

## Molecular quantities

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This worksheet introduces the basic concepts of molecular quantities (moles, percent volume, percent mass, etc.) used in the study of chemistry and chemical reactions.

**Periodic Table of the Elements**

**H** 1  
Hydrogen  
1.00794  
1s<sup>1</sup>

**He** 2  
Helium  
4.00260  
1s<sup>2</sup>

**Li** 3  
Lithium  
6.941  
2s<sup>1</sup>

**Be** 4  
Beryllium  
9.012182  
2s<sup>2</sup>

**Na** 11  
Sodium  
22.989768  
3s<sup>1</sup>

**Mg** 12  
Magnesium  
24.3050  
3s<sup>2</sup>

**Electron configuration diagram for Potassium (K):**

Symbol →	K	← Atomic number
Name →	Potassium	← Atomic mass
Electron configuration →	4s <sup>1</sup>	← (averaged according to occurrence on earth)

*Metalloids*

<b>B</b> 5 Boron 10.81 2p <sup>1</sup>	<b>C</b> 6 Carbon 12.011 2p <sup>2</sup>	<b>N</b> 7 Nitrogen 14.0067 2p <sup>3</sup>	<b>O</b> 8 Oxygen 15.9994 2p <sup>4</sup>	<b>F</b> 9 Fluorine 18.9984 2p <sup>5</sup>	<b>Ne</b> 10 Neon 20.179 2p <sup>6</sup>
<b>Al</b> 13 Aluminum 26.9815 3p <sup>1</sup>	<b>Si</b> 14 Silicon 28.0855 3p <sup>2</sup>	<b>P</b> 15 Phosphorus 30.9738 3p <sup>3</sup>	<b>S</b> 16 Sulfur 32.06 3p <sup>4</sup>	<b>Cl</b> 17 Chlorine 35.453 3p <sup>5</sup>	<b>Ar</b> 18 Argon 39.948 3p <sup>6</sup>

*Nonmetals*

<b>As</b> 33 Arsenic 74.92159 4p <sup>3</sup>	<b>Se</b> 34 Selenium 78.96 4p <sup>4</sup>	<b>Br</b> 35 Bromine 79.904 4p <sup>5</sup>	<b>Kr</b> 36 Krypton 83.80 4p <sup>6</sup>
<b>Sb</b> 51 Antimony 121.75 5p <sup>3</sup>	<b>Te</b> 52 Tellurium 127.60 5p <sup>4</sup>	<b>I</b> 53 Iodine 126.905 5p <sup>5</sup>	<b>Xe</b> 54 Xenon 131.30 5p <sup>6</sup>
<b>Po</b> 84 Polonium (209) 6p <sup>4</sup>	<b>At</b> 85 Astatine (210) 6p <sup>5</sup>	<b>Rn</b> 86 Radon (222) 6p <sup>6</sup>	

