original value. Why 0.96? Let's work that out together

Physicists talk about increasing “by some factor” because it often simplifies a problem to think in terms of **proportions**.

When we say that *A* is proportional to *B* (written in fancy schamncy math notation as $A \propto B$), we mean that if *B* increases by some factor, then *A* must increase by the same factor.

In other words, the ratio of two values of *B* is equal to the ratio of the corresponding values of *A*:

$$B_2/B_1 = A_2/A_1 .$$

For instance, the circumference of a circle equals 2π times the radius: $C = 2\pi r$. Therefore $C \propto r$. If the radius doubles, the circumference also doubles.

The area of a circle is proportional to the *square* of the radius ($A = \pi r^2$, so $A \propto r^2$). The area must increase by the same factor as the radius *squared*, so if the radius doubles, the area increases by a factor of $2^2 = 4$.

Written as a proportion, $A_2/A_1 = (r_2/r_1)^2 = 2^2 = 4$

Why is $A_2/A_1 = (r_2/r_1)^2$? Let's work that out together

$$A_1 = \pi r_1^2, A_2 = \pi r_2^2$$

$$\frac{A_2}{A_1} = \frac{\pi r_2^2}{\pi r_1^2} = \frac{r_2^2}{r_1^2} = \left(\frac{r_2}{r_1}\right)^2$$

I found that if I drive my car 110 miles, I use 4 gallons of gas. If I assume that the relationship between gas guzzled and distance driven is linearly proportional, how many gallons of gas do I use if I drive 275 miles?

I found that if I drive my car 110 miles, I use 4 gallons of gas. If I assume that the relationship between gas guzzled and distance driven is linearly proportional, how many gallons of gas do I use if I drive 275 miles?

Gas = K × Distance] Linear

(K:) constant, we don't need to know it!

$4\,\text{gal} = K(110\,\text{miles})$

$X = K(275\,\text{miles})$

So $\dfrac{X}{4\,\text{gal}} = \dfrac{K(275\,\text{miles})}{K(110\,\text{miles})} \rightarrow X = 4\,\text{gal}\left(\dfrac{275}{110}\right)$

$= \underline{10\,\text{gal}}$

In **scientific notation**, any number is written as a number between 1 and 10 times an integer power of ten.

Thus the radius of Earth, approximately 6,380,000 m at the equator, can be written 6.38×10^6 m.

The radius of a hydrogen atom, 0.000 000 000 053 m, can be written 5.3×10^{-11} m.

Scientific notation eliminates the need to write zeros to locate the decimal point correctly.

Who wants to count that many zeros?!?!?

Roughly how many particles are there in the Universe?

**100,000,000,000,000,000,000,000,000,000,000,000,000,
000,000,000,000,000,000,000,000,000,000,000,000,
000,000,000**

Roughly how many particles are there in the Universe?

Any guesses what that number is?

Roughly how many particles are there in the Universe?

Roughly 10^{80} (a lot easier to read!)

Roughly what is the density of the Universe?

Any guesses?

Roughly what is the density of the Universe?

Roughly 10^{-27} …

Roughly what is the density of the Universe?

