

Chemistry & STEM Measurement II

Discussion Guide 1.4

Density An Objects' Relationship of its Mass & Volume Dr. Ron Rusay

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Comparison of Relative Properties FUNCTIONS



SINCE 1828
Function
Dictionary
Thesaurus

Definition of FUNCTION

- 1 : professional or official position : *occurrence* • His job combines the *functions* of a manager and a worker.
- 2 : the action for which a person or thing is specially fitted or used or for which a thing exists : *PURPOSE*
- 3 : any of a group of related actions contributing to a larger action; especially : the normal and specific contribution of a bodily part to the economy of a living organism • The *function* of the heart is to pump blood through the body.
- 4 : an official or formal ceremony or social gathering • They went to several *functions* during their college reunion weekend.
- 5 a : a mathematical correspondence that assigns exactly one element of one set to each element of the same or another set
b : a variable (such as a quality, trait, or measurement) that depends on and varies with another • *heights* is a *function* of age; also : *stress* • *limuses* that are a *function* of stress.
- 6 : characteristic behavior of a chemical compound due to a particular reactive unit; also : FUNCTIONAL GROUP
- 7 : a computer subroutine; specifically : one that performs a calculation with variables (see *variable* 1a) provided by a program and supplies the program with a single result

Density is a function of an object's mass and volume.

Comparison of Relative Properties FUNCTIONS

About 481,000,000 results (0.66 seconds)

Function (mathematics) - Wikipedia

[https://en.wikipedia.org/wiki/Function_\(mathematics\)](https://en.wikipedia.org/wiki/Function_(mathematics)) • In mathematics, a *function* is a relation between a set of inputs and a set of permissible outputs with the property if

real number x

Graph of a function

Function |

www.diction

A relationship

second set. If:

function of x :

Composite fu

TYPES OF FUNCTIONS

types of functions
types of functions and their graphs
types of functions in c language
types of functions
types of functions khan academy
types of functions in discrete mathematics
types of functions in javascript
types of functions song
types of functions in sql
types of functions in python
types of functions calculus

What is a function? (video) | Functions | Khan Academy

https://www.khanacademy.org/_functions/_functions/_what-is-...

Uploaded by Khan Academy

Functions assign a single unique output for each of their inputs. In this video, we

see examples of various kinds...

Functions | Algebra I | Math | Khan Academy

<https://www.khanacademy.org/math/algebra/algebra-functions>

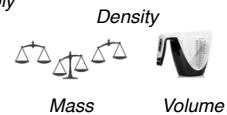
Functions are mathematical entities that assign unique outputs to given inputs. Sounds simple? Think again! In this topic you will evaluate, graph, analyze, and create various types of functions.

Comparisons of Relative Properties FUNCTIONS

Example: density : mass : volume

Functions & variables can be described interchangeably between:

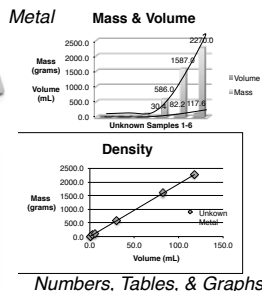
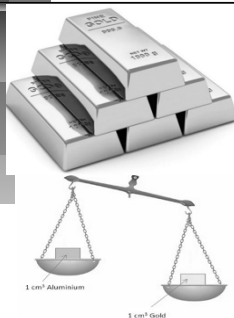
- 1) Images (Symbols)
- 2) Words
- 3) Sounds (Voice)
- 4) Numbers
- 5) Tables
- 6) Graphs
- 7) Formulas



Density is a function of an object's mass and volume.

Density Mass & Volume

Numbers
Tables
Graphs



Density

Formulas

<http://www.density.com/what.htm>

Density = Mass / Volume [g/mL or g/cm³; g/L]

$$d = \frac{m}{V} = \frac{156 \text{ g}}{20.0 \text{ cm}^3} = 7.80 \text{ g/cm}^3$$

Archimedes 250 B.C.E. Does iron float?... The RMS Titanic?

Density

<http://www.density.com/what.htm>

Archimedes 250 B.C.E. Does iron float?.... The RMS Titanic?