*Metals*

<b>K</b> 19 Potassium 39.0983 4s <sup>1</sup>	<b>Ca</b> 20 Calcium 40.078 4s <sup>2</sup>	<b>Sc</b> 21 Scandium 44.955910 3d <sup>1</sup> 4s <sup>2</sup>	<b>Ti</b> 22 Titanium 47.88 3d <sup>2</sup> 4s <sup>2</sup>	<b>V</b> 23 Vanadium 50.9415 3d <sup>3</sup> 4s <sup>2</sup>	<b>Cr</b> 24 Chromium 51.9961 3d <sup>5</sup> 4s <sup>1</sup>	<b>Mn</b> 25 Manganese 54.93805 3d <sup>5</sup> 4s <sup>2</sup>	<b>Fe</b> 26 Iron 55.847 3d <sup>6</sup> 4s <sup>2</sup>	<b>Co</b> 27 Cobalt 58.93320 3d <sup>7</sup> 4s <sup>2</sup>	<b>Ni</b> 28 Nickel 58.69 3d <sup>8</sup> 4s <sup>2</sup>	<b>Cu</b> 29 Copper 63.546 3d <sup>10</sup> 4s <sup>1</sup>	<b>Zn</b> 30 Zinc 65.39 3d <sup>10</sup> 4s <sup>2</sup>	<b>Ga</b> 31 Gallium 69.723 4p <sup>1</sup>	<b>Ge</b> 32 Germanium 72.61 4p <sup>2</sup>	<b>As</b> 33 Arsenic 74.92159 4p <sup>3</sup>	<b>Se</b> 34 Selenium 78.96 4p <sup>4</sup>	<b>Br</b> 35 Bromine 79.904 4p <sup>5</sup>	<b>Kr</b> 36 Krypton 83.80 4p <sup>6</sup>
<b>Rb</b> 37 Rubidium 85.4678 5s <sup>1</sup>	<b>Sr</b> 38 Strontium 87.62 5s <sup>2</sup>	<b>Y</b> 39 Yttrium 88.90585 4d <sup>1</sup> 5s <sup>2</sup>	<b>Zr</b> 40 Zirconium 91.224 4d <sup>2</sup> 5s <sup>2</sup>	<b>Nb</b> 41 Niobium 92.90638 4d <sup>4</sup> 5s <sup>1</sup>	<b>Mo</b> 42 Molybdenum 95.94 4d <sup>5</sup> 5s <sup>1</sup>	<b>Tc</b> 43 Technetium (98) 4d <sup>5</sup> 5s <sup>2</sup>	<b>Ru</b> 44 Ruthenium 101.07 4d <sup>7</sup> 5s <sup>1</sup>	<b>Rh</b> 45 Rhodium 102.90550 4d <sup>8</sup> 5s <sup>1</sup>	<b>Pd</b> 46 Palladium 106.42 4d <sup>10</sup> 5s <sup>0</sup>	<b>Ag</b> 47 Silver 107.8682 4d <sup>10</sup> 5s <sup>1</sup>	<b>Cd</b> 48 Cadmium 112.411 4d <sup>10</sup> 5s <sup>2</sup>	<b>In</b> 49 Indium 114.82 5p <sup>1</sup>	<b>Sn</b> 50 Tin 118.710 5p <sup>2</sup>	<b>Sb</b> 51 Antimony 121.75 5p <sup>3</sup>	<b>Te</b> 52 Tellurium 127.60 5p <sup>4</sup>	<b>I</b> 53 Iodine 126.905 5p <sup>5</sup>	<b>Xe</b> 54 Xenon 131.30 5p <sup>6</sup>
<b>Cs</b> 55 Cesium 132.90543 6s <sup>1</sup>	<b>Ba</b> 56 Barium 137.327 6s <sup>2</sup>	<i>57 - 71 Lanthanide series</i>	<b>Hf</b> 72 Hafnium 178.49 5d <sup>2</sup> 6s <sup>2</sup>	<b>Ta</b> 73 Tantalum 180.9479 5d <sup>3</sup> 6s <sup>2</sup>	<b>W</b> 74 Tungsten 183.85 5d <sup>4</sup> 6s <sup>2</sup>	<b>Re</b> 75 Rhenium 186.207 5d <sup>5</sup> 6s <sup>2</sup>	<b>Os</b> 76 Osmium 190.2 5d <sup>6</sup> 6s <sup>2</sup>	<b>Ir</b> 77 Iridium 192.22 5d <sup>7</sup> 6s <sup>2</sup>	<b>Pt</b> 78 Platinum 195.08 5d <sup>9</sup> 6s <sup>1</sup>	<b>Au</b> 79 Gold 196.96654 5d <sup>10</sup> 6s <sup>1</sup>	<b>Hg</b> 80 Mercury 200.59 5d <sup>10</sup> 6s <sup>2</sup>	<b>Tl</b> 81 Thallium 204.3833 6p <sup>1</sup>	<b>Pb</b> 82 Lead 207.2 6p <sup>2</sup>	<b>Bi</b> 83 Bismuth 208.98037 6p <sup>3</sup>	<b>Po</b> 84 Polonium (209) 6p <sup>4</sup>	<b>At</b> 85 Astatine (210) 6p <sup>5</sup>	<b>Rn</b> 86 Radon (222) 6p <sup>6</sup>
<b>Fr</b> 87 Francium (223) 7s <sup>1</sup>	<b>Ra</b> 88 Radium (226) 7s <sup>2</sup>	<i>89 - 103 Actinide series</i>	<b>Unq</b> 104 Unnilquadium (261) 6d <sup>2</sup> 7s <sup>2</sup>	<b>Unp</b> 105 Unnilpentium (262) 6d <sup>3</sup> 7s <sup>2</sup>	<b>Unh</b> 106 Unnilhexium (263) 6d <sup>4</sup> 7s <sup>2</sup>	<b>Uns</b> 107 Unnilseptium (262)	108	109									

