

**Unit conversion problems**, by Tony R. Kuphaldt (2006)

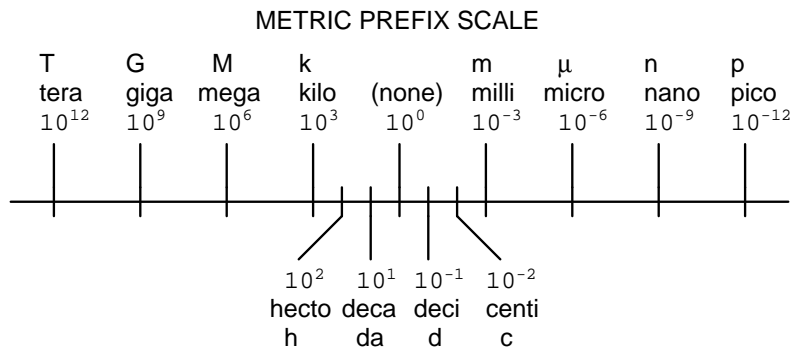
This worksheet and all related files are licensed under the Creative Commons Attribution License, version 1.0. To view a copy of this license, visit <http://creativecommons.org/licenses/by/1.0/>, or send a letter to Creative Commons, 559 Nathan Abbott Way, Stanford, California 94305, USA. The terms and conditions of this license allow for free copying, distribution, and/or modification of all licensed works by the general public.

---

## Metric prefixes and conversion constants

- **Metric prefixes**

- Yotta =  $10^{24}$  Symbol: Y
- Zeta =  $10^{21}$  Symbol: Z
- Exa =  $10^{18}$  Symbol: E
- Peta =  $10^{15}$  Symbol: P
- Tera =  $10^{12}$  Symbol: T
- Giga =  $10^9$  Symbol: G
- Mega =  $10^6$  Symbol: M
- Kilo =  $10^3$  Symbol: k
- Hecto =  $10^2$  Symbol: h
- Deca =  $10^1$  Symbol: da
- Deci =  $10^{-1}$  Symbol: d
- Centi =  $10^{-2}$  Symbol: c
- Milli =  $10^{-3}$  Symbol: m
- Micro =  $10^{-6}$  Symbol:  $\mu$
- Nano =  $10^{-9}$  Symbol: n
- Pico =  $10^{-12}$  Symbol: p
- Femto =  $10^{-15}$  Symbol: f
- Atto =  $10^{-18}$  Symbol: a
- Zepto =  $10^{-21}$  Symbol: z
- Yocto =  $10^{-24}$  Symbol: y



- **Conversion formulae for temperature**

- $^{\circ}\text{F} = (^{\circ}\text{C})(9/5) + 32$
- $^{\circ}\text{C} = (^{\circ}\text{F} - 32)(5/9)$
- $^{\circ}\text{R} = ^{\circ}\text{F} + 459.67$
- $\text{K} = ^{\circ}\text{C} + 273.15$

### Conversion equivalencies for distance

- 1 inch (in) = 2.540000 centimeter (cm)
- 1 foot (ft) = 12 inches (in)
- 1 yard (yd) = 3 feet (ft)
- 1 mile (mi) = 5280 feet (ft)

**Conversion equivalencies for volume**

1 gallon (gal) = 231.0 cubic inches (in<sup>3</sup>) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm<sup>3</sup>)

**Conversion equivalencies for velocity**

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

**Conversion equivalencies for mass**

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

**Conversion equivalencies for force**

1 pound-force (lbf) = 4.44822 newton (N)

**Conversion equivalencies for area**

1 acre = 43560 square feet (ft<sup>2</sup>) = 4840 square yards (yd<sup>2</sup>) = 4046.86 square meters (m<sup>2</sup>)

**Conversion equivalencies for common pressure units (either all gauge or all absolute)**

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

**Conversion equivalencies for absolute pressure units (only)**

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

**Conversion equivalencies for energy or work**

1 british thermal unit (Btu – “International Table”) = 251.996 calories (cal – “International Table”) = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10<sup>10</sup> ergs (erg) = 778.169 foot-pound-force (ft-lbf)

**Conversion equivalencies for power**

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

**Acceleration of gravity (free fall), Earth standard**

9.806650 meters per second per second (m/s<sup>2</sup>) = 32.1740 feet per second per second (ft/s<sup>2</sup>)

### Physical constants

Speed of light in a vacuum ( $c$ ) =  $2.9979 \times 10^8$  meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number ( $N_A$ ) =  $6.022 \times 10^{23}$  per mole ( $\text{mol}^{-1}$ )

Electronic charge ( $e$ ) =  $1.602 \times 10^{-19}$  Coulomb (C)