NOVA: The Secrets of Archimedes
<https://www.youtube.com/watch?v=0n347dxm5uE>

NOVA: Why Do Ships Sink?
https://www.youtube.com/watch?v=n_xDZjrZ6zs


Density

Density = Mass / Volume [g/mL or g/cm³; g/L] (kg/m³)


Very Dense Astronomical Objects: White Dwarfs
<http://antwrp.gsfc.nasa.gov/apod/ap961203.html>

$$D(\rho) = 1 \times 10^9 \text{ kg/m}^3 = 1 \times 10^3 \text{ kg/cm}^3 = 1 \times 10^6 \text{ g/cm}^3$$

A White Dwarf's mass is comparable to our Sun's, but its volume is about a million times smaller; the average density is ~1,000,000 times greater than the Sun's 1.4 kg/m³



Our Sun will eventually become a white dwarf "butterfly".... but not for ~5 billion years.



Dimensional Analysis


Conversion/Unit Factor Calculations

- Using exact numbers / "scale factors" UNITS
- A Bookkeeping Process: Example

Calculating the density [D(ρ) = ? g/cm³] of a white dwarf, 1.0 x 10⁹ kg / 1 m³

- (1 kg = 1000g; 1 m³ = 1 x 10⁶ cm³; 1 Ton (T) = 1000kg)

kg	m ³	g	=	? g
m ³	cm ³	kg		? cm ³



Dimensional Analysis


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Calculating the density [D(ρ) = ? g/cm³] of a white dwarf, 1.0 x 10⁹ kg / 1 m³

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1.0 x 10 ⁹	kg	1	1,000	1,000,000 = 1.0 x 10 ⁶	=	? g
	m ³	cm ³	kg	1		? cm ³
1 m ³						1
						1.000 x 10 ⁶ = (100 cm) ³



Dimensional Analysis


Continued

- Example for an astronomical object where 1 teaspoon weighs 3 Tons. (~ 3 pick up trucks).

3 T / 1 tsp → ? g/cm³

- (1 tsp = 4.9289 mL; 1 T (Ton) = 1,000 kg; 1 kg = 1,000 g; 1 mL = 1 cm³)

T	tsp	mL	kg	g	=	? g
tsp	mL	cm ³	T	kg		? cm ³



Dimensional Analysis


Continued

- Example for an astronomical object where 1 teaspoon weighs 3 Tons. (~ 3 pick up trucks).

3 T / 1 tsp → ? g/cm³

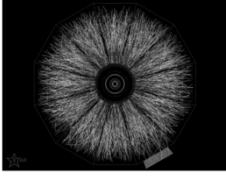
- (1 tsp = 4.9289 mL; 1 T (Ton) = 1,000 kg; 1 kg = 1,000 g; 1 mL = 1 cm³)

3	T	1 tsp	1 mL	kg	g	=	? g
1	tsp	mL	1 cm ³	1 T	1 kg		? cm ³
							6 x 10 ⁵ g/cm ³



Density

$Density = Mass / Volume [g/mL \text{ or } g/cm^3; g/L; kg/m^3]$



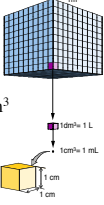
"Besides black holes, there's nothing denser than what we're creating," said David Evans, a team leader for the Large Hadron Collider's ALICE detector, which helped observe the quark-gluon plasma shown. "If you had a cubic centimeter of this stuff, it would weigh 40 billion tons."

<http://www.zmescience.com/science/physics/quark-gluon-plasma-lhc-26052011/#xzz3foandtPt>

How does quark-gluon plasma's density compare to a white dwarf? (1 ton = 1,000 kg)

Calculate the density $[D(\rho) = ?]$ (kg/cm^3 ...or g/cm^3 ...or kg/m^3) of quark-gluon plasma: 1 cm^3 has a mass of $4.0 \times 10^{10} \text{ T}$ (metric tons) **4.0×10^{10} greater** for comparison to White Dwarf.
($1 \text{ T} = 1,000 \text{ kg}$; $1 \text{ kg} = 1,000\text{g}$; $1,000,000 \text{ cm}^3 = 1 \text{ m}^3$)