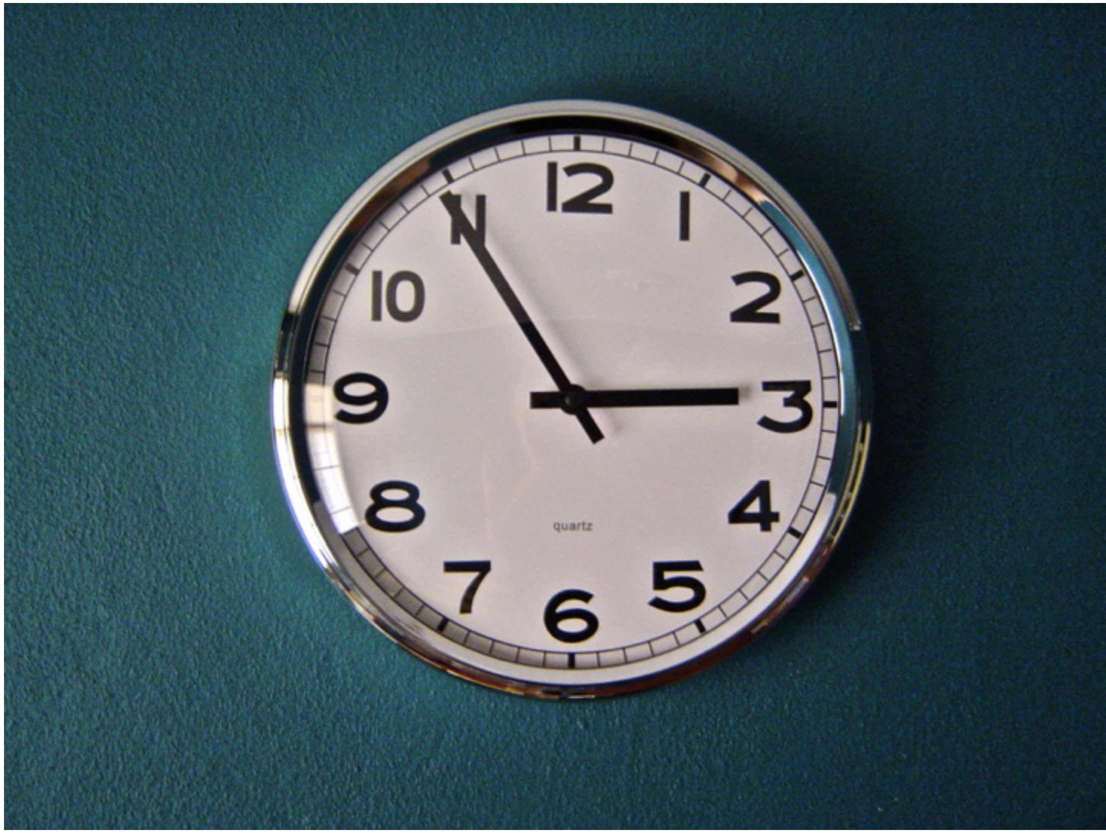
Roughly 10^{-27} kg/m^3

In science, a measurement or the result of a calculation must indicate the **precision** to which the number is known.

The precision of a device used to measure something is limited by the finest division on the scale.

Using a meter-stick with millimeter divisions as the smallest separations, we can measure a length to a precise number of millimeters and we can estimate a fraction of a millimeter between two divisions.

Precision of this clock is to the nearest minute (current time is 2:54... and maybe 20 seconds)



The most basic way to indicate the precision of a quantity is to write it with the correct number of **significant figures**.

The significant figures are all the digits that are known accurately plus the one estimated digit.

If we say that the distance from here to the state line is 12 km, that does not mean we know the distance to be exactly 12 kilometers. Rather, the distance is 12 km to the nearest kilometer.

If instead we said that the distance is 12.0 km, that would indicate that we know the distance to the nearest tenth of a kilometer.

More significant figures indicate a greater degree of precision.

Hopefully this is at least partially intuitive? Think about this in the context of reporting a measurement. If we say that this very nice car (not mine!) goes from 0 to 60 miles per hour in 2.8 seconds, we know that it's more than 2.7 and less than 2.9 seconds

Would you trust me if I said it was 2.8544069293049294 seconds? Do you think I can really make that precise of a measurement?

1. Nonzero digits are always significant (such as both numbers in 2.8 seconds)

2. Final or ending zeros written to the right of the decimal point are significant (such as all three numbers in 2.80 seconds)

3. Zeros written to the right of the decimal point for the purpose of spacing the decimal point are **not** significant (which numbers in 0.0000282 are significant?)