<i>Lanthanide series</i>	<b>La</b> 57 Lanthanum 138.9055 5d <sup>1</sup> 6s <sup>2</sup>	<b>Ce</b> 58 Cerium 140.115 4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>	<b>Pr</b> 59 Praseodymium 140.90765 4f <sup>3</sup> 6s <sup>2</sup>	<b>Nd</b> 60 Neodymium 144.24 4f <sup>4</sup> 6s <sup>2</sup>	<b>Pm</b> 61 Promethium (145) 4f <sup>5</sup> 6s <sup>2</sup>	<b>Sm</b> 62 Samarium 150.36 4f <sup>6</sup> 6s <sup>2</sup>	<b>Eu</b> 63 Europium 151.965 4f <sup>7</sup> 6s <sup>2</sup>	<b>Gd</b> 64 Gadolinium 157.25 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	<b>Tb</b> 65 Terbium 158.92534 4f <sup>9</sup> 6s <sup>2</sup>	<b>Dy</b> 66 Dysprosium 162.50 4f <sup>10</sup> 6s <sup>2</sup>	<b>Ho</b> 67 Holmium 164.93032 4f <sup>11</sup> 6s <sup>2</sup>	<b>Er</b> 68 Erbium 167.26 4f <sup>12</sup> 6s <sup>2</sup>	<b>Tm</b> 69 Thulium 168.93421 4f <sup>13</sup> 6s <sup>2</sup>	<b>Yb</b> 70 Ytterbium 173.04 4f <sup>14</sup> 6s <sup>2</sup>	<b>Lu</b> 71 Lutetium 174.967 4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>
<i>Actinide series</i>	<b>Ac</b> 89 Actinium (227) 6d <sup>1</sup> 7s <sup>2</sup>	<b>Th</b> 90 Thorium 232.0381 6d <sup>2</sup> 7s <sup>2</sup>	<b>Pa</b> 91 Protactinium 231.03588 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>U</b> 92 Uranium 238.0289 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>Np</b> 93 Neptunium (237) 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>Pu</b> 94 Plutonium (244) 5f <sup>6</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Am</b> 95 Americium (243) 5f <sup>7</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Cm</b> 96 Curium (247) 5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>	<b>Bk</b> 97 Berkelium (247) 5f <sup>9</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Cf</b> 98 Californium (251) 5f <sup>10</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Es</b> 99 Einsteinium (252) 5f <sup>11</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Fm</b> 100 Fermium (257) 5f <sup>12</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>Md</b> 101 Mendelevium (258) 5f <sup>13</sup> 6d <sup>0</sup> 7s <sup>2</sup>	<b>No</b> 102 Nobelium (259) 6d <sup>0</sup> 7s <sup>2</sup>	<b>Lr</b> 103 Lawrencium (260) 6d <sup>1</sup> 7s <sup>2</sup>

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### Question 2

A mixture of oxygen and helium gases is prepared for use by scuba divers, mixing the following quantities of these two gases together:

- 27 moles of pure oxygen (O<sub>2</sub>) gas
- 108 moles of pure helium (He) gas

A chemist calculates the mass of this gas mixture in preparation to verify the mixture by means of a mass scale. In calculating mass, the chemist writes the following mathematical expression:

$$\left(\frac{27 \text{ mol O}_2}{1}\right) \left(\frac{32 \text{ g}}{\text{mol O}_2}\right) + \left(\frac{108 \text{ mol He}}{1}\right) \left(\frac{4 \text{ g}}{\text{mol He}}\right)$$

Complete this calculation for the total mass of the oxygen/helium gas mixture, and then explain the chemist's rationale for writing the calculation as she did.

[file i04805](#)

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### Question 3

Calculate the mass (in grams) for each of these substance quantities:

- 1 mole of pure <sup>12</sup>C
- 1 mole of carbon (naturally occurring)
- 1 mole of pure <sup>56</sup>Fe
- 5.5 moles of mercury (naturally occurring)
- 0.002 moles of helium (naturally occurring)

Hint: you will find the Periodic Table of the Elements extremely helpful here!