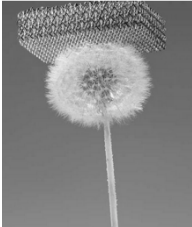
$4.0 \times 10^{10} \text{ T}$	$1,000 \text{ kg}$	$= 4.0 \times 10^{13} \text{ kg/cm}^3$
cm^3	T	$1 \times 10^3 \text{ kg/cm}^3$
$4.0 \times 10^{10} \text{ T}$	$1,000 \text{ kg}$	$1,000 \text{ g}$
cm^3	T	kg
		$= 4.0 \times 10^{16} \text{ g/cm}^3$
		$1 \times 10^6 \text{ g/cm}^3$
$4.0 \times 10^{13} \text{ kg}$	$1,000,000 \text{ cm}^3$	$= 4.0 \times 10^{19} \text{ kg/m}^3$
cm^3	m^3	$1 \times 10^9 \text{ kg/m}^3$



Density: Ultralight microlattices

$Density = Mass / Volume [g/mL \text{ or } g/cm^3; g/L; kg/m^3]$

T. A. Schaedler et al. Science 2011;334:962-965



<http://www.gizmag.com/ultralight-micro-lattice-material/20537/>

0.9 mg/cm^3 (air = 1.2 mg/cm^3)

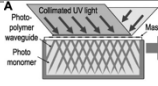
Science
Published by AAAS

Engineering Ultralight Microlattices

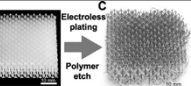
$Density = Mass / Volume [g/mL \text{ or } g/cm^3; g/L; kg/m^3]$

T. A. Schaedler et al. Science 2011;334:962-965


A




B



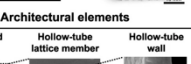
C



D



E



Size scale

$\sim \text{mm} - \text{cm}$

Controllable architectural features

Unit cell symmetry, spatial location of lattice members

$\sim \mu\text{m} - \text{mm}$

Diameter, wall thickness, node geometry

$\sim \mu\text{m} - \mu\text{m}$

Microstructure, multilayer, composition

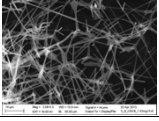
$\sim \text{nm} - \mu\text{m}$

0.9 mg/cm^3

Science
Published by AAAS

Density

$Density = Mass / Volume [g/mL \text{ or } g/cm^3; g/L; kg/m^3]$




- Aerographite is a synthetic foam consisting of a porous interconnected network of carbon nanotubes. It was first reported by researchers at the University of Kiel and the Technical University of Hamburg in Germany in a scientific journal in June 2012. It's density is:
- $D = 0.18 \text{ mg/cm}^3$

Density

$Density = Mass / Volume [g/mL \text{ or } g/cm^3; g/L; kg/m^3]$

<https://www.youtube.com/watch?v=3biXUBXj070>



0.16 mg/cm^3

Chao Gao et. al., Zhejiang University, Department of Polymer Science and Engineering
Nature 494, 404 (28 February 2013)
doi:10.1038/494404a

Density

Density = Mass / Volume [g/mL or g/cm³; g/L; kg/m³]

<https://www.youtube.com/watch?v=VlcZdc42F0g>


NEW 3-D MATERIAL:

5% THE DENSITY OF STEEL
10x THE STRENGTH OF STEEL

Structural 3-D Graphene
One of the strongest lightweight materials known
MIT: January 2017

QUESTION

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.



The density of the metal is shown in parenthesis.
Useful information: 1 ft² = 929 cm²


A) Aluminum (2.70 g/cm³) B) Copper (8.95 g/cm³)
C) Gold (19.3 g/cm³) D) Zinc (7.15 g/cm³)

Set up a dimensional analysis path to solve the problem

Dimensional Analysis

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

The density of the metal is shown in parenthesis.
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A) Aluminum (2.70 g/cm³) B) Copper (8.95 g/cm³)
C) Gold (19.3 g/cm³) D) Zinc (7.15 g/cm³)

What goes in here?