4. Zeros written to the left of the decimal point may be significant, or they may only be there to space the decimal point.

   For example, 200 cm (also known as 200. cm) could have one, two, or three significant figures; it's not clear whether the distance was measured to the nearest 1 cm, to the nearest 10 cm, or to the nearest 100 cm.

   On the other hand, 200.0 cm has four significant figures (let's discuss why after looking at rule 5 on next slide).

5. Rewriting the number in scientific notation is one way to remove the ambiguity (can we see why? How can we rewrite 200 cm?)
6. Zeros written between significant figures are significant.

When two or more quantities are added or subtracted, the result is as precise as the least precise of the quantities

Let's talk about why this might be in the abstract

If the quantities are written in scientific notation with different powers of ten, first rewrite them with the same power of ten. After adding or subtracting, round the result, keeping only as many decimal places as are significant in all of the quantities that were added or subtracted.

When quantities are multiplied or divided, the result has the same number of significant figures as the quantity with the smallest number of significant figures.

Let's talk about why this might be in the abstract

In a series of calculations, rounding to the correct number of significant figures should be done *only at the end*, not at each step.

Rounding at each step would increase the chance that roundoff error could snowball and adversely affect the accuracy of the final answer.

It's a good idea to keep at least two extra significant figures in calculations, then round at the end.

We may be a bit loose and fast with this in the course but this should be something you know, both for exams and also in your labs!

When an integer, or a fraction of integers, is used in an equation, the precision of the result is not affected by the integer or the fraction; the number of significant figures is limited only by the measured values in the problem.

The fraction 1/2 in an equation is exact (we can rewrite it as 0.50000000000000000....); it does not reduce the number of significant figures to one.

In an equation such as $C = 2\pi r$ for the circumference of a circle of radius r, the factors 2 and π are exact.

We use as many digits for π as we need to maintain the precision of the other quantities.

Do you think we ever need this many digits of pi? Why not?

Pfizer

Pfizer Press release from last spring

Contact Us

Monday, May 23, 2022 - 06:45am

https://www.pfizer.com/news/press-release/press-release-detail/pfizer-biontech-covid-19-vaccine-demonstrates-strong-immune#:~:text=search%20results%20for-,Pfizer%2DBioNTech%20COVID%2D19%20Vaccine%20Demonstrates%20Strong%20Immune%20Response%2C,of%20Age%20Following%20Third%20Dose&text=NEW%20YORK%20%26%20MAINZ%2C%20Germany%2D%2D(BUSINESS%20WIRE)%2D%2D%20Pfizer%20Inc.

- *Based on topline data, three doses of the Pfizer-BioNTech COVID-19 Vaccine met all immunobridging criteria required for Emergency Use Authorization*
- *The third 3-µg dose was well tolerated among 1,678 children under 5 years of age with a safety profile similar to placebo*
- *Vaccine efficacy of 80.3% was observed in descriptive analysis of three doses during a time when Omicron was the predominant variant*
- *The 3-µg dose level, which is one-tenth the dose for adults, was selected for children under 5 years of age based on safety, tolerability and immunogenicity*

NEW YORK & MAINZ, Germany--(BUSINESS WIRE)-- Pfizer Inc. (NYSE: PFE) and BioNTech SE (Nasdaq: BNTX) today announced topline safety, immunogenicity and vaccine efficacy data from a Phase 2/3 trial evaluating a third 3-µg dose of the Pfizer-BioNTech COVID-19 Vaccine in children 6 months to under 5 years of age. Following a third dose in this age group, the vaccine was found to elicit a strong immune response, with a favorable safety profile similar to placebo.