Boltzmann's constant ( $k$ ) =  $1.38 \times 10^{-23}$  Joules per Kelvin (J/K)

Stefan-Boltzmann constant ( $\sigma$ ) =  $5.67 \times 10^{-8}$  Watts per square meter-Kelvin<sup>4</sup> ( $\text{W}/\text{m}^2 \cdot \text{K}^4$ )

Molar gas constant ( $R$ ) = 8.314 Joules per mole-Kelvin (J/mol-K)

### Properties of Water

Freezing point at sea level =  $32^\circ\text{F} = 0^\circ\text{C}$

Boiling point at sea level =  $212^\circ\text{F} = 100^\circ\text{C}$

Density of water at  $4^\circ\text{C} = 1000 \text{ kg}/\text{m}^3 = 1 \text{ g}/\text{cm}^3 = 1 \text{ kg}/\text{liter} = 62.428 \text{ lb}/\text{ft}^3 = 1.94 \text{ slugs}/\text{ft}^3$

Specific heat of water at  $14^\circ\text{C} = 1.00002 \text{ calories}/\text{g} \cdot ^\circ\text{C} = 1 \text{ BTU}/\text{lb} \cdot ^\circ\text{F} = 4.1869 \text{ Joules}/\text{g} \cdot ^\circ\text{C}$

Specific heat of ice  $\approx 0.5 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Specific heat of steam  $\approx 0.48 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Absolute viscosity of water at  $20^\circ\text{C} = 1.0019 \text{ centipoise (cp)} = 0.0010019 \text{ Pascal-seconds (Pa}\cdot\text{s)}$

Surface tension of water (in contact with air) at  $18^\circ\text{C} = 73.05 \text{ dynes}/\text{cm}$

pH of pure water at  $25^\circ\text{C} = 7.0$  (*pH scale = 0 to 14*)

### Properties of Dry Air at sea level

Density of dry air at  $20^\circ\text{C}$  and 760 torr =  $1.204 \text{ mg}/\text{cm}^3 = 1.204 \text{ kg}/\text{m}^3 = 0.075 \text{ lb}/\text{ft}^3 = 0.00235 \text{ slugs}/\text{ft}^3$

Absolute viscosity of dry air at  $20^\circ\text{C}$  and 760 torr =  $0.018 \text{ centipoise (cp)} = 1.8 \times 10^{-5} \text{ Pascal-seconds (Pa}\cdot\text{s)}$

file conversion\_constants

## Questions

---

### Question 1

What is *force*, the mathematical symbol for force, and what are some of the units used to measure force? Identify whether these units are English or metric.

[file i04142](#)

---

### Question 2

What are some of the units used to measure length or distance, and what are the mathematical symbols for both of these variables? Identify whether these units are English or metric.

[file i03333](#)

---

### Question 3

What is *area*, the mathematical symbol for area, and what are some of the units used to measure area? Identify whether these units are English or metric.

[file i00006](#)

---

### Question 4

What is *volume*, the mathematical symbol for volume, and what are some of the units used to measure volume? Identify whether these units are English or metric.

[file i00007](#)

---

### Question 5

Use pairs of volume quantities from the following string of equalities to form *unity fractions* useful for the following unit conversions:

1 gallon (gal) = 231.0 cubic inches (in<sup>3</sup>) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

$$\left(\frac{85 \text{ gal}}{1}\right) \left(\frac{\quad}{\quad}\right) = ??? \text{ pt}$$

$$\left(\frac{220 \text{ qt}}{1}\right) \left(\frac{\quad}{\quad}\right) = ??? \text{ gal}$$

$$\left(\frac{815 \text{ fl. oz.}}{1}\right) \left(\frac{\quad}{\quad}\right) = ??? \text{ l}$$

$$\left(\frac{139 \text{ pt}}{1}\right) \left(\frac{\quad}{\quad}\right) = ??? \text{ in}^3$$

After you have set up the proper unity fractions to perform these volumetric conversions, perform the calculations and show cancellation of units.

[file i00997](#)

---

### Question 6

Suppose your recipe book specified 462 quarts of cooking oil to deep-fry a camel, but your local wholesale food outlet only sold cooking oil by the 55-gallon drum. Realizing the need to convert units, you decide to convert the 462 quarts into gallons by dividing by 4, then convert gallons into drums by dividing by 55.

A friend of yours decides to help by showing you a simple method for organizing conversion calculations. On a piece of paper, he writes the following product of fractions:

$$\frac{462 \text{ quarts}}{1} \times \frac{1 \text{ gallon}}{4 \text{ quarts}} \times \frac{1 \text{ drum}}{55 \text{ gallons}}$$

Then, he proceeds to show you how to cancel units as though they were equal numbers, leaving only the unit of “drums” at the end (462 quarts equals 2.1 drums).