[file i00566](#)

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### Question 4

Suppose a chemist asks you to provide her with a beaker containing 2.6 moles of pure sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). You have no way to directly measure “moles” of acid when you go to retrieve the acid from a storage tank and pour it into the beaker, so how do you fulfill the chemist's request?

[file i02580](#)

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### Question 5

Calculate the mass (in grams) for each of these substance quantities (when calculating, round all atomic masses to the nearest hundredth):

- 1 mole of water: H<sub>2</sub>O
- 1 mole of *heavy water* (deuterium oxide, or D<sub>2</sub>O)
- 1 mole of sulfuric acid: H<sub>2</sub>SO<sub>4</sub>
- 14 moles of methane: CH<sub>4</sub>
- 5 moles of ammonium carbonate: (NH<sub>4</sub>)<sub>2</sub>CO<sub>3</sub>

Note: “deuterium” is an isotope of hydrogen, each atom containing one proton *and* one neutron in the nucleus.

[file i00567](#)

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Question 6

Calculate the mass of the following quantities of pure chemical compound. In each case, feel free to use atomic mass values rounded to the nearest whole number (from a Periodic Table) in your calculations:

- 35.2 moles of alumina  $\text{Al}_2\text{O}_3$  at  $25\text{ }^\circ\text{C}$
- 10.6 moles of nitroglycerine  $\text{C}_3\text{H}_5\text{N}_3\text{O}_9$  at  $77\text{ }^\circ\text{C}$
- 3.7 moles of phosgene  $\text{COCl}_2$  at  $145\text{ }^\circ\text{F}$
- 130 moles of tetraethyl pyrophosphate or “TEPP”  $[(\text{CH}_3\text{CH}_2\text{O})_2\text{PO}]_2\text{O}$  at  $-10\text{ }^\circ\text{F}$

**Suggestions for Socratic discussion**

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- Calculate the amount of heat required to warm 30 moles of water from 20 degrees Celsius to 25 degrees Celsius.
- Calculate the amount of heat required to warm 200 moles of hydrogen gas from 50 degrees Celsius to 70 degrees Celsius.

[file i04113](#)

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Question 7

Calculate the mass of 2.1 moles of ammonium carbonate  $(\text{NH}_4)_2\text{CO}_3$ . Feel free to use atomic mass values rounded to the nearest whole number (from a Periodic Table) in your calculation.

**Suggestions for Socratic discussion**

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

[file i04117](#)

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Question 8

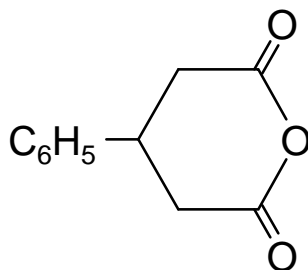
Calculate the mass of 55.4 moles of alumina ( $\text{Al}_2\text{O}_3$ ). Feel free to use atomic mass values rounded to the nearest whole number (from a Periodic Table) in your calculation.

[file i04800](#)

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Question 9

Calculate the mass of 3.4 moles of glutaric anhydride, the “line drawing” for this organic molecule shown here:



[file i02649](#)

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Question 10

A sample of “table” salt (sodium chloride, NaCl) has a mass of 10 kg. How many *moles* of salt is this equal to?

[file i02582](#)

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Question 11

Calculate the molar quantity ( $n$ , in moles) for the following quantities of pure chemical substances. Feel free to use atomic mass values rounded to the nearest whole number (from a Periodic Table) in your calculations:

- 500 grams of pure iron at 10 °C and 1.2 atmospheres
- 1.1 kilograms of pure propane C<sub>3</sub>H<sub>8</sub> at –30 °C and 3 atmospheres
- 250 kilograms of naphthalene C<sub>10</sub>H<sub>8</sub> at 0 °C and 45 kPaA
- 71 grams of hexafluoroacetone (CF<sub>3</sub>)<sub>2</sub>CO at 110 °F and 50 bar (gauge)

**Suggestions for Socratic discussion**

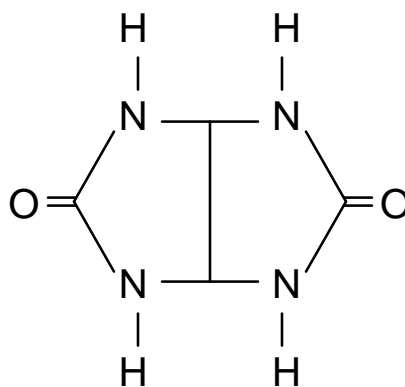
- What effects do temperature and pressure have on the mass of a sample?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- Does the *phase* of the substance (i.e. gas, liquid, solid) matter in these calculations? Why or why not?