This press release features multimedia. View the full release here: https://www.businesswire.com/news/home/20220522005063/en/

Vaccine efficacy, a secondary endpoint in this trial, was 80.3% in children 6 months to under 5 years of age. This descriptive analysis was based on 10 symptomatic COVID-19 cases identified from seven days after the third dose and accrued as of April 29, 2022. The trial protocol specifies a formal analysis will be performed when at least 21 cases have

Pfizer Press release from last spring

https://www.pfizer.com/news/press-release/press-release-detail/pfizer-biontech-covid-19-vaccine-demonstrates-strong-immune#:~:text=search%20results%20for-,Pfizer%2DBioNTech%20COVID%2D19%20Vaccine%20Demonstrates%20Strong%20Immune%20Response%2C,of%20Age%20Following%20Third%20Dose&text=NEW%20YORK%20%26%20MAINZ%2C%20Germany%2D%2D(BUSINESS%20WIRE)%2D%2D%20Pfizer%20Inc.

Press release: Vaccine efficacy for little kids (near and dear to my heart!) was 80.3%. But a closer look suggests the uncertainty on 80.3% is ~50%! Does it make any sense to quote 80.3%? Or 81%? (I might argue that the results are fully meaningless at this stage!)

Conclusion: Uncertainties and how you report results… matter!

Vaccine efficacy, a secondary endpoint in this trial, was 80.3% in children 6 months to under 5 years of age. This descriptive analysis was based on 10 symptomatic COVID-19 cases identified from seven days after the third dose and accrued as of April 29, 2022. The trial protocol specifies a formal analysis will be performed when at least 21 cases have

The **metric system** of units (the *Système International d'Unités*, abbreviated **SI**) is based on powers of ten. The metric system the meter (m) for length, the kilogram (kg) for mass, the second (s) for time, and four more base units (see next slides).

This is in contrast to what many of us are used to using (inches, feet, pounds, ounces), unfortunately, but SI units are easier for physics and are the scientific standard

SI Units

Quantity	Unit Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

Derived units are constructed from combinations of the base units.

For example, the SI unit of force is $kg \cdot m/s^2$ (which can also be written $kg \cdot m \cdot s^{-2}$); this combination of units is given a special name, the newton (N), in honor of Isaac Newton. The newton is a derived unit because it is composed of a combination of base units.

https://en.wikipedia.org/wiki/Unit_prefix

SI uses prefixes for units to indicate power of ten factors.

When an SI unit with a prefix is raised to a power, the prefix is also raised to that power.

$2\ \text{cm} \times 2\ \text{cm} \times 2\ \text{cm} = 8\ \text{cm}^3$

Note the above, the answer is not 8 cm, and it is not $2\ \text{cm}^3$

Metric prefixes in everyday use			
Prefix	Symbol	Factor	Power
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
(none)	(none)	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	µ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
V•T•E			

Anyway know what the next ones are?

Converting Units If the statement of a problem includes a mixture of different units, the units must be converted to a single, consistent set before the problem is solved.

Quantities to be added or subtracted *must be expressed in the same units. You can't add 1 apple and 2 bananas (NOT equal to 3 oranges!)*

1 piece of fruit + 2 pieces of fruit = 3 pieces of fruit

0.2 grams of fruit + 0.3 grams of fruit = 0.5 grams of fruit

KEY: We can always multiply or divide any number by 1 without changing it!

YOU NEED TO LEARN TO DO THIS AS SECOND NATURE IN THIS COURSE

The total area of solar panels on the roof of your friend’s house is 70 m^2 . What is the area in (a) square centimeters and (b) square inches?