Explain how and why this technique for unit conversions works.

Challenge question: explain why the following example is an *improper* use of this unit conversion technique. Converting a temperature rate-of-change from 80° F per minute to degrees C per hour:

$$\frac{80^\circ \text{ F}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hour}} \times \frac{0^\circ \text{ C}}{32^\circ \text{ F}}$$

[file i00094](#)

---

### Question 7

An oil refinery processes 200,000 barrels of oil per day. Given the equivalence of 42 gallons = 1 barrel (petroleum), how many gallons per minute is this? Be sure to show how you performed the conversion.

[file i00104](#)

---

### Question 8

Sally needs to dispense 1-1/2 pints of flour into a bowl in preparation to bake bread. Unfortunately, someone has stolen her measuring cups, leaving her with nothing but a teaspoon. How many teaspoons of flour must Sally count to equal 1-1/2 pints?

#### Conversion factors:

- 1 tablespoon = 3 teaspoons
- 16 tablespoons = 1 cup
- 4 quarts = 1 gallon
- 2 cups = 1 pint

Be sure to show how you used these conversion equivalents to get your answer!

[file i00102](#)

---

### Question 9

Suppose you needed to convert the distance of 35 feet into inches. The calculation is trivial, but you decide to practice the use of “unity fractions” to solve for the answer:

$$\frac{35 \text{ ft}}{1} \times \frac{12 \text{ in}}{1 \text{ ft}}$$

Units of “feet” (ft) cancel to leave you with an answer of 420 inches. So far, so good.

Now suppose you must convert the area of 70 square feet (ft<sup>2</sup>) into square inches (in<sup>2</sup>). There should be a way that you can use the “unity fraction” concept to do this, but it will not work if we set it up identically to the last problem:

$$\frac{70 \text{ ft}^2}{1} \times \frac{12 \text{ in}}{1 \text{ ft}} = \text{Wrong Answer!}$$

The reason this will not work as a final solution for the area problem is because square feet do not cancel with *linear* feet. The quantities are still one-dimensional: feet, not square feet; inches, not square inches.

But what if we did this?

$$\frac{70 \text{ ft}^2}{1} \times \frac{12^2 \text{ in}^2}{1^2 \text{ ft}^2}$$

. . . which is the same as doing this . . .

$$\frac{70 \text{ ft}^2}{1} \times \frac{12 \text{ in}}{1 \text{ ft}} \times \frac{12 \text{ in}}{1 \text{ ft}}$$

Will this give us the correct answer? Why or why not? If not, explain how we *can* get the correct answer using the “unity fraction” method of units conversion.

Finally, once you are decided on a proper way to do convert units of area, generalize this rule to cover conversions involving units for volume (*cubic* feet and inches – ft<sup>3</sup> and in<sup>3</sup>).

[file i00107](#)

---

### Question 10

In Europe, automobile engines are rated in kilowatts (kW) instead of horsepower (hp). How many kilowatts would a 250 horsepower engine be rated at? Be sure to show how you performed the conversion.

[file i00103](#)

---

### Question 11

A bullet’s speed is measured to be 1460 feet per second. Use unity fractions to convert this speed into *miles per hour*. You may use any of the following conversion equivalents in your work, but whatever you do you *must* show how you obtained the correct answer by using “unity fractions” to cancel out all unwanted units and replace with desired units:

- 24 hours = 1 day
- 1 yard = 3 feet
- 1 horsepower = 746 Watts
- 1 mile = 5280 feet
- 1 PSI = 2.036 ”Hg
- 1 acre = 43560 square feet

[file i04804](#)

---

Question 12

A rectangular parcel of land measures 600 feet by 280 feet. Calculate its area in *acres*.

[file i01160](#)

---

Question 13

John has a bicycle with 26 inch diameter wheels. How fast are the wheels spinning (in revolutions per minute, or “RPM”) when John rides the bike at a velocity of 15 miles per hour? Remember that the circumference of a circle is equal to the diameter multiplied by  $\pi$ . This figure will be the distance traveled for each revolution of the wheel.

[file i00105](#)

---

Question 14

A cylindrical tank has a capacity of 100 cubic yards. Convert this volume into units of *gallons*, using only the following conversion factors:

- 1 yard = 3 feet
- 1 foot = 12 inches
- 1 gallon = 231 cubic inches ( $\text{in}^3$ )

[file i00106](#)

---

Question 15

Calculate how deep a circular swimming pool (20 feet in diameter) needs to be filled with water before its water weight is equal to 51800 pounds. Assume a density of  $62.4 \text{ lb/ft}^3$  for water.