[file i04118](#)

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Question 12

Calculate the number of moles of glycoluril required to make a total mass of 2 kg. The “line drawing” for this organic molecule is shown here:

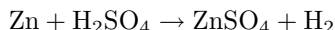


[file i02650](#)

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### Question 13

When acid attacks metal, the result is typically a release of hydrogen gas and the production of a *salt*. If we immerse a piece of solid zinc metal (Zn) into liquid sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), we see this general tendency in the production of hydrogen gas (H<sub>2</sub>) and a salt called zinc sulfate (ZnSO<sub>4</sub>). The chemical equation describing this reaction is shown here:



For every single atom of zinc, it takes one molecule of sulfuric acid to react. The reaction products for the one atom of zinc and one molecule of sulfuric acid will be one molecule of zinc sulfate and one molecule of hydrogen.

Identify how many moles of zinc metal and how many moles of pure sulfuric acid will be required to produce 15 moles of hydrogen gas.

[file i04115](#)

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### Question 14

Dilute chemical concentrations are often measured in the unit of *parts per million*, abbreviated *ppm*. For extremely dilute solutions, the unit *parts per billion* (ppb) is used. These are nothing more than ratios, much like *percentage*. In fact, the unit of “percent” may be thought of as nothing more than “parts per hundred” although it is never conventionally expressed as such.

In light of this definition for *ppm*, express the tolerance of a  $\pm 5\%$  carbon-composition resistor in ppm instead of percent.

Also calculate the following volumetric and mass concentrations in units of ppm:

- 3.6 milliliters of methyl alcohol mixed into 10.5 liters of pure water
- 55 cubic inches of natural gas released into a room of air 10 feet by 15 feet by 8 feet
- 10 grams of hydrofluoric acid added to 560 kg of water
- 140 grams of H<sub>2</sub>S gas released into open air

[file i00587](#)

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### Question 15

Dilute chemical concentrations are often measured in the unit of *parts per million*, abbreviated *ppm*. For extremely dilute solutions, the unit *parts per billion* (ppb) is used. These are nothing more than ratios, much like *percentage*. In fact, the unit of “percent” may be thought of as nothing more than “parts per hundred” although it is never conventionally expressed as such.

In light of this definition for *ppm*, calculate the following volumetric and mass quantities:

- The quantity of hydrazine vapor in 34000 cubic feet of air, where the volumetric concentration of hydrazine is 2.3 ppm
- The quantity of H<sub>2</sub>S gas in a room measuring 25 feet by 8 feet by 31 feet, where the volumetric concentration of hydrogen sulfide gas is 93 ppm
- The quantity of sulfuric acid in 50 kg of water, where the mass concentration of acid is 247 ppm

[file i02583](#)

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Question 16

What does it mean if a particular sample of ethyl alcohol has a *molarity* of 0.1 *M*, or 0.1 molar?

[file i03004](#)

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Question 17

If a 2 kilogram sample of pure water is mixed with 1 gram of pure  $\text{H}_2\text{SO}_4$ , what will the resulting sulfuric acid's *molarity* be? Note: I am asking you to calculate molality (*m*), not molarity (*M*), of the acid solution!

[file i03005](#)

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Question 18

Calculate the sodium ion molarity of a solution made from 0.05 moles of table salt ( $\text{NaCl}$ ) completely dissolved in 30 cups of water.

Calculate the chlorine ion molarity of a solution made from 0.05 moles of table salt ( $\text{NaCl}$ ) completely dissolved in 30 cups of water.

[file i04130](#)

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Question 19

A pressure "cylinder" containing hydrogen gas at a pressure of 2000 PSIG (137 atmospheres) was filled by a technician at Acme Hydrogen, Inc. Unfortunately, the technician doesn't remember if he filled it with regular hydrogen gas ( $^1\text{H}_2$ ) or with "heavy" hydrogen gas (deuterium,  $^2\text{H}_2$ ). Assuming the cylinder has an empty weight of 37.1 pounds, and now weighs 38.36 pounds, determine the type of hydrogen gas it's filled with.