31.2 ft ²	$\frac{929 \text{ cm}^2}{1 \text{ ft}^2}$	$\frac{2.30 \times 10^{-6} \text{ cm}}{1 \text{ cm}}$	$\frac{0.4767 \text{ g}}{1 \text{ g}}$	=	$\frac{? \text{ g}}{? \text{ cm}^3}$
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QUESTION

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

The density of the metal is shown in parenthesis.
Useful information: 1 ft = 12 in; 1 in = 2.54 cm

A) Aluminum (2.70 g/cm³) B) Copper (8.95 g/cm³)
C) Gold (19.3 g/cm³) D) Zinc (7.15 g/cm³)

Dimensional Analysis Solved in 2 Steps

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft² and an average thickness of 2.30 × 10⁻⁶ cm. If the mass of this sample is 0.4767 g, predict the identity of the metal.

• The density of the metal is shown in parenthesis.
• Useful information: 1 ft = 12 in; 1 in = 2.54 cm

ft ²	in ²	cm ²	cm	=	? cm ³
	ft ²	in ²			

Densities of Various Common Substances*

Substance	Physical State	Density (g/cm ³)
Oxygen	Gas	0.00133
Hydrogen	Gas	0.000084
Ethanol	Liquid	0.789
Benzene	Liquid	0.880
Water	Liquid	0.9982
Magnesium	Solid	1.74
Salt (sodium chloride)	Solid	2.16
Aluminum	Solid	2.70
Iron	Solid	7.87
Copper	Solid	8.96
Silver	Solid	10.5
Lead	Solid	11.34
Mercury	Liquid	13.6
Gold	Solid	19.32

*At 1 atmosphere pressure

QUESTION

Which would provide more grams of NaCl, sample one with a mass of 2,350 mg, or sample two, a solid with a volume of 2.00 cm³? (The density of solid salt is 2.16 g/cm³.) Select the most massive sample and its mass in grams.

- A. Sample two; 1.08 grams
- B. Sample two; 4.32 grams
- C. Sample one; 2.35 grams
- D. Sample one; 2.350 grams

QUESTION

The volume of any material can be obtained from its density and mass.

If the mass of a sample of acid from a battery were 5.00 grams and its density was 1.2 g/mL, what would the correct reported volume in mL with the proper number of significant digits?

- A. 6.0 mL
- B. 6.00 mL
- C. 4.2 mL
- D. 4.17 mL

Density

$$\text{Density} = \text{Mass} / \text{Volume} [\text{g/mL or g/cm}^3; \text{g/L}]$$

$$\text{Mass} = \text{Density} \times \text{Volume}$$

- How many grams of air are there in PS 277?
 - The room has dimensions of ~ 3.5 m x 11 m x 10. m.
 - $D_{\text{air}} = 1.22 \times 10^{-3} \text{ g/cm}^3$ (1.22 g/L)
 - $1 \text{ m}^3 = 100 \text{ cm} \times 100 \text{ cm} \times 100 \text{ cm};$
 - $1000 \text{ cm}^3 = 1 \text{ L}; 1 \text{ mL} = 1 \text{ cm}^3$
- A. $1.22 \times 10^3 \text{ g}$
 B. 385,000,000 g
 C. $3.85 \times 10^6 \text{ g}$
 D. 47,000,000 g
 E. $4.70 \times 10^8 \text{ g}$



Dimensional Analysis

Conversion/Unit Factor Calculations

- How many grams of air are there in PS 277?
- The room has dimensions of ~ 3.50 m x 11.0 m x 10.0 m. = 385 m^3
- $D_{\text{air}} = 1.22 \times 10^{-3} \text{ g/cm}^3$ (1.22 g/L)
- $1 \text{ m}^3 = 100 \text{ cm} \times 100 \text{ cm} \times 100 \text{ cm};$
- $1000 \text{ cm}^3 = 1 \text{ L}; 1 \text{ mL} = 1 \text{ cm}^3$

$$\frac{385 \text{ m}^3}{1} \times \frac{1 \times 10^6 \text{ cm}^3}{1 \text{ m}^3} \times \frac{1.22 \text{ g}}{1 \text{ cm}^3} =$$



QUESTION

Density

$$\text{Density} = \text{Mass} / \text{Volume} [\text{g/mL or g/cm}^3; \text{g/L}]$$

If the room were filled with pure oxygen,
 $D_{\text{oxygen}} = 1.429 \times 10^{-3} \text{ g/cm}^3$ (1.429 g/L)
 there will be a higher mass of gas in the room.