[file i01159](#)

---

Question 16

Albert Einstein determined that mass and energy were equivalent, and related the two in his famous equation  $E = mc^2$ , where  $E$  is energy in units of joules,  $m$  is mass in kilograms, and  $c$  is the velocity of light in meters per second ( $3 \times 10^8$  meters per second).

The first atomic bomb used in war was a 10-kiloton device dropped on the city of Hiroshima, Japan. “10 kiloton” means the equivalent energy release of 10,000 tons of TNT chemical explosive. 1 ton equivalent of TNT is equal to  $4.184 \times 10^9$  joules of energy. Based on these figures, how much mass was converted into energy with the detonation of the world’s first atomic weapon?

[file i00108](#)

---

Question 17

A student needs to convert a temperature value from degrees Fahrenheit to degrees Celsius. Unfortunately, they are not sure of the correct formula. They think the formula goes like this, but they are unsure:

$$^{\circ}C = \left(\frac{5}{9}\right)^{\circ}F - 32$$

Devise a simple way for this student to *test* whether or not the formula is correct, without seeking help from a reference document of any kind.

**Suggestions for Socratic discussion**

- Why do you suppose it is helpful to develop the habit and skill of “testing” hypotheses in this way, as opposed to simply consulting a reference to see if the formula is written correctly?

[file i00805](#)



---

Question 18

Convert between the following units of temperature:

- $350\text{ K} = ???^\circ\text{ C}$
- $575^\circ\text{ F} = ???^\circ\text{ R}$
- $-210^\circ\text{ C} = ???\text{ K}$
- $900^\circ\text{ R} = ???^\circ\text{ F}$
- $-366^\circ\text{ F} = ???^\circ\text{ R}$
- $100\text{ K} = ???^\circ\text{ C}$
- $2888^\circ\text{ C} = ???\text{ K}$
- $4502^\circ\text{ R} = ???^\circ\text{ F}$
- $1000\text{ K} = ???^\circ\text{ R}$
- $3000^\circ\text{ R} = ???\text{ K}$

**Suggestions for Socratic discussion**

- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.
- What practical purpose does a temperature scale such as Kelvin or Rankine serve, especially since the scales of Celsius and Fahrenheit are so well-known and commonly used?

[file i00340](#)

---

Question 19

Convert between the following units of temperature:

- $235^\circ\text{ C} = ???^\circ\text{ R}$
- $567.2^\circ\text{ F} = ???\text{ K}$
- $0.004\text{ K} = ???^\circ\text{ F}$
- $830^\circ\text{ R} = ???^\circ\text{ C}$
- $-200^\circ\text{ C} = ???^\circ\text{ R}$
- $-98.25^\circ\text{ F} = ???\text{ K}$
- $992.8^\circ\text{ C} = ???^\circ\text{ F}$
- $-105.3^\circ\text{ C} = ???^\circ\text{ F}$
- $1040\text{ K} = ???^\circ\text{ R}$
- $5222.6^\circ\text{ R} = ???^\circ\text{ C}$

**Suggestions for Socratic discussion**

- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.

[file i00341](#)

---

Question 20

Complete the following table of equivalent temperatures:

| °F   | °R   | °C  | K    |
|------|------|-----|------|
| 580  |      |     |      |
|      | 10   |     |      |
|      |      | -35 |      |
|      |      |     | 5543 |
| -310 |      |     |      |
|      | 3668 |     |      |
|      |      | 622 |      |
|      |      |     | 300  |

[file i00689](#)

---

Question 21

Some units of pressure measurement may be used to express either gauge pressure or absolute pressure. Pounds per square inch (PSI) is one of those versatile units: we can express a pressure either in terms of PSIG (PSI gauge pressure) or PSIA (PSI absolute pressure).

However, there are some other units of pressure measurement that may only be used to express absolute pressure. In other words, there are some *intrinsically absolute* pressure units. Identify these particular pressure units.

[file i02941](#)

---

Question 22

Explain what is wrong with this attempt to convert a gauge pressure of 65 PSI into units of atmospheres (atm):

$$\left(\frac{65 \text{ PSI}}{1}\right) \left(\frac{1 \text{ atm}}{14.7 \text{ PSI}}\right) = 4.422 \text{ atm}$$

**Suggestions for Socratic discussion**

- The mistake made here is common for new students to make as they learn to do pressure unit conversions. Identify a “sure-fire” way to identify and avoid this mistake.