The cylinder has an interior volume of 25 liters and is at ambient temperature of 20 °C.

Hint: the Ideal Gas Law relates pressure, volume, molecular quantity, and temperature for most gases:

$$PV = nRT$$

Where,

*P* = Absolute pressure (atmospheres)

*V* = Volume (liters)

*n* = Gas quantity (moles)

*R* = Universal gas constant (0.0821 L · atm / mol · K)

*T* = Absolute temperature (K) = degrees Celcius (°C) + 273.15

[file i02581](#)

## Answers

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Answer 1

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Answer 2

$$\left(\frac{27 \text{ mol O}_2}{1}\right) \left(\frac{32 \text{ g}}{\text{mol O}_2}\right) + \left(\frac{108 \text{ mol He}}{1}\right) \left(\frac{4 \text{ g}}{\text{mol He}}\right) = 1296 \text{ g} = 1.296 \text{ kg}$$

The fraction  $\frac{32 \text{ g}}{1 \text{ mol O}_2}$  expresses the proportionality between grams of mass and moles of oxygen gas, as a “unity fraction”. The fraction  $\frac{4 \text{ g}}{1 \text{ mol He}}$  does the same for helium gas. This allows the chemist to proceed with calculations of mass as though it were nothing more than a simple unit conversion problem, with units of “moles” canceling to leave no unit left except for “grams”.

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Answer 3

- 1 mole of pure  $^{12}\text{C} = 12 \text{ g}$
- 1 mole of carbon (naturally occurring) = 12.011 g
- 1 mole of pure  $^{56}\text{Fe} = 56 \text{ g}$
- 5.5 moles of mercury (naturally occurring) = 1.1032 kg
- 0.002 moles of helium (naturally occurring) = 8.0052 mg

To calculate each of these masses, simply multiply the number of moles by the atomic mass given or found in the periodic table.

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Answer 4

You might not be able to directly measure moles of acid, but you can certainly obtain a mass balance or scale to measure *grams* of acid!

Sulfuric acid –  $\text{H}_2\text{SO}_4$  – has a molecular weight (approximately) equal to:

$$(2)(1) + (32)(1) + (16)(4) = 98 \text{ amu}$$

This means 1 mole of pure sulfuric acid will have a mass of 98 grams. We may use this equivalence to set up a “unity fraction” and treat this as a units-conversion problem:

$$\left(\frac{2.6 \text{ mol acid}}{1}\right) \left(\frac{98 \text{ g}}{1 \text{ mol acid}}\right) = 254.8 \text{ g}$$

So, you just fill up the beaker with 254.8 grams of pure sulfuric acid, and you will have filled it with 2.6 moles of acid!



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Answer 5

- *Each molecule of  $H_2O$  contains:*
- 2 atoms of H at 1.01 amu each
- 1 atom of O at 16 amu each

$$(1 \text{ mol})[(2 \text{ atoms})(1.01 \text{ amu/atom}) + (1 \text{ atom})(16 \text{ amu/atom})] = 18.02 \text{ g}$$

- *Each molecule of  $D_2O$  contains:*
- 2 atoms of D ( $H^2$ ) at 2 amu each
- 1 atom of O at 16 amu each

$$(1 \text{ mol})[(2 \text{ atoms})(2 \text{ amu/atom}) + (1 \text{ atom})(16 \text{ amu/atom})] = 20 \text{ g}$$

- *Each molecule of  $H_2SO_4$  contains:*
- 2 atoms of H at 1.01 amu each
- 1 atom of S at 32.06 amu each
- 4 atoms of O at 16 amu each

$$(1 \text{ mol})[(2 \text{ atoms})(1.01 \text{ amu/atom}) + (1 \text{ atom})(32.06 \text{ amu/atom}) + (4 \text{ atoms})(16 \text{ amu/atom})] = 98.08$$

g

- *Each molecule of  $CH_4$  contains:*
- 1 atom of C at 12.01 amu each
- 4 atoms of H at 1.01 amu each

$$(14 \text{ mol})[(1 \text{ atom})(12.01 \text{ amu/atom}) + (4 \text{ atoms})(1.01 \text{ amu/atom})] = 224.7 \text{ g}$$