True (A) / False (B)
 (Be able to explain the reason(s) for your answer.)



QUESTION

General Chemistry Level Challenge

- How many pounds of air are there in PS 277?
- It has a volume of ~220 yd³.
- $D_{\text{air}} = 1.22 \times 10^{-3} \text{ g/cm}^3$ (1.22 g/L)
- Mass = Density x Volume

$$\text{Mass} = 450 \text{ lbs (451.996005)}$$

$$\frac{220 \text{ yd}^3}{1} \times \frac{27 \text{ ft}^3}{1 \text{ yd}^3} \times \frac{28316.8 \text{ cm}^3}{1 \text{ ft}^3} \times \frac{0.00122 \text{ g}}{1 \text{ cm}^3} \times \frac{1 \text{ lb}}{454 \text{ g}} = ? \text{ lb}$$



QUESTION

General Chemistry Level Challenge



Titanium is abundant in the earth's crust, but horrendously difficult to turn into a bicycle frame. From extraction, to final welding and finishing, titanium is fraught with very complex processes that are as expensive as they are essential. One slip, omission on behalf of the mill, machinist, welder or finisher or the slightest contamination of oxygen, nitrogen, and hydrocarbon (i.e. human fingertips) at the wrong time and the frame will almost certainly fail at some point. Hence most bike companies don't use titanium.

<http://cyclefit.co.uk/journal/5-questions-to-ask-before-buying-a-titanium-bike>

QUESTION

General Chemistry Level Challenge



However, titanium's tolerance to cyclical load is infinite. This is a huge advantage both in terms of safety and for ride quality. It means that as long as the tube spec and frame design is well executed, a bicycle will offer exceptional comfort, performance and ride the same in its first mile as its millionth!

- Titanium is much lighter than steel alloy, which has been commonly used in frames.
- Titanium (4.50 g/cm^3); steel alloy (7.75 g/cm^3).

<http://cyclefit.co.uk/journal/5-questions-to-ask-before-buying-a-titanium-bike>

QUESTION

General Chemistry Level Challenge



6.8 cm



\$4,199.00

- A titanium bicycle frame contains the same amount of titanium as a titanium cube measuring 6.8 cm on a side.
- Use the density of titanium to calculate the mass in kilograms of titanium in the frame.
- What would be the mass of a similar frame composed of steel alloy?

Titanium (4.50 g/cm^3); Steel alloy (7.75 g/cm^3).

QUESTION

General Chemistry Level Challenge

\$9,000.00 frame



- A stiff light weight carbon fiber bicycle frame is said to weigh as little as 690g.
- Carbon fiber frames are the mainstay of the Tour de France.



- What is the percent difference in the weight of a carbon fiber frame versus titanium?
- What is the relative cost per kg for each of them?
- Assuming the volume of carbon fiber in the frame is equal to titanium, what is the density of the carbon fiber?

QUESTION

General Chemistry Level Challenge

<http://chemconnections.org/general/chem108/3D%20printing%20transforms%20the%20economics%20of%20manufacturing.pdf>

<http://chemconnections.org/general/chem108/3D%20printers%20start%20to%20build%20factories%20of%20the%20future.pdf>

Weighty matters

	Value of weight saving, \$/kg
F1 motorsport	More than 120,000
Spacecraft	25,000
Aircraft	1,200-13,000
Automotive	20-600
Trucks, excavators, etc	1.3-12.7
Factory equipment	0-6

Source: Marcus Pont, Domin Field Power, 2017

Reducing weight offers large returns besides winning the Tour de France.

Read the linked articles above, and briefly explain how 3D printing relates to these savings in one or more of the examples from the table. Also, are there any opportunities in your chosen career path for 3D printing applications?