[file i02940](#)

---

Question 23

2.036 inches of mercury ("Hg) is an equivalent pressure to 27.68 inches of water ("W.C. or "H<sub>2</sub>O). This fact allows us to create a "unity fraction" from these two quantities for use in converting pressure units from inches mercury to inches water or vice-versa. Two examples are shown here:

$$\left(\frac{310 \text{ "Hg}}{1}\right) \left(\frac{27.68 \text{ "W.C.}}{2.036 \text{ "Hg}}\right) = 4215 \text{ "W.C.}$$
$$\left(\frac{45 \text{ "W.C.}}{1}\right) \left(\frac{2.036 \text{ "Hg}}{27.68 \text{ "W.C.}}\right) = 3.31 \text{ "Hg}$$

But what if we are performing a unit conversion where the initial pressure is given in inches of mercury or inches of water *absolute*? Can we properly make a unity fraction with the quantities 2.036 "HgA and 27.68 "W.C.A as in the following examples?

$$\left(\frac{310 \text{ "HgA}}{1}\right) \left(\frac{27.68 \text{ "W.C.A}}{2.036 \text{ "HgA}}\right) = 4215 \text{ "W.C.A}$$
$$\left(\frac{45 \text{ "W.C.A}}{1}\right) \left(\frac{2.036 \text{ "HgA}}{27.68 \text{ "W.C.A}}\right) = 3.31 \text{ "HgA}$$

Explain why or why not.  
[file i02942](#)

---

Question 24

Complete the following table of equivalent pressures:

| PSIG | PSIA | inches Hg (G) | inches W.C. (G) |
|------|------|---------------|-----------------|
| 18   |      |               |                 |
|      | 400  |               |                 |
|      |      | 33            |                 |
|      |      |               | 60              |
|      |      | 452           |                 |
|      |      |               | 12              |
|      | 1    |               |                 |
| -5   |      |               |                 |

There is a technique for converting between different units of measurement called "unity fractions" which is imperative for students of Instrumentation to master. For more information on the "unity fraction" method of unit conversion, refer to the "Unity Fractions" subsection of the "Unit Conversions and Physical Constants" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

[file i02938](#)

---

Question 25

Complete the following table of equivalent pressures:

| Atm | PSIG | inches W.C. (G) | PSIA |
|-----|------|-----------------|------|
| 3.5 |      |                 |      |
|     | 81   |                 |      |
|     |      | 8834            |      |
|     |      |                 | 0    |
|     |      | 7.12            |      |
|     |      |                 | 368  |
|     | 2    |                 |      |
| 100 |      |                 |      |

There is a technique for converting between different units of measurement called “unity fractions” which is imperative for students of Instrumentation to master. For more information on the “unity fraction” method of unit conversion, refer to the “Unity Fractions” subsection of the “Unit Conversions and Physical Constants” section of the “Physics” chapter in your *Lessons In Industrial Instrumentation* textbook.

[file i02939](#)

---

Question 26

Convert between the following units of pressure:

- 22 PSI = ??? PSIA
- 13 kPa = ??? "W.C.
- 81 kPa = ??? PSI
- 5 atm = ??? PSIA
- 200 "Hg = ??? "W.C.
- 17 feet W.C. = ??? "Hg
- 8 PSI vacuum = ??? PSIA
- 900 Torr = ??? "W.C.A
- 300 mm Hg = ??? PSI
- 250 "W.C. = ??? bar (gauge)
- 70 "W.C. = ??? "Hg
- 300 PSIG = ??? atm

There is a technique for converting between different units of measurement called “unity fractions” which is imperative for students of Instrumentation to master. For more information on the “unity fraction” method of unit conversion, refer to the “Unity Fractions” subsection of the “Unit Conversions and Physical Constants” section of the “Physics” chapter in your *Lessons In Industrial Instrumentation* textbook.

**Suggestions for Socratic discussion**

- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.

[file i00226](#)

---

Question 27

A flow transmitter is calibrated for a flow measurement range of 0 to 24 gallons per minute, with a linear current output of 4 to 20 mA. How many milliamps will it output if the flow rate going through the instrument is 106 cubic yards per day?

[file i03608](#)

## Answers

---

Answer 1

*Force* (symbol: **F**) is that agency responsible for altering the velocity of any mass.

Measured in *pounds* (English), abbreviated as “lb”; and *newtons* (Metric), abbreviated “N”.

---

Answer 2

English units of measurement for length or distance: inch, foot, yard, mile.

Metric units of measurement for length or distance: meter, centimeter, millimeter.

The mathematical symbol for length is  $l$  (lower-case “ell”). The mathematical symbol for distance is  $s$ .

---

Answer 3

Area (symbol:  $A$ ) is the measurement of two-dimensional space.

Area may be expressed in terms of squared distance units (square inches, square miles, square centimeters, etc.), or in special units unique to the variable of area (such as acre or hectare).

---

Answer 4

Volume (symbol:  $V$ ) is the measurement of three-dimensional space.

Like area, volume may be expressed in terms of cubed distance units (cubic inches, cubic miles, cubic centimeters, etc.), or in special units unique to the variable of area (such as the English unit of “gallon” or the metric unit of “liter”).