Solution

(a) 1 m = 100 cm, so

$$70\ \text{m}^2 \times \left(100\ \frac{\text{cm}}{\text{m}}\right)^2 = 7.0 \times 10^5\ \text{cm}^2$$

Here, (100 cm / 1 m) = (1 m / 100 cm) = 1. You can divide and multiply by both of these, but only one will work. Note that we need TWO factors of this to get the right units

(b) Using 1 in. = 2.54 cm,

$$7.0 \times 10^5\ \text{cm}^2 \times \left(\frac{1\ \text{in.}}{2.54\ \text{cm}}\right)^2 = 1.1 \times 10^5\ \text{in.}^2$$

Let’s think back to our “take 2 aspirin and call me in the morning”. Assume the (bad scientist and) doctor meant “take two 300 mg aspirin tablets and call me in the morning”

How many pounds of aspirin does the doctor want you to take? Let’s work that out

300 mg / tablet of aspirin
10^6 mg = 1 kg
2.2 lb = kg

$$2 \text{ aspirin tablets} \times \frac{300\text{ mg}}{\text{tablet aspirin}} \times \frac{1\text{ kg}}{10^6\text{ mg}} \times \frac{2.2\text{ lb}}{\text{kg}}$$

Look at all the units canceling! Left with

$$\frac{2 \times 300}{10^6} \times 2.2\text{ lb} = \underline{1.3 \times 10^{-3}\text{ lbs}}$$

Dimensions are basic *types* of units, such as time, length, and mass.

Many different units of length exist: meters, inches, miles, nautical miles, fathoms, leagues, astronomical units, angstroms, cubits, etc.

All have dimensions of length; each can be converted into any other.

Dimensional analysis: We can add, subtract, or equate quantities only if they have the same dimensions (although they may not necessarily be given in the same units initially, we can do a conversion).

It is possible to add 3 meters to 2 inches (after converting units), but it is not possible to add 3 meters to 2 kilograms.

Sometimes problems in the course will involve specific numbers that you can plug into a calculator:

If I start out traveling at 2.2 m/s and I uniformly accelerate at 4.1 m/s^2, how far do I travel in 5.0 seconds, in meters? Answer: 62 meters

But other times the questions involve **Symbols**.

If I start out traveling at X m/s and I uniformly accelerate at Y m/s^2, how far do I travel in Z seconds, in meters? Answer: X*Z+0.5*Y*Z*Z

You need to be comfortable with both types of questions in this course!

Order-of-Magnitude Estimates Sometimes a problem may be too complicated to solve precisely, or information may be missing that would be necessary for a precise calculation.

In such a case, an order-of-magnitude solution is the best we can do.

By order of magnitude, we mean "roughly what power of ten?"

An order of magnitude calculation is done to *at most one significant figure*.

Why compute an order of magnitude estimate? If your more-detailed calculation comes out with a different order of magnitude, you can go back and search for an error.

Suppose a problem concerns a vase that is knocked off a fourth-story window ledge. We can guess by experience the order of magnitude of the time it takes the vase to hit the ground.

It might be 1 s, or 2 s, but we are certain that it is not 1000 s or 0.00001 s.

Famous order of magnitude estimation problem from Enrico Fermi (namesake of Fermilab).

How many piano tuners are there in the Chicagoland area?

Note that we need to be careful of correct units! But we can estimate this!

Let's assume:

- X million people in Chicagoland
- On average, there are Y people per household
- Roughly 1 household in Z has a piano that is regularly tuned
- Pianos need tuning on average P time/year
- A piano tuner needs Q hours/tuning (including travel time)
- A piano tuner typically works R hours/day, S days/week, T weeks/year

Let's get some estimates together for the above and write them on the board (we can then compare to my estimates)

Let's assume:

- 10 million people in Chicagoland
- On average, there are 3 people per household
- Roughly 1 household in 20 has a piano that is regularly tuned
- Pianos need tuning on average 1 time/year
- A piano tuner needs 2 hours/tuning (including travel time)
- A piano tuner typically works 8 hours/day, 5 days/week, 50 weeks/year

The “per” means “divided by” - do we all see that?