- *Each molecule of  $(NH_4)_2CO_3$  contains:*
- 2 atoms of N at 14.01 amu each
- 8 atoms of H at 1.01 amu each
- 1 atom of C at 12.01 amu each
- 3 atoms of O at 16 amu each

$$(5 \text{ mol})[(2 \text{ atoms})(14.01 \text{ amu/atom}) + (8 \text{ atoms})(1.01 \text{ amu/atom}) + (1 \text{ atom})(12.01 \text{ amu/atom}) + (3 \text{ atoms})(16 \text{ amu/atom})] = 480.55 \text{ g}$$

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Answer 6

- 35.2 moles of alumina  $Al_2O_3$  at 25 °C = **3590.4 grams = 3.5904 kg**
- 10.6 moles of nitroglycerine  $C_3H_5N_3O_9$  at 77 °C = **2406.2 grams = 2.4062 kg**
- 3.7 moles of phosgene  $COCl_2$  at 145 °F = **366.3 grams = 0.3663 kg**
- 130 moles of tetraethyl pyrophosphate or “TEPP”  $[(CH_3CH_2O)_2PO]_2O$  at -10 °F = **37,700 grams = 37.700 kg**

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Answer 7

$$m = 201.6 \text{ grams} = 0.2016 \text{ kg}$$

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Answer 8

$$m = 5648.4 \text{ grams} = 5.6484 \text{ kg}$$

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Answer 9

Converting the line drawing into a molecular formula, we get  $C_{11}H_{10}O_3$ . Remember that the general rule for interpreting line drawings is that every vertex or intersection of lines marks the location of one carbon atom having four bonds, and that any bonds not shown are bonds to hydrogen atoms. The molecular weight for this formula is approximated as follows:

$$(12)(11) + (1)(10) + (16)(3) = 190 \text{ amu} = 190 \text{ grams per mole glutaric anhydride}$$

Calculating mass given the molar quantity of this compound:

$$\left( \frac{3.4 \text{ mol glutaric anhydride}}{1} \right) \left( \frac{190 \text{ g}}{\text{mol glutaric anhydride}} \right) = 646 \text{ g}$$

---

Answer 10

“Table” salt is sodium chloride (NaCl), with 1 atom of sodium bound to 1 atom of chlorine. Together, the number of atomic mass units (amu) for each sodium chloride molecule is the sum of the individual atoms’ atomic masses:

- *Each molecule of NaCl contains:*
- 1 atom of Na at 22.99 amu each
- 1 atom of Cl at 35.45 amu each

$$[(1 \text{ atom})(22.99 \text{ amu/atom}) + (1 \text{ atom})(35.45 \text{ amu/atom})] = 58.44 \text{ g per mole of NaCl}$$

Since we now know the number of grams per mole for NaCl, we may calculate the number of moles needed to make 10 kg (10000 g) of salt:

$$(10000 \text{ g})(1 \text{ mol} / 58.44 \text{ g}) = 171.1 \text{ mol}$$

Therefore, 10 kg of “table” salt is equal to 171.1 moles.

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Answer 11

**Partial answer:**

- 1.1 kilograms of pure propane  $C_3H_8$  at  $-30^\circ\text{C}$  and 3 atmospheres = **25 moles**
- 71 grams of hexafluoroacetone  $(CF_3)_2CO$  at  $110^\circ\text{F}$  and 50 bar (gauge) = **0.4277 moles**

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Answer 12

Converting the line drawing into a molecular formula, we get  $C_4H_6N_4O_2$ . Remember that the general rule for interpreting line drawings is that every vertex or intersection of lines marks the location of one carbon atom having four bonds, and that any bonds not shown are bonds to hydrogen atoms. The molecular weight for this formula is approximated as follows:

$$(12)(4) + (1)(6) + (14)(4) + (16)(2) = 142 \text{ amu} = 142 \text{ grams per mole glycoluril}$$

Calculating moles given the mass of this sample:

$$\left( \frac{2000 \text{ g}}{1} \right) \left( \frac{\text{mol glycoluril}}{142 \text{ g}} \right) = 14.08 \text{ mol glycoluril}$$

---

Answer 13

15 moles of zinc and 15 moles of sulfuric acid are needed to produce 15 moles of hydrogen gas, since the molecular ratio for all reactants and products is 1:1.