---

Answer 5

$$\begin{aligned}\left(\frac{85 \text{ gal}}{1}\right)\left(\frac{8 \text{ pt}}{1 \text{ gal}}\right) &= 680 \text{ pt} \\ \left(\frac{220 \text{ qt}}{1}\right)\left(\frac{1 \text{ gal}}{4 \text{ qt}}\right) &= 55 \text{ gal} \\ \left(\frac{815 \text{ fl. oz.}}{1}\right)\left(\frac{3.7854 \text{ l}}{128 \text{ fl. oz.}}\right) &= 24.102 \text{ l} \\ \left(\frac{139 \text{ pt}}{1}\right)\left(\frac{231 \text{ in}^3}{8 \text{ pt}}\right) &= 4013.6 \text{ in}^3\end{aligned}$$

Answer 6

Hint: treat the units of measurement as you would algebraic *variables*:

$$\frac{462a}{1} \times \frac{1b}{4a} \times \frac{1c}{55b}$$

Answer to challenge question: this technique of multiplying by fractions comprised of equal physical quantities (numerator and denominator) is perfectly fine so long as those unit scales share the same zero point. When different units of measurement for a common variable are *shifted* from each other by a constant (e.g. 32 degrees of shift in the case of °C and °F), this technique will not work.

---

Answer 7

$$200,000 \text{ barrels/day} = 5833.33 \text{ gallons/minute}$$

---

Answer 8

Sally will need to count out a *lot* of teaspoon-fulls! Hint: the answer is between 100 and 200.

---

Answer 9

$$70 \text{ ft}^2 = 10,080 \text{ in}^2$$

It is possible to take any one-dimensional unity fraction and turn it into an equivalent two- or three-dimensional unity fraction simply by applying a power (exponent) to the entire fraction. Since the physical value of a unity fraction is always 1, squaring or cubing such a fraction won't change its physical value any more than squaring or cubing the fraction  $\frac{1}{1}$  will change its value.

To give some examples:

$$\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)^2 = \frac{144 \text{ in}^2}{1 \text{ ft}^2}$$

$$\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)^3 = \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\left(\frac{1 \text{ in}}{2.54 \text{ cm}}\right)^2 = \frac{1 \text{ in}^2}{6.4516 \text{ cm}^2}$$

$$\left(\frac{1 \text{ in}}{2.54 \text{ cm}}\right)^3 = \frac{1 \text{ in}^3}{16.387 \text{ cm}^3}$$

This is nice to know, as it reduces the number of conversion factors you need to memorize. Rather than memorizing 12 inches to 1 foot *and* 144 square inches to 1 square foot *and* 1728 cubic inches to 1 cubic foot, all you need to commit to memory is 12 inches = 1 foot and then you can square or cube when necessary to derive the other unity fractions.

---

Answer 10

$$250 \text{ hp} = 186.425 \text{ kW}$$

In America, the unit of “watt” is typically linked with electrical power, while mechanical power is almost always rated in the unit of “horsepower.” So, while it may seem odd for an engine to be rated in units of kilowatts (or for that matter, a light bulb rated in horsepower!), our preference of units is nothing more than *convention*. Both watts and horsepower are valid units of measurement for any form of power, be it electrical, mechanical, optical, or otherwise.

The conversion between horsepower and watts is quite simple: 745.7 watts to one horsepower. The conversion calculation (using a unity fraction) will therefore look like this:

$$\frac{250 \text{ HP}}{1} \times \frac{745.7 \text{ W}}{1 \text{ HP}} = 186,425 \text{ W} = 186.425 \text{ kW}$$

---

Answer 11

$$\left(\frac{1460 \text{ feet}}{\text{second}}\right) \left(\frac{1 \text{ mile}}{5280 \text{ feet}}\right) \left(\frac{60 \text{ seconds}}{1 \text{ minute}}\right) \left(\frac{60 \text{ minutes}}{1 \text{ hour}}\right) = 995.5 \text{ MPH}$$

---

Answer 12

$$(600 \text{ ft}) \times (280 \text{ ft}) = 168000 \text{ ft}^2$$

Using the conversion equivalent of 43560 square feet = 1 acre, this equates to **3.857 acres**

---

Answer 13

$$15 \text{ MPH} = 193.924 \text{ RPM}$$

At first this might not even seem like a unit conversion problem, but it is. Obviously, John's bicycle wheels will not be spinning when the velocity is 0 miles per hour, and the wheels' rotational speed will directly follow the bicycle's velocity in a linear fashion. What we are dealing with here is a direct proportion, and this is what unit conversions are really about: direct proportions.