10 million people/(3 people per household) =
3.33 million households in Chicagoland

3.33 million households*(1 piano / 20 households) =
1.67×10^5 pianos

1.67×10^5 pianos * (1 piano tuning / (piano year)) =
1.67×10^5 tunings / year

(50 weeks / year) * (5 days / week) * (8 hours / day) =
2000 hours of work per piano tuner per year

(2000 hours / year) / (2 hours / tuning) =
1000 piano tunings per piano tuner per year

(1.67×10^5 tunings / year) / (1000 tunings/tuner/year) =
167 piano tuners in Chicagoland

So the guess is 200 (order 10^2 piano tuners) are in the area

Search on website of professional tuners association found 85 such tuners in the area - not too bad!

GROUP WORK TIME!
https://forms.gle/szBuuVefZzgBuykM9

A spherical balloon is partially blown up and its surface area is measured. More air is then added, increasing the volume of the balloon

If the surface area of the balloon expands by a factor of 2.0 during this procedure, by what factor does the radius of the balloon change?

A spherical balloon is partially blown up and its surface area is measured. More air is then added, increasing the volume of the balloon

If the surface area of the balloon expands by a factor of 2.0 during this procedure, by what factor does the volume of the balloon change?

Blood flows through the aorta at an average speed of $v = 18$ cm/s. The aorta is roughly cylindrical with a radius $r = 12$ mm. The volume rate of blood flow through the aorta is $\pi r^2 v$.

Calculate the volume rate of blood flow in liters/minute
(note: $1L = 10^3\ cm^3$)

Compute the following, giving the correct number of significant digits:

a) 2.212×10^3 s + 122 s
b) 2.212×10^3 s - 1220. s
c) 2.2120×10^3 s * 122
d) 2.212×10^3 s / 120.

In the United States, we use miles per hour (mi/h) to discuss highway speed, but the SI unit of speed is meters per second (m/s).

a) What is the conversion factor to go from m/s to mi/h?

b) What might be an easy, quick and dirty way to convert between the two?

HINT: There are 2.54 cm / inch, 12 inches / foot, and 5280 feet / mile

The age of the Earth is approximately 4.5 billion years old. The age of the Universe is approximately 13.8 billion years old.

a) By what factor is the Universe older than the Earth? Give the answer with the appropriate number of significant digits
b) Convert the age of the Universe to SI units (give your answer in scientific notation) with the appropriate number of significant digits

Estimate the number of auto repair shops in Chicago

Hint: What is the size of the population? How often does an auto need repair? How many cars can each shop service per day?

A 350-seat rectangular concert hall has a width of 60.0 feet, length of 81.0 feet and a height of 26.0 feet. The density of air is 0.0755 lb/ft^3.

a) What is the volume of the concert hall in cubic meters?
b) What is the weight of the air in the concert hall, in Newtons

Distances in space are often described in terms of "Astronomical Units" (AU). The AU is a unit of length roughly corresponding to the distance between the Earth and the sun. But this changes over the course of the year, so one AU is now defined
as 149,597,870,700 meters.

a) How many inches is this (give your answer using scientific notation)
b) The closest the Earth gets to the sun ("Perihelion") is 147.1 million kilometers from the sun. The furthest it gets ("Aphelion") is 152.1 million kilometers. Convert each of these to AU
c) By what factor is the earth-sun distance larger at Perihelion when compared to Aphelion?

a) Jane has a mass of 54.40 kg. Charlie has a mass of 63.321 kg. What is their combined mass?
b) Jane starts a weightlifting program and increases her mass by 5%. What is her new mass?
c) Charlie goes on a diet and loses 3% of his original mass. What is his new mass?
d) What is π*Jane's mass?
e) What is Charlie's mass / 2?
f) What is Jane's mass * Charlie's mass?

Compute the following, giving the correct number of significant digits:

a) 6.212×10^3 g + 122 kg
b) 6.212×10^3 g + 1.22 kg
c) 6.212×10^3 g - 122 kg
d) 6.212×10^3 g - 1.22 kg
e) 6.212×10^3 g * 122
f) 6.212×10^3 g * 1.22
g) 6.212×10^3 g / 122
h) 6.212×10^3 g / 1.22