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Answer 14

**Partial answer:**

$\pm 5\%$  (gold color code) is **50,000 ppm**.

- 3.6 milliliters of methyl alcohol mixed into 10.5 liters of pure water = **342.74 ppm** *If your calculated answer was 342.86 ppm, you made a minor error: you took 10.5 liters to be the total volume of liquid after adding the alcohol. 10.5 liters is just the water's volume, not the total solution (mixed) volume!*
  - 10 grams of hydrofluoric acid added to 560 kg of water = **17.86 ppm**
- 

Answer 15

- The quantity of 2.3 ppm (by volume) hydrazine vapor in 34000 cubic feet of air = **0.0782 cubic feet of pure hydrazine vapor**
  - The quantity of 93 ppm (by volume)  $\text{H}_2\text{S}$  gas in a room measuring 25 feet by 8 feet by 31 feet = **0.5766 cubic feet of pure  $\text{H}_2\text{S}$  gas**
  - The quantity of 247 ppm (by mass) sulfuric acid in 50 kg of water = **12.35 grams of pure sulfuric acid**
- 

Answer 16

For a solution of 0.1 molar (0.1  $M$ ) concentration, there are 0.1 moles of solute (pure ethyl alcohol) for every 1 liter of total solution volume. It should be noted that the molarity of a solution changes with temperature, because a solution's volume will change with temperature even though the quantity of solute in moles does not!

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Answer 17

*Molality* is defined as the number of moles of solute per kilograms of solvent (not of the total solution!). We were given the solvent mass in kilograms (2 kg) already. All we need to know is the molar quantity of the pure acid and we can solve for molality.

First, let's tally the number of grams per mole for  $\text{H}_2\text{SO}_4$ , based on the atomic mass units (amu) for the constituent elements:

For  $\text{H}_2\text{SO}_4$ , each molecule contains:

- 2 atoms of H at 1.01 amu each
- 1 atom of S at 32.06 amu each
- 4 atoms of O at 16 amu each

This gives a total of 98.08 grams per mole of pure  $\text{H}_2\text{SO}_4$ .

This figure may be used as a unity fraction to convert moles into grams, or grams into moles. For our application, we need to convert the given mass of 1 gram into moles:

$$(1 \text{ g})(1 \text{ mol} / 98.08 \text{ g}) = 0.0102 \text{ mol}$$

Taking this quantity in moles and dividing by the mass of solvent (2 kg) gives us the molality of the acid solution:

$$0.0102 \text{ mol} / 2 \text{ kg} = 0.0051 \text{ } m$$

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Answer 18

$$\text{Molarity of sodium ions in the saltwater solution} = 0.05 \text{ mol} / 7.098 \text{ liters} = 0.007045 \text{ } M$$

$$\text{Molarity of chlorine ions in the saltwater solution} = 0.05 \text{ mol} / 7.098 \text{ liters} = 0.007045 \text{ } M$$

The molarities are equal because sodium chloride ( $\text{NaCl}$ ) completely dissociates into  $\text{Na}^+$  and  $\text{Cl}^-$  ions in solution, with equal molecular quantities. For every mole of  $\text{Na}^+$  originating from the salt, there will be one mole of  $\text{Cl}^-$  in the solution as well.

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Answer 19

One problem-solving strategy would be to calculate the number of moles ( $n$ ) of gas filling this cylinder at the stated conditions of 2000 PSIG, 25 liters, and 20 °C. 2000 PSIG is equivalent to 137 atmospheres of absolute pressure. 20 °C is equivalent to 293.15 Kelvin absolute temperature. Solving for  $n$ :

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(137)(25)}{(0.0821)(293.15)} = 142.3 \text{ moles of gas}$$

The weight of the gas is simply the current weight of the cylinder minus the cylinder's empty weight:

$$38.36 - 37.1 = 1.26 \text{ lb} = 0.5715 \text{ kg} = 571.5 \text{ grams}$$

Taking the ratio of grams to moles tells us the molecular weight of the gas filling the cylinder:

$$\frac{571.5 \text{ g}}{142.3 \text{ mol}} = 4.02 \text{ amu}$$

The gas in question must be deuterium ("heavy" hydrogen,  $^2\text{H}_2$ ), with each molecule having an atomic mass of 4.