The key to solving this problem is coming up with a unity fraction that relates one revolution of the bicycle wheel to the amount of distance traveled. Keeping everything in units of inches, we have a distance of 81.68 inches per revolution. These figures are what we will use to build the unity fraction to convert velocity into rotational speed (the fourth fraction in this long calculation):

$$\frac{15 \text{ mi}}{1 \text{ hr}} \times \frac{5280 \text{ ft}}{1 \text{ mi}} \times \frac{12 \text{ in}}{1 \text{ ft}} \times \frac{1 \text{ rev}}{81.68 \text{ in}} \times \frac{1 \text{ hr}}{60 \text{ min}}$$

---

Answer 14

$$100 \text{ cubic yards} = 20,197.4 \text{ gallons}$$

The trickiest part of this problem is using the linear conversion factors (1 foot = 12 inches and 1 yard = 3 feet) to convert *cubic* units.

$$\frac{100 \text{ yd}^3}{1} \times \left(\frac{3 \text{ ft}}{1 \text{ yd}}\right)^3 \times \left(\frac{12 \text{ in}}{1 \text{ ft}}\right)^3 \times \frac{1 \text{ gal}}{231 \text{ in}^3}$$

Expanding the cubed unity fractions and canceling units . . .

$$\frac{100 \text{ yd}^3}{1} \times \frac{27 \text{ ft}^3}{1 \text{ yd}^3} \times \frac{1728 \text{ in}^3}{1 \text{ ft}^3} \times \frac{1 \text{ gal}}{231 \text{ in}^3}$$

---

Answer 15

The pool will need to be filled 2.64 feet deep with water.



---

Answer 16

10 kilotons TNT = 0.00046489 kilograms = 0.46489 grams

Solving this problem requires two major steps: first, converting the unit of kilotons' explosive potential into joules of energy, then using Einstein's famous formula to convert that quantity of energy into mass. First, the kiloton/joules conversion:

$$\frac{10,000 \text{ tons TNT}}{1} \times \frac{4.184 \times 10^9 \text{ J}}{1 \text{ ton TNT}} = 4.184 \times 10^{13} \text{ J}$$

Now that we have a figure for the amount of energy released in that explosion, we manipulate Einstein's equation to solve for mass, then plug that figure in to solve for mass in units of kilograms. Note that  $c$  (the speed of light) is expressed in units of meters per second:

$$E = mc^2$$

$$m = \frac{E}{c^2}$$

$$m = \frac{4.184 \times 10^{13} \text{ J}}{(3 \times 10^8 \text{ m/s})^2} = 0.00046489 \text{ kg} = 0.46489 \text{ g}$$

---

Answer 17

If the student can remember the freezing and/or boiling points of water in both degrees F and degrees C, it is a trivial matter to test the formula for correctness!

---

Answer 18

- 350 K = 76.85° C
- 575° F = 1034.67° R
- -210° C = 63.15 K
- 900° R = 440.33° F
- -366° F = 93.67° R
- 100 K = -173.15° C
- 2888° C = 3161.15 K
- 4502° R = 4042.33° F
- 1000 K = 1800° R
- 3000° R = 1666.67 K

---

Answer 19

- $235^{\circ} \text{C} = 914.67^{\circ} \text{R}$
- $567.2^{\circ} \text{F} = 570.48 \text{K}$
- $0.004 \text{K} = -459.663^{\circ} \text{F}$
- $830^{\circ} \text{R} = 187.96^{\circ} \text{C}$
- $-200^{\circ} \text{C} = 131.67^{\circ} \text{R}$
- $-98.25^{\circ} \text{F} = 200.79 \text{K}$
- $992.8^{\circ} \text{C} = 1819.04^{\circ} \text{F}$
- $-105.3^{\circ} \text{C} = -157.54^{\circ} \text{F}$
- $1040 \text{K} = 1872^{\circ} \text{R}$
- $5222.6^{\circ} \text{R} = 2628.29^{\circ} \text{C}$

---

Answer 20

| $^{\circ}\text{F}$ | $^{\circ}\text{R}$ | $^{\circ}\text{C}$ | K       |
|--------------------|--------------------|--------------------|---------|
| 580                | 1039.67            | 304.4              | 577.59  |
| -449.67            | 10                 | -267.59            | 5.556   |
| -31                | 428.67             | -35                | 238.15  |
| 9517.73            | 9977.4             | 5269.85            | 5543    |
| -310               | 149.67             | -190               | 83.15   |
| 3208.33            | 3668               | 1764.63            | 2037.78 |
| 1151.6             | 1611.27            | 622                | 895.15  |
| 80.33              | 540                | 26.85              | 300     |

---

Answer 21

The *atmosphere* (atm) and the *torr*.

---

Answer 22

The given pressure is in units of PSI *gauge* (PSIG), while the final unit (atmospheres) is an *absolute* pressure unit. In order for this conversion to be correct, there must somewhere be an offset (addition) in the calculation to account for the 14.7 PSI shift between gauge pressure and absolute pressure.

Here is the proper conversion technique:

$$\text{Step 1: } 65 \text{ PSIG} + 14.7 \text{ PSI} = 79.7 \text{ PSIA}$$

$$\text{Step 2: } \left( \frac{79.7 \text{ PSIA}}{1} \right) \left( \frac{1 \text{ atm}}{14.7 \text{ PSIA}} \right) = 5.422 \text{ atm}$$

---

Answer 23

This is perfectly legitimate, because in either case all the pressure units involved in each conversion are of the same type: either all gauge or all absolute. Where we encounter difficulties is if we try to mix different units in the same “unity fraction” conversion that do not share a common zero point.

A classic example of this mistake is trying to do a temperature conversion from degrees F to degrees C using unity fractions (e.g.  $100^{\circ} \text{C} = 212^{\circ} \text{F}$ ):

$$\left(\frac{60^{\circ} \text{F}}{1}\right) \left(\frac{100^{\circ} \text{C}}{212^{\circ} \text{F}}\right) \neq 28.3^{\circ} \text{C}$$

This cannot work because the technique of unity fractions is based on proportion, and there is no simple proportional relationship between degrees F and degrees C; rather, there is an *offset* of 32 degrees between the two temperature scales. The only way to properly manage this offset in the calculation is to include an appropriate addition or subtraction (as needed).

However, if there is no offset between the units involved in a conversion problem, there is no need to add or subtract anything, and we may perform the entire conversion using nothing but multiplication and division (unity fractions). Such is the case if we convert pressure units that are all gauge, or if we convert pressure units that are all absolute.

To summarize, it is perfectly acceptable to construct a unity fraction of  $\frac{27.68 \text{ "W.C.}}{2.036 \text{ "Hg}}$  because 0 "W.C. is the same as 0 "Hg (i.e. they share the same zero point; there is no offset between units "W.C. and "Hg). Likewise, it is perfectly acceptable to construct a unity fraction of  $\frac{27.68 \text{ "W.C.A}}{2.036 \text{ "HgA}}$  because 0 "W.C.A is the same as 0 "HgA (i.e. they share the same zero point; there is no offset between units "W.C.A and "HgA).

---

Answer 24

| PSIG   | PSIA  | inches Hg (G) | inches W.C. (G) |
|--------|-------|---------------|-----------------|
| 18     | 32.7  | 36.65         | 498.25          |
| 385.3  | 400   | 784.5         | 10665           |
| 16.21  | 30.91 | 33            | 448.6           |
| 2.168  | 16.87 | 4.413         | 60              |
| 222.0  | 236.7 | 452           | 6145.1          |
| 0.4335 | 15.13 | 0.8826        | 12              |
| -13.7  | 1     | -27.89        | -379.2          |
| -5     | 9.7   | -10.18        | -138.4          |

---

Answer 25

| Atm   | PSIG   | inches W.C. (G) | PSIA  |
|-------|--------|-----------------|-------|
| 3.5   | 36.75  | 1017.3          | 51.45 |
| 6.51  | 81     | 2242            | 95.7  |
| 22.71 | 319.1  | 8834            | 333.8 |
| 0     | -14.7  | -406.9          | 0     |
| 1.017 | 0.2572 | 7.12            | 14.96 |
| 25.03 | 353.3  | 9779.6          | 368   |
| 1.136 | 2      | 55.36           | 16.7  |
| 100   | 1455.3 | 40284           | 1470  |

---

Answer 26

- $22 \text{ PSIG} = 36.7 \text{ PSIA}$
- $13 \text{ kPa} = 52.19 \text{ "W.C.}$
- $81 \text{ kPa} = 11.75 \text{ PSI}$
- $5 \text{ atm} = 73.5 \text{ PSIA}$
- $200 \text{ "Hg} = 2719 \text{ "W.C.}$
- $17 \text{ feet W.C.} = 15.01 \text{ "Hg}$
- $8 \text{ PSI vacuum} = 6.7 \text{ PSIA}$
- $900 \text{ Torr} = 481.9 \text{ "W.C.A}$
- $300 \text{ mm Hg} = 5.801 \text{ PSI}$
- $250 \text{ "W.C.} = 0.6227 \text{ bar (gauge)}$
- $70 \text{ "W.C.} = 5.149 \text{ "Hg}$
- $300 \text{ PSIG} = 21.41 \text{ atm}$

---

Answer 27

Output signal = 13.91 mA

(Flow rate = 14.87 gallons per